Foreword

History is a pageant and not a philosophy.—AUGUSTINE BIRRELL.

It is the true office of history to represent the events themselves, together with the counsels, and to leave the observations and conclusions thereupon to the liberty and faculty of every man's judgment.—SIR FRANCIS BACON.

I have but one lamp by which my feet are guided, and that is the lamp of experience.—
PATRICK HENRY.

ESSENTIALLY this volume is history. Some of the contributors have peered speculatively into the future; but communion with the crystal ball has been at a minimum. Some have interpreted events and expounded their personal philosophy and conclusions; but for the most part these have been left to the "liberty and faculty" of the reader's judgment. Behind this perhaps is a characteristic of most engineers—a reluctance to venture far out on an intellectual limb. The authors appear to concur in Birrell's belief that history should be a "pageant and not a philosophy."

The book is 99 per cent fact, with just enough fancy to season it to the taste of the average engineer. As the title avers, the volume is a record of 75 years of progress in the mineral industry—a progress that is intimately linked with the life and growth of the American Institute of Mining and Metallurgical Engineers since its establishment in May 1871, at Wilkes-Barre, Pennsylvania.

First is a series of 13 articles, each dealing with progress during the period in one of the major branches of the mineral industry or in one of the arts practiced by its engineers and technologists. The author in each case ranks high among his fellows as a recognized authority on the subject. A sizable volume might be written on any one of these topics; but the object of the authors has been to select for discussion the more significant highlights. It is hoped that in the future, when some one desires to study any one of these subjects, he can cover the important ground up to 1947 by reading the review in this volume—with resulting economy of time and effort.

Next comes the History of the Institute itself. Here again limitations of space have controlled. The issues of MINING AND METALLURGY since 1920, and particularly the TRANSACTIONS volumes issued before that year, are replete with fascinating material, rich in human interest, that the historian would like to have used to enliven the pages. It was, however, necessary to confine the account largely to a recital of the more significant—even if less exciting—events and developments.

Finally come the Proceedings of the 75th Anniversary Celebration held on March 17–19, 1947, at The Waldorf-Astoria, in New York City, participated in by 3000 people, including 69 Official Delegates representing institutions and organizations in no less than 20 foreign countries. The sessions constituted a World Conference on Mineral Resources, during which 16 distinguished speakers dealt with resources, economics, technology and, indeed, with sundry vital political aspects of all the major minerals. Metals, coal, petroleum and the other nonmetallic minerals each received appropriate attention. These addresses, most of them in expanded form, appear in this volume.

Ours is a Mineral Age. In its material aspects the civilization of any people is conditioned by its use of minerals. Possession of natural mineral resources is an asset; but capitalization of this asset, and effective use of the resulting products, depend on competent and resourceful engineering and technology. Leadership in these fields has been taken by the A.I.M.E.

The career of the Institute is inextricably woven with 75 years of progress in the mineral industry. It is with pride that the American Institute of Mining and Metallurgical Engineers offers to the industry and to the profession at large, as well as to its own members, this published record of unsurpassed industrial, technologic, and engineering progress and achievement.

THE EDITOR.

Introduction

Between 1871 and 1946—the span of the Institute's past life—the value of the annual production of minerals in the United States increased from $240,000,000 to $8,900,000,000. During the same period the population increased from 39,000,000 to 140,000,000, so that the per capita increase of mineral production was slightly more than tenfold. Perhaps a more revealing comparison is between the output of 1896, when the Institute was 25 years old, and that of 1946. The figures for the earlier year are 70,000,000 for population and $650,000,000 for mineral output. Accordingly, the per capita value of mineral production during the relatively short period of the last 50 years has increased sevenfold.

It is true, of course, that abnormal industrial expansion in the United States, caused by World War II and its aftermath, tends to accentuate the increase; but, even after due allowance is made, the expansion is nothing short of phenomenal. One other significant comparison is this: the United States accounts for about one sixteenth of the population of the world; but, including imported raw materials, it consumes roughly half the minerals of industrial importance that are used in the world. On the basis of per capita consumption, it ranks well ahead even of the most highly industrialized countries in other continents.

The reasons for this favored position are several: One, of course, is the possession within its borders of tremendous mineral resources put into the earth by a bounteous Nature. It has a population of vigorous and enterprising people who have capitalized on the natural wealth of the country—the soil, the forests, and the climate, as well as mineral resources—and thereby accumulated the economic means to exploit and utilize its mineral wealth. It has been able also to import in large quantity sundry mineral commodities of which the domestic supply is inadequate or even lacking entirely.

But there is another factor of prime importance. The United States always has ranked near the top in the competence, initiative, capacity, and resourcefulness of the engineers and technologists engaged in all branches of the mineral industry. These activities include the development of new and improved techniques, methods, processes, and mechanics for (1) finding new deposits, (2) removing the crude minerals from the ground, (3) beneficiating the crude materials and converting them to refined form, (4) processing of many kinds, and (5) utilization by industry.

The group of farsighted engineers who founded the Institute in May 1871 realized that the attainment of their primary objective, "to promote the economic production of the useful minerals and metals," could best be attained if the Institute would promote the free and convenient interchange of experience and information among those actually and practically engaged in the industry. The Founders planned that meetings should be held periodically in great mining and metallurgical centers where members could exchange data and ideas for their mutual benefit and for the benefit of the profession. It was planned that the discussions of these meetings should be permanently recorded in the TRANSACTIONS and other publications of the Institute, thereby creating a store of professional literature for the mineral industry.

Of the three basic industries upon which man depends for his existence—agriculture, fishing, and mining—only the latter is nonreproductive. Agriculture harvests new crops of food and materials annually. Within the span of a single generation new forests can be grown to replace those felled to meet man's needs. Millions of tons of fish hatch every year to renew the supply. But a mineral, although often it may be used, recovered, and utilized again, is neither replaced nor renewed by Nature. Once taken from the earth, all that marks its point of origin is a barren hole in the ground. No replacement mineral grows there; no renewal mineral breeds there!

We have already tapped, and partly drained, many of the most readily recoverable mineral deposits in this country. The cream, one might say, has been skimmed. Nevertheless, we now know that, thanks to the achievements of members of our profession and the industries in which they are engaged, we can maintain a steady flow of mineral supplies while, at the same time, we block out adequate reserves to meet our foreseeable needs.

By extending scientific knowledge, by perfecting methods of production and processing, our engineers have, in effect, increased our store of underground resources.

Forty years ago we believed that our copper was almost exhausted; but the development of porphyry coppers and the application of mass production methods multiplied these resources hundreds of times. Ever since 1920 we have been hearing dire warnings of the impending exhaustion of petroleum reserves. Yet today, despite the almost unbelievably large quantities of this fluid mineral that have been supplied to meet the demands of the automotive and aviation age, we have larger proven resources of petroleum than ever before. And these are but examples of what the persevering skill of mineral engineers and technologists have accomplished.

The fact must not be overlooked, however, that the maintenance of our all-important mineral supplies at an adequate level will always require the constant and most careful observance of all the stern precepts of economy and efficiency with respect to the handling of raw materials. In addition, governmental agencies and lawmakers must take cognizance of the problems, responsibilities, and delicate balances that are peculiar to the mineral industry.

Although we may have fresh in our minds the horrible destruction and cost of war, it is still true that the past 75 years constitute an era of progress unequaled in the history of the world. Man has developed ingenious and swift modes of transportation that have brought the far horizons of our forefathers almost within arm's length. Methods of communication have been perfected to a degree beyond the imagination of even the most visionary dreamers of a quarter century ago. Modern dwelling conveniences have little in common with those of the days when water was hand-drawn, when homes were heated by hand-cut fuel, and when such now ordinary marvels as electric lights and appliances were still unknown.

No claim is made that this phenomenal industrial progress is the exclusive achievement of mining, metallurgical and petroleum engineers and the other groups of technologists that constitute the A.I.M.E. In passing, it may be remarked that one fifth of them reside outside the United States and their activities are world-wide. We do not begrudge the credit that is justly due engineers in other branches of the profession in contributing to a progress that is reflected in the highest standards of living known anywhere in the world. However, it is fair to attribute a major share of this achievement to the mineral engineers and technologists who have provided the metals, the coal, the petroleum, and the other essential minerals that are basic to industrial growth and expansion.

The unvarnished record of these achievements is related in this volume; and in the latter part, distinguished authorities in various branches of the industry have ventured a few predictions as to what may be expected in the future. In conclusion, I want again to emphasize the part that has been played by the American Institute of Mining and Metallurgical Engineers. Its TRANSACTIONS constitute the most authentic, comprehensive and continuing record of this engineering and technologic advance, an advance made possible in large measure by the free exchange and wide dissemination of discoveries and experience of its members. In sum this volume, and the Anniversary that it commemorates, mark an important milestone. It records only the first chapter in a continuing and amazing story of industrial, economic, and social progress.

LOUIS SHATTUCK CATES,
President A.I.M.E., 1946.

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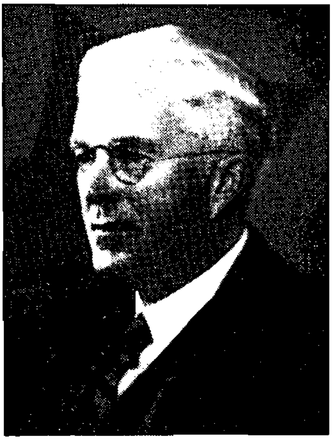
Seventy-five Years of Progress

Seventy-five Years of Progress in Mining Geology

By L. C. Graton

Civilization did not begin until metals became the material of tools, implements and machines.—
Rickard, *Man and Metals.*



L. C. GRATON

Professor of Mining Geology at Harvard University since 1912, Dr. Graton is a recognized authority on the principles of ore deposition and the development of geologic art as it relates to metalliferous ores. Various important corporations have engaged his services as consulting geologist; and he is the author of reports on the geology of mining districts in many parts of the world and of articles dealing with geologic subjects of national and international significance.

History is no more an end in itself than is a backsight the sum total of a survey. This Institute may view with satisfaction the remarkable development of the mineral industry since its founding three score and fifteen years ago, its own enlarging service to that industry, and the contribution thus made toward the enhanced welfare, opportunity and mutual understanding now in greater or less degree reaching and benefiting all peoples of the globe. But neither this professional society nor the dynamic mining industry as a whole wishes on this anniversary to direct its gaze chiefly toward the past. The foremost purpose of historical review should be to throw into clear perspective the strong points and the defects in the forward march thus far, primarily as the basis for conceiving and designing a still sounder progress henceonward.

At various times since the Institute's founding, the *theories* of ore deposition have been considered from the historical viewpoint.[1–7] For the present occasion it seems fitting to lay prime emphasis on the *practice and utilization* of geology in its varied relations to the problems of the mining industry.

It is hoped that the reader will understand and accept the degree to which the whole is sampled by parts familiar to the present writer, and the disproportionate attention to thought and achievement within the United

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[1] References are on page 38.

States. Draughts have freely been made on the unwritten experience and conclusions of generous fellow workers, not only through direct appeal for the present purpose but acquired also in the course of numberless informal discussions during past years in diverse lands. Because of the many from whom the present article has thus gained, it is hoped that this collective acknowledgment will be accepted as assurance of the writer's grateful appreciation.

Geology the Offspring of Mining

Mining evolved from that blend of curiosity and self-interest that drove early man to seek and win selected components of the solid earth. Even in its primitive stages, the immediate problems of operation came to be attended by more subtle but no less important queries regarding these concentrations of useful metalliferous substances: *where? how?*—questions that lie at the very core of geologic genesis. About the middle of the sixteenth century the true complexity of the mining art became so manifest that its various subdivisions began to acquire entity. This was especially true in the already long-famous mining districts of Saxony, then the chief metal-producing center of the world. In the initial paragraph of his best known work, Agricola, a resident of that region, recites the wide range of qualifications of "the miner"; and first among the requirements are listed: knowledge of where prospecting is profitable and where futile, understanding of the veins, stringers and seams, and thorough familiarity with the rocks and minerals, the mineral-bearing solutions and their deposits. Thus in very truth was Geology sired by Mining.

More than one chronicler has implied that for a long period after publication of Agricola's seven large works interest languished in the geological aspects of ore occurrence, and even in geology generally. The truth is that Agricola was far ahead of his time. His explicit observations and rational conclusions, when once on record, undoubtedly discouraged much of the prior kind of superficial and speculative writings. But in the mines as well as in the broader aspects of the science, Agricola's views exerted a dominating and constructive influence on geological thought and method for two centuries.

With the eighteenth century began the establishment of the famous mining schools among the mining districts of Central Europe. The earliest, 1702, in the Saxon Erzgebirge, was reorganized in 1765 to become the renowned Freiberg Mining Academy. This close interrelation of mines and schools powerfully affected the development of all the major branches of the art. As will later appear, the course of geology, and particularly of mining geology, in the United States was profoundly influenced by the teachings and experience brought back from these European sources during the third quarter of the last century.

Geology still finds the mines to afford a most fruitful soil for its further growth—and more and more is the dependence becoming reciprocal, as progressive exhaustion of the world's ores requires specialized new talents and techniques for the finding of further supplies.

General Background Preceding 1871

Save for lingering imperfections here and there, the face of the earth could be regarded as known at 1871. The successive waves of exploration since the fourteenth century B.C. and the ensuing colonization and development that had yielded this geographical knowledge were actuated by a common aim—riches; and among these the metals were predominant.

METAL DISCOVERY AND PRODUCTION

Of the countless districts that had yielded metals to man during the five or six millennia of his use of them, surely a great number had left no memory behind. Others, like Ophir, had retained little more than a name. Only a very few continued known and productive on a scale proportionate to mid-nineteenth century needs. Most of the exploitable occurrences of metal to the end of the Medieval Era had been found wholly by chance; and the regions of the Old World that had long been inhabited by civilized races were not, at that time, replacing their exhausting mines by discovery of others. Even for the grander cycle of metal production that had opened with rapid exploration of the New World, it must not be forgotten that very important fractions came from long-accumulated stores in treasuries, temples and tombs of the natives whom the *conquistadores* subjugated and plundered. And most of the "discoveries" of actual mining places rested on the information freely proffered or forcefully wrung from the indigenous peoples whose forefathers had found and first worked these occurrences.

In the seventeenth and eighteenth centuries, discoveries of prime importance occurred in many lands. More and more, these were virgin finds, as prospecting extended and improved. In the meantime, sudden realization of the value in what had been the least prized products of the mines—namely, iron and coal—was chiefly responsible for the Industrial Revolution. Significantly, the steam engine, symbol of that new era, was first put to use in mine pumping. Expanding utilization of mechanical power enormously stimulated production of coal and the industrial metals. With manufacture, commerce and general trade mounting dizzily, new monetary requirements arose which fortunately were met by the spectacular gold discoveries in California and Australia; and these, in turn, brought forth a new and unprecedented cycle of search for ores of all kinds, which was in full vigor when the Institute was founded in 1871.

GEOLOGICAL THOUGHT AND PRACTICE

By 1871 geology had been recognized for three quarters of a century as an independent science. It possessed a substantial and expanding literature; it had become segregated into a number of accepted subdivisions, of which Economic Geology was one; and it embraced an integrated and growing group of professional workers. Besides the older schools of Freiberg, Clausthal, Paris and Cambourne, younger institutions in both Europe and America were offering instruction in geology as applied to mining.

Many of the grand principles of geological science were then in view, and more or less firmly established. But numerous questions second in importance only to these were in highly controversial state; examples relating to ore occurrence may be typified by the following:

> The broad concept of igneous intrusion was widely accepted in Europe, and the striking relation of many ore occurrences to the margins of intrusive bodies had already been emphasized; yet numerous geologists, notably in North America, urged that granite and other varieties had been produced by metamorphism of sediments.
>
> The common contrast in character between the parts of an ore body near the surface and those at greater depth, the bands of altered country rock marginal to veins, and the phenomenon of pseudomorphism were matters of common observation; nevertheless, the principle of replacement had not yet been enunciated with convincing clarity.
>
> That the great majority of ores had been transported and deposited by a water-rich solution had gained overwhelming acceptance; yet for great classes of deposits there was strong divergence of view as to whether the transport was from above or below, and whether the water was derived from rain or magma.
>
> Erratic shape and highly restricted localization of workable ores was the overwhelming experience of mining; yet ore minerals present in *part* of the areal extent of a sedimentary bed were urged by many as coeval—syngenitic—with the commingled unquestionably sedimentary sand, mud or calcium carbonate.
>
> Stream placers, the type of ore concentration longest known and worked, were accepted as a special product of sedimentary deposition; but active controversy persisted as to their subsequent "enrichment" and the "growth" of nuggets.
>
> Observers of equal competence held divergent views as to the downward persistence of various types of deposits; but there was common agreement that the "true fissure vein" bottomed below any possible reach by man.

The mobile and controversial state of the science, together with the speculative excitement attending new ore discoveries, afforded fertile ground for the charlatan and the unscrupulous promoter. On the other hand, the reliable geologists were fortunately supported by the mining engineers, mine superintendents and even metallurgists, who wisely reflected their close contacts with ores and ore deposits in contributions of authority and value.

The actual employment of geologists in connection with the mining industry at 1871 was virtually limited to teachers, members of the national and state geological surveys under either civil or military authority, and those

temporarily engaged for some given problem or project, not uncommonly involved with mine promotion. Perhaps the earliest important instance of engagement of a consulting geologist in the present-day sense was the retention of Baron Ferdinand von Richthofen by a group of the Comstock mines, beginning in 1864, to give counsel on the threatening decline of the ores with depth and upon the Sutro Tunnel project. His intelligent and realistic treatment of these problems did much to establish the dignity and value of the profession in the United States at a most opportune time in its mineral development, and without doubt influenced support for the establishment, in 1879, of the United States Geological Survey.

To the inroads that mining had already made upon the world's mineral resources, some of the wisest minds of the time were not oblivious. But the succession of great discoveries, the rapid industrial developments and all the resultant effects caused the industry to be mainly permeated by the same unbounded optimism that had fired the ancient searchers for the Golden Fleece. True perspective of the period is now to be had in the following approximate ratios of output of major products at the beginning and at the end of the seven decades preceding the founding of the Institute (compare with Table 2):

TABLE 1—*Relative World Production,* 1801–1871

Product	1801	1871	Product	1801	1871
Gold	1	10.6	Iron	1	17.4
Silver	1	1.9	Lead	1	15.0
Copper	1	7.1	Zinc	1	384
Tin	1	3.9	Coal	1	21.5

These ratios give more than a measure of the increase in discovery, extraction and consequent exhaustion. They imply also the increased difficulty of finding new supplies, a matter then given little serious concern but that nevertheless led to gradually increasing dependence on those adequately trained and experienced in the special domain of mineral deposits.

The Seventy-five Years 1871–1946

ROLE OF THE INSTITUTE

From its inception, the American Institute of Mining Engineers gave wholehearted haven to mining geology. Of the three signers of the proposal to establish such an organization, two are found among the contributors to the literature of geology. One fourth of the 68 charter members and 8 of the 18 original officers are in the same category. The first scientific paper

presented at the founding meeting in Wilkes-Barre and assigned to open Volume I of the Institute's TRANSACTIONS treats of the geographic and geologic distribution of the mining districts of the United States, by that grand patriarch of the Institute, Dr. Rossiter W. Raymond; and 14 of the other papers in that initial volume deal with geological subjects. During its existence thus far, the presidency of the Institute has been accorded to eight geologists, and thirteen renowned geologists over the world have been elected as Honorary Members.

Through the years, the sympathetic environment and live discussion drew to the Institute's meetings oral presentation of the summarized fruits of investigation by leading mining geologists of this continent. The TRANSACTIONS, of high technical excellence, afforded worldwide distribution of these and other contributions, and are among the most valued archives of the subject. Among its outstanding offerings may be cited the following, each of which, within its particular scope, has exerted a profound influence on the understanding of ore deposits:

	VOLUME
The Genesis of Certain Ore Deposits, by S. F. Emmons	XV
Structural Relations of Ore Deposits, by S. F. Emmons	XVI
The Genesis of Ore Deposits, by F. Posepny	XXIII
The Secondary Enrichment of Ore Deposits, by S. F. Emmons	XXX
Metasomatic Processes in Fissure Veins, by W. Lindgren	XXX
Some Principles Controlling the Deposition of Ores, by C. R. Van Hise	XXX
The Ground Waters, by J. F. Kemp	XXXVI
Ore Deposits at Butte, Montana, by R. H. Sales	XLVI
Relations of Metalliferous Lode Systems to Igneous Intrusives, by W. H. Emmons	LXXIV
Magmas, Dikes and Veins, by W. Lindgren, with extended reply by J. E. Spurr and discussion by many others	LXXIV

The Committee on Mining Geology, since its establishment in 1913, has effectively continued the early tradition of this subdivision of the Institute's activity by organizing broad and timely programs, which have drawn excellent attendance at sessions of the annual meetings. During recent years many of these sessions have been arranged jointly with the Society of Economic Geologists.

Special reference must also be made to the three special volumes devoted to mining geology, each issued in honor of an outstanding leader: the the Posepny Volume, in 1902; the Emmons Volume, in 1913; and the Lindgren Volume, in 1933. The first two assembled noteworthy papers previously published; the third embraced a carefully organized group of new contributions. All three had the common purpose of throwing added light on the genesis of ores. It is safe to say that no other three volumes yet printed

hold contributions on such fundamental aspects of this subject by so many authoritative specialists. The period they cover, 1886–1933, is peculiarly significant in the history of the subject—and perhaps never again will so brief a period yield so much for the future to build upon. Truly may the Institute take pride in this geological series, unapproached as it yet is in any other of its fields of interests.

ROLE OF GOVERNMENTAL AGENCIES

At 1871, the operating locus of most professional geologists was in either the educational establishments or some governmental organization. Several of the nations had already founded geological surveys; and a number of the states of this and other countries had established corresponding organizations. These had contributed much to the scientific foundation of general geology, with notable additions here and there to an understanding of ore deposits. But up to about 1870 metalliferous geology by governmental agencies had not attained great prominence.

With the discovery of gold in California and the rapid succession of important mineral disclosures in other western states and territories, mainly on lands of national ownership, the United States Government had increased the geological explorations in that great unfolding domain.

During the latter part of the '60s and through the '70s four official surveys were simultaneously engaged on western geology. One of these, the Geological Survey of the Fortieth Parallel, 1867–77, was the first important organization under any government to apply intensive geological investigation to ore deposits. Directed by Clarence King, and with J. D. Hague, Arnold Hague, and S. F. Emmons, alumni of Freiberg, as assistants, this unusually capable organization may fairly be said to have set a new standard in both general and economic geological work. Prompt recognition of this achievement led to the all-important next step.

Work of the U. S. Geological Survey

In 1879, all geological activities of the Federal Government were consolidated into the United States Geological Survey, with Clarence King as Director. In one of his first official acts, King established a Division of Mining Geology, under the joint supervision of S. F. Emmons and G. F. Becker. Their instructions were broad and challenging:

> You will make accurate, detailed and exhaustive studies . . . so that . . . the varied types of deposits in all important mining-districts will have been studied; and the many phenomena bearing upon the genesis of ore-deposits thus accurately determined should be sufficient for a new theory of ore-deposits, based on facts actually determined in the light of modern geology.

Merely to mention all those who in the succeeding years have worthily shared in execution of that central program would unbalance this review; it must suffice to typify all these by three leaders of the Survey's early middle years, Lindgren, Spurr and Ransome. Even more is it impossible to summarize the principal contributions to an understanding of ore occurrence made by Survey geologists, but the major objectives and methods of this greatest geological organization in the world merit consideration.

The production of an accurate topographic-geologic map of such area and scale as to reveal broad setting and close detail has almost invariably been the foundation of the Survey's studies in mining districts. Carried out under a scheme of supervision that, at least potentially, brings to bear on each special area the Survey's cumulative knowledge of stratigraphy, structure, and igneous history of the greater province in which the district lies; enriched and safeguarded by the ministrations at Washington headquarters of corps of specialists in paleontology, petrography, mineralogy, chemistry, etc; and reproduced with beauty and rare precision, these special maps of the mine fields stand in the eyes of the mining industry as symbol and acme of the Survey's work and contribution. This has remained true from the beginning; and every itinerant geologist knows that, whether in prospector's shack or the geological quarters of a large mine, the Survey's map of the local region is carefully preserved for constant reference long after the "main report" to which it was attached may have been lost or shelved.

In the earlier days, the detailed studies of such scholarly and penetrating specialists as those already mentioned were of great value to the local operators. Disclosure of district-wide relationships, details of underground geology, ore structure, and genesis, and broad inferences as to downward continuity and tenor—these represented rich contributions which the local companies were in no position to provide for themselves. Coupled with a fine record of dealing with confidential material, achievements of this kind in district after district brought enthusiastic support for the Survey while also further expanding its own scientific grasp and power. (Pending issuance of the elaborate official report, the concentrated essence of such studies has in many instances been presented before the Institute—see outstanding examples already cited—or in the pages of *Economic Geology*. They constitute veritable gems of the science.)

In more recent years, the background against which the Survey's work in mining geology is performed has materially changed, and in two somewhat contrasting directions.

In the first place, most mining companies of substantial size in this country now carry on their own geological work. Even in this the Survey has had important, if indirect, part: it set a general pattern of investigation which the

companies recognized as desirable to adopt; numerous able Survey geologists, entering corporate practice, have aided in adoption of the pattern; still other Survey men, joining university staffs, have expounded the pattern to those whom the mines are to employ. Elaboration and fitting modification of the Survey technique plus quite independent extensions in new directions have been achieved by the mine staffs themselves. As a result, many mines are now qualified in most respects to conduct their own geological investigations on a high plane of scientific reliability and practical utility.

Such advantages as inhere in total richness of staff and broad scientific background of the Survey have to be balanced against the constant and continuing attack of the mine staff on the ever-changing facets of the local problems, and the close integration of the geological with the other company departments and with the complex variations of the local economic picture. Moreover, in recent years the Survey has been obliged to secure its future leaders in a three-cornered competition with university faculties and mining companies for the best among the oncoming supply of young geologists; the while mounting administrative loads attending marked increase in Survey personnel have gravitated to its contemporary leaders, thus restricting their own productive contact with the realities of outcrop and stope and their opportunity in the presence of these realities to guide and inspire their younger colleagues.

As consequence, the flow of geological benefits is no longer in a single direction. In detailed mapping, on surface and underground, Survey practice in recent years has tended not so much to lead as to follow what has become conventional in the mines. Likewise, there has been effort to incorporate in the Survey's work in mining areas something of the basic quantitative approach the mines have been forced to develop. These and similar trends became highly accentuated and conspicuous during the recent war, when duties unprecedented in magnitude and kind were imposed on the Survey, as well as on the sister organization, the Bureau of Mines, and the several special war agencies for mineral development and acquisition at home and abroad (see the revealing summary by Bateman[8]). Now that the turbulent pressures and breathless haste are past and the Survey's fine contribution to the war effort is of record, realization that the effective future role for the Survey does not lie in duplication of or competition with the functions of company geology is plainly shared by the present Survey administration.

It would seem to follow, then, that the initial program of the Survey, which brought it so much of acclaim and support—namely, the intensive study of great mining districts—should no longer hold primacy in its future plans of activity in mining geology. This will be progression, not withdrawal. It will represent wise and satisfying recognition that the Survey's early

function of pioneering leadership in one great objective has now been so well discharged that it may safely leave further extension in that area to the private endeavors it has aided, taught and inspired; and that the Survey is thus freed to turn more fully to the subjugation of other problems where governmental attack is now as appropriate and necessary as was the study of Comstock and Leadville, Butte and Cripple Creek scores of years ago. Moreover, if leadership is to continue the Survey will expect again and again in the future to devise, perfect and eventually turn over to industry one fruitful program in order to attack a new one, in quite the same way that the research department of a great corporation feeds its findings to the production department.

The second great change brought by the years points to exploitation by the Survey of new concepts and methods as the effective means of present-day adherence to the initial lofty objective of scientific advancement and practical usefulness which time has so fully confirmed. For decades, the implication in the instructions handed to Emmons and Becker was sufficiently valid; namely, that the best keys to broad understanding of ore deposition are to be found in the individual mining districts. One by one, the districts have yielded up specific, fundamental secrets: Leadville (1882), replacement and certain aspects of structural control; Marquette (1893), structural barriers for descending solutions; Butte (1896), secondary sulphide enrichment; Seven Devils (1899), contact-metamorphic ores; Rico (1901), structural barriers for ascending solutions; Coeur d'Alene (1908), pre-ore faulting of vein structures; Goldfield (1909), alunitic alteration—to name but a few examples. But to perpetuate indefinitely this district program in the manner available to the Survey would, from the all-important standpoint of genetic understanding, almost surely lead toward diminishing returns. Concurrently, the tasks of ensuring (1) that the known major districts will in due time be scoured centrally, peripherally and vertically until they retain little ore that is worth getting, and (2) that districts now ascribed lower levels of promise will receive eventual thorough testing, are now properly becoming responsibilities of the mining companies. An example of the seriousness and effectiveness with which this corporate responsibility is being discharged is seen in a paper just published on the Michigan copper region.[9]

The outstanding unfilled need lying ahead is the discovery of *new* mineralized districts. Enough scattered effort has already been directed toward this objective to confirm that it is much more difficult and even more speculative than has been mine finding up to now. It is hardly debatable that this is precisely the type of endeavor in which government can and must take leadership. And there is widespread conviction both within and outside the Survey that here lies its own chief future role insofar as concerns metalliferous re-

sources. The present Director, W. E. Wrather, long in intimate touch with the Survey tradition and of extended experience in commercial geological practice, is fully abreast of these objectives, with definite plans for realizing them. Fortunately the chief requirements fit exactly with the Survey's greatest strengths of the past: precise mapping and fundamental research. Extension of aereal mapping and related study to regions not now productive but possessed of the lithologic and structural potentialities of ore concentration seems fully justified, and holds great promise of bringing to light numerous places for more localized and intensive exploration by mining companies. In recent addresses before groups of the mining industry, Dr. Wrather has advanced a most proper and reassuring policy for this branch of the Federal Government. The following paragraph is quoted from his address before the American Mining Congress at Denver in 1946:

> I believe the efforts of the Survey should be designed to supplement those of industry, that the Survey's work in exploration should leave off where industry begins. . . . Therefore, the activities of the Survey in the field of mineral exploration should presumably represent the public interest in undertaking work which (*a*) private groups either cannot undertake, (*b*) will not undertake, or (*c*) cannot do as well as a Federal agency.

On another occasion he outlined the Survey's contemplated program of fundamental research as embracing: (1) discovery and elaboration of basic geological principles, (2) interpretation of these principles as applied to specific regions and problems, (3) development of appropriate instrumentation and techniques for geological, geophysical and geochemical investigations.

Among the directions that would seem particularly fruitful is a continuation of systematic studies of the ore occurrence of large regions, such as those already made by Lindgren in New Mexico, by Butler, Loughlin, and Burbank in Utah and Colorado, and now in progress under Ferguson in Nevada. Also deserving of active attack are topical studies, like that on interpretation and appraisal of aureoles of hydrothermal alteration as clues to ore, currently being followed in given districts by T. S. Lovering and G. M. Schwartz. It is gratifying to see work of that nature placing such strong emphasis on investigation in the field as contrasted with the library. For special inquiries of this kind, a topic entrusted to an individual or small team could profitably be pursued in district after district to the exclusion of all other district features that do not bear significantly on the theme in hand.

Work of Other Nations

Problems of past and present similar to those discussed in the foregoing pages have faced and still face the corresponding Surveys of other nations. It is natural that the outstanding contributions to mining geology have come

from those countries most blessed with mineral resources; and on the whole it seems to be true that in these the governmental geological agency is more alert and productive than when geology for geology's sake mainly prevails. High place on the roster of attainment in studies of ores must be accorded to Canada and its Provinces, Mexico, Sweden, Norway, the Australian states and the Union of South Africa. The Canadian bureaus are particularly noteworthy in their active aid to mineral development by early field investigation and prompt publication.

EDUCATION IN MINING GEOLOGY

In the training of men for the worldwide mining profession, the mining schools of Europe were at peak influence in 1871. The Freiberg Academy in particular at that time drew many students from outside Germany, and sent even larger numbers as graduates far and wide. Among the considerable number of Americans trained in those schools, a noteworthy proportion chose a career in mining geology, and proved to play a most influential part in shaping the ideals and the course of that science as it developed in this country. Although these undoubtedly were men of marked inherent ability, it is indubitable that their eminence derived at least equally from the training and viewpoint they had absorbed abroad.

It was fortunate, as we now can see, that the ablest of these men, instead of taking up teaching, should have been drawn to a career of systematic field work in the West at a time when new discoveries gave need and opportunity for their best. Their studies and writings extended, vitalized and dignified the broad principles and revealing relationships that were to enrich future instruction in mining geology.

It is significant that the new wealth of truths regarding ore occurrence being brought to light especially by the U. S. Geological Survey was utilized by teachers of deep faith and extended experience in field study—such men as Kemp, Van Hise, Lawson and Smyth. In due time the universities called to their geological faculties a number of those, typified by Ransome and J. D. Irving, who had acquired experience in mining districts under those seniors, Emmons, Lindgren and others earlier mentioned. Lindgren, youngest of the mining geologists coming from European training, climaxed 30 years of active field studies with 25 more of teaching and writing of the most stimulating kind.

The basic writings and textbooks dealing with ore deposits at the beginning of the period under review were chiefly of European origin. Conspicuous among these were the papers of de Beaumont and the treatise by von Cotta; but a translation of the latter by Prime, one of the charter members of the Institute, and Whitney's Metallic Wealth were available in

English. Most of the texts appearing up to the '90s followed a common pattern. Imperfect efforts toward generalization and a groping for genetic understanding constituted a comparatively brief preliminary part; relatively uninspired descriptions of great numbers of individual mining districts occupied the major part of the book. By 1893, De Launay and, in particular, Posepny had presented substantial treatises in which the principles and general relationships were given dominance, with local descriptions introduced chiefly to illustrate the genetic features discussed. Posepny's work, presented through the medium of the Institute, made a profound impression on American thought. Scholarly and sane increments to a consistent philosophy of ore genesis are found in Stelzner's manuscript (edited and published by Bergeat, 1904), De Launay's three-volume work (1913), and Lindgren's successive editions (1913–1933). In all these cases, the high quality and insight seem to be intimately connected with the author's long-sustained contacts with ores in the field.

The emphasis given to mining geology in the colleges and universities in this country varies markedly, but has increased with time. At one extreme stands a single course, designated economic geology, which covers metallic and nonmetallic occurrences, water supply, soils, etc., given by a professor carrying other subjects also. Certain of the larger institutions emphasize one or more special branches, such as petroleum geology, engineering geology, or geophysical prospecting. At a few places two or more faculty members deal exclusively with various aspects of the geology of ores.

Certain generalizations are rather plainly deducible from this experience of three quarters of a century. The increasing dependence of the mines on geology, already so evident in the quantitative sense, must extend also in the sense of better quality if the accelerating exhaustion of known ores is to be offset. This improvement of quality and power must be attained both in the course of practical application and in the preceding educational preparation. Because the fundamental principles and relationships in geology itself and in the sciences on which it rests are increasing in number and complexity, it is already clear that both better teaching and longer study are required.

The mounting need to utilize more of physics, chemistry and mathematics in geological interpretation must be disclosed by the teacher rather than left for discovery by the student. The individual teacher will progressively lose power if he relies solely on a background of field experience acquired early in his career; continuing touch with the reality in its own habitat is indispensable. Worthy and valuable investigations are possible in laboratory and library; but exclusive restriction to these is unwise, since *ore* is a treacherous image when divorced from the dollar sign.

Steadily it is becoming more evident that successful ore finding is to be

achieved only by research in the highest sense, ***conducted right on the ground.*** As in other sciences, no one in geology is qualified for research until he has mastered its body of fundamental principles and relationships. For the student of mining geology who justifiably aspires to full stature in the profession, the conventional four-year undergraduate course no longer suffices. Decision as to whether to pursue graduate study at once or after acquisition of some practical experience depends on circumstances. But in any event, before his scholastic preparation can effectively function in use it must be integrated with the training and background to be had only in the mines. This can be achieved in part during the summer holidays by a sympathetic policy of cooperation and very modest remuneration extended rather generally by the mining companies. Better still are the carefully organized training programs already instituted by a few companies. In any case, it is clear that the mines that recognize and meet the necessity for the postcollegiate professional training of geologists will secure the pick of the young graduates. Fortunately, the number of mines in this category is growing. Results in these deserve watching.

GEOLOGY IN THE MINES

In the professional study of the geology of ores, the mining companies, strangely enough, were preceded by governmental officials and teachers primarily concerned with discovery and illumination of basic scientific principles. And before American companies came to adopt geology for the central purposes of finding ore or facilitating its extraction, less constructive intermittent use had been made of geological talent and prestige in mine promotion and mine litigation. By the '60s and '70s, however, mining engineers whose training had included courses in geology were dealing, either as regular employees or as retained consultants, with the geological problems arising in normal operation and in exploration.

Anaconda's Leadership

The first geological department of any importance established by a mining company—and perhaps the earliest on any scale—was that of the Anaconda company at Butte. The later record of this department is so noteworthy that the conditions of its initiation merit summary record here. Systematic study of the Butte deposits by the U. S. Geological Survey had begun in 1896 under the direction of S. F. Emmons and continued for several years. Controversy having arisen in 1898 over extralateral rights, D. W. Brunton (later a president of the Institute), as consulting engineer for Anaconda, advocated geological study of the ground in dispute, and engaged for

that purpose H. V. Winchell (himself later a president of the Institute), who organized a staff and began systematic underground mapping. Following the larger consolidation into the Amalgamated company, Winchell's staff was expanded; and in 1901, R. H. Sales, who had earlier worked in other of the mines and had been assigned to cooperate on part time with the Federal geologists, joined the company's geological department. In 1906 Sales became chief geologist, and has since directed Anaconda's geological activities at Butte and elsewhere.

In its early years, Anaconda's geological work remained closely concerned with the tensely contested problems of boundary rights. The underground study was therefore carried out with unprecedented care and detail to make the maps, sections and models express most effectively the exact conditions underground. Inasmuch as Butte is characterized by numerous strong, through-going veins of various attitudes, and by several sets of strong fault displacements, and since extralateral litigation involves primarily geometrical considerations, the geological work of those early years was concerned chiefly with interpretation and solution of the structural problems.

After consolidation of ownership of most of the Butte mines had practically ended the period of litigation, and the department had come to deal with the geological features on a collective, district-wide basis, two important developments arose. First, the accumulation of geological understanding was turned to the directly constructive service of normal mine operation and production. In particular, great proficiency was acquired in projecting the known pattern of intersecting veins and faults into contiguous unopened ground. It became standard practice to give the operating staff precise directions for appropriate procedure even before the fault had been cut—a rare achievement in those days.

Second, the nature as well as the geometry of the mineralization received consistent attention. Systematic variations in mineral character and texture and in kind and intensity of wall-rock alteration were gradually shaped into the now well-known zonal pattern. Sale's Institute paper of 1913, already mentioned (p. 6), made Butte one of the classic examples of mineral zoning, besides treating most revealingly of faulting, vein structure and other important features of one of the world's foremost mining districts. It stands as one of the great geological contributions made directly by a mining company.

For many years the largest and strongest of its kind, the Anaconda geological department trained a large number of workers in the procedures and techniques that had been developed at Butte; in particular, a standardized and effective method of geological mapping underground. In the course of time, many of these geologists took up work elsewhere over the world, so that underground observation and mapping according to the "Anaconda school"

is now in very wide use, being especially appropriate where persistent tabular loci are important factors in ore distribution.

Current Practice

Emulation of Anaconda's success came rather slowly, but where sympathetic officials, carefully chosen geologists and tough geological problems coincided, the value of company geology began to receive general recognition. The allocation of geological tasks to trained geologists was, indeed, but one exemplification of the rapid spread of specialization throughout the mining industry as size of operating unit and complexity of problems increased. At the present time, most mining companies of importance employ geology, some of the larger departments comprising up to 20 or more geologists. Even numerous small companies contrive to utilize geology on a scale commensurate with their resources. For it has become clear that among the reasons why properties of small and intermediate size so commonly gravitate into the control of larger companies is not merely the greater resources of the latter in funds and facilities but also the superior geological judgment of possibilities for ore.

The function of the geological department has considerably expanded in recent years.* Formerly, the geologists' maps and other records, together with appropriate explanation, were submitted to the operating department for such use as might be made by the latter in laying out exploratory and development work. More and more the direction of exploration in and about the mine, whether by open work or by drilling, has been delegated directly to the geological department. Also, geological counsel now enters automatically with respect to rock character and structure as affecting location of main workings and plant, prediction of heavy or bursting ground, methods of extraction and support, water hazards, and related questions.

With steadily declining grades of ore and narrowing margins of profit, the necessity for reliable underground sampling naturally increased. In contrast with ores of great monotony in composition and structure, there are many others in which conscientious mechanical precision is not enough to assure a true sample. In a growing number of mines the sampling crews now work under supervision of the geological staff.

Likewise, periodic census of ore reserves is gravitating increasingly to the geologists. Many feel that this introduces more specialized skill and more objectivity into the proper determination of cutoffs and average grades, the

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* The organization of the Anaconda department as it was nearly 20 years ago is described by Sales.[10] Other illuminating discussions of geological procedure in representative mines, by McLaughlin, Sales, Linforth, Perry, Bjorge, Shoemaker and Billingsley, constitute chapter 12 of the Institute's Lindgren Volume, 1933. See also: J. D. Forrester.[11]

controls over dilution vs. clean mining, and the balance between extraction only vs. combined extraction and marginal exploration from the stopes, than where the responsibility for sampling and estimation as well as breaking of the ore is left to the operating staff. But whatever the division of responsibility, effective pooling of operating and geological information is essential.

Various incidental uses of geological experience are proving valuable to the mining companies. Microscopical study of the ore minerals and of the successive milling and metallurgical products has often aided in improved recoveries and lowered costs. Mine depletion and mine life as affecting rate of depreciation are important considerations in these days of heavy taxation. Several companies that operate custom smelters now afford geological service to the client mines as a cooperative assurance of maintained output of material in proportions for best smelting practice.

There are, of course, a few large companies and numerous smaller ones in which systematic geology is not yet employed. Obviously, in these ore still "comes easy." Presumably, for most of them a different outlook will eventually arise. The prosperous companies that work without geologists are less likely to understand the origin and controls of their deposits and are least likely, when their mine shall be exhausted, to meet the moral obligation of leaving for the future science and industry an enlightening record of the treasure they have destroyed.

EXPLORATION

Examination and appraisal of mines and prospects owned by others had long been entrusted to mining engineers. In the first two decades of this century, some of the most powerful mining organizations set up exploration subsidiaries for the more continuous and aggressive quest for new properties. In some of these, competent geological talent was engaged to join in the investigation and appraisal of the known ore and the possibilities of developing more. General Development Co. and Guggenheim Exploration Co. were in the latter category. Anaconda achieved the same end simply by assignments from its regular geological staff, which was increased accordingly. This latter practice has now spread, so that most geological departments carry the major responsibility for outside exploration.

The progressively increasing use of geology is interestingly revealed in the exploration that has yielded the largest number of great new mines in the last quarter century; namely, Northern Rhodesia. The rich copper deposits of the Katanga region to the north had been "discovered" by the standard method of gaining information from the natives combined with prospecting of the conventional kind. In the Rhodesian area, numerous copper-stained outcrops had for years teased prospectors and companies' representatives,

and at Bwana M'Kubwa an operation had been started—extravagantly extolled but soon fading. During the eight or ten years beginning with 1923, three important field groups, with strong London backing, explored this cupriferous region. The general philosophy, method and results of each may be briefly recalled.

The first group, under Raymond Brooks, mining engineer with extended experience in Katanga, "started out to find mines, wherever and however they occurred, having no preconceived ideas as to where they would be found or in what kinds of formations."[12] All facilities in the region were then most primitive. The scouting was organized in teams containing a prospector skilled in the African bush and the local dialects, and a young man with enough engineering training to keep track of locations and data. The native inhabitants were depended upon as the chief source of information. Locations were established by compass and wheel-odometer traverses. Promising exposures were probed by conventional shallow work, with a little drilling, done under difficulties. An important discovery was made at N'Changa, the Mufulira outcrop was located, Chambishi and N'Kana, which had already attracted attention, had been partly tested out, and several smaller deposits had been found before control changed hands; Roan Antelope was not in the ownership under the direction of Brooks. In what proved to be a rich region, this intelligent use of time-tried methods in an essentially virgin area accomplished much in the short period of its operation.

The second group, under J. A. Bancroft, geologist, took over in 1923 part of the area in which Brooks had started and added still further areas in its explorations. The program was designed to be essentially geological; and a very large corps of young geologists were central in it. Under this regime, each party consisted of a geologist, a native to push the odometer, and incidental helpers. Systematic, closely spaced traverses were run, with natives ranging the bush for fixed distances on either side to locate the sparsely scattered rock outcrops. As soon as an outcrop was found, it would be inspected by the geologist. On the basis of such outcrop data, boundaries of rock formations were deduced and thus geological maps were constructed; and from the interpretation of these, in turn, were deduced whatever ideas could be gained as to localities potentially promising for ore. The general geological relations of a large area were fairly well ascertained and ultimately published,[13] together with outline descriptions of such mines, previously located, as lay within the concessions studied. It may never be known whether the methods of this group, so lavish in geological manpower, would have been as successful in ore finding as those of their predecessor had the identical areas and the same priority of opportunity been involved.

In the meantime, a third group took over study of that restricted tract known as N'Kana Concession, on which some work under Brooks had already been done. Under R. J. Parker and Anton Gray,[14,15] this was primarily a geological enterprise. It had the advantages of the roads and other physical improvements just previously made, of more concentrated attack because of much smaller area covered, and of the clues to major ore control (within a single sedimentary formation) deducible from the environments of deposits already in evidence: Kansanshi, Bwana M'Kubwa, Roan Antelope, N'Kana, Chambishi, N'Changa and Mufulira. This control was strikingly confirmed and explained by the mapping (involving study of both outcrops and the residual soils), and the favored stratigraphic horizon in which great tabular dissemination of ore had been introduced was correlated with the "Série des Mines" of Katanga. Selection of the most promising smaller tracts and drilling of these led at the end of two years to the following major results: "three large mines were developed and an extension to a fourth property was found. These were: Mufulira, Chambishi, Baluba and Roan Antelope Extension." (N'Changa, Roan Antelope main mine and N'Kana were being concurrently developed under other auspices.)

The following general inferences seem deducible with respect to this sudden blossoming of one of the greatest known mining regions:

1. Intelligent prospecting of the conventional kind remains a powerful tool in virgin regions where distinguishing surface exposures are combined with an indigenous population that has mined them on a primitive scale; a corollary is that early arrival on the scene gives enormous advantage.

2. No intrinsic magic attaches to effort merely because designated geological; results will vary with the vision behind the geological procedures and the quality and leadership of the geological staff.

3. Geology is as yet probably best justified and most productive when conditions of time-competition and property control permit its application in a fairly intensive manner; this ordinarily implies tracts of moderate, not enormous size.

4. Since neither conventional prospecting nor scientific geology can succeed where no ore exists, final judgment of the relative merits of the two procedures can hardly be made while the district is so young; but the several "blind" occurrences thus far located by geological study, such as Baluba, West Extension and Chingola, suggest that more may follow. Conceivably geophysical methods will find more occurrences in the future.*

5. It is to be remembered that exploratory effort brought in such imposing tonnages so rapidly because of two important groups of conditions: (*a*) the region, of friendly climate, is a tableland of very gentle relief, open woods

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* Cf. the successful geophysical results of Lunsemfwa, page 85 of ref. 12.

and residual soil; all the major discoveries were made within 30 miles of an existing railway, which tapped abundant coal 500 miles to the south; (*b*) the copper deposits are tabular bodies conformable with the bedding at a fixed horizon, and maintain unusually consistent grade over long distances along strike and dip. These are highly favorable conditions, especially for the geological type of exploration. It may well be a long time before a new district of anything like such magnitude is opened so easily and quickly.

A method recently adopted by the Swedish Geological Survey for reconnoitering large undeveloped areas with sparse outcrops is noteworthy for its economy of funds and geological manpower. Experienced young woodsmen, after brief specialized training, are sent out individually to comb a given area, note the position and size of outcrops and collect specimens from them. When such a scout returns to base, his collections are given competent inspection and any deserving specimens are at once subjected to further investigation. Those deemed worthy of examination in situ are tabulated, and in due time the scout takes a geologist to the site of each tabulated specimen. The plan is regarded enthusiastically by Swedish geologists.

Courageous and highly effective application of geological principles and the indices of geological favorability to the search for mines is illustrated by Ventures Limited and other activities in which Thayer Lindsley is a moving spirit. It is to be hoped that he may be persuaded to put on record the essentials of his method of calibrating the geological yardsticks, his criteria of selecting areas for investigation and his procedure in appraising the merits of ground chosen for consideration.

TECHNIQUES, THEORIES AND TRENDS

The governmental geologist is assigned to study a district with the direct expectation that the product will be a report. This is fundamentally true whether the district be notable for ore occurrence or for other reasons. The geologist of a mining company, by contrast, is set to work in a district to find ore or promising places for exploration, or else to decide that ore hunting does not appear economically attractive. In either group, the conscientious geologist is fully aware that the one or the other of these objectives is his obligation as an employee,* and he acts accordingly. Invidious conclusions, of whichever complexion, that some incline to draw from these undeniable differences of purpose and condition are not likely to be constructive. But recognition that the differences exist and in large degree are inescapable is essential to clear understanding of the function and methods of the company

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* Field work of his own choosing by the college teacher ordinarily fits the pattern of the governmental worker, whereas the independent consultant in mining geology naturally approximates the company viewpoint.

geologist. Because the governmental geologist does ordinarily publish his findings in full, his general approach and technique are well known.

During the half century that company geology has been practiced, the trend has been toward reduction of the contrasts in methods and objectives of the two groups of workers; this has been especially manifest in recent years, as already noted in the section on governmental geology. Beyond the fact that man is inherently imitative, each group possessed something lacked by the other. So far as the United States is concerned, search for minerals during the war pressed governmental geology probably too far in the "practical" direction, an unbalance now apparently being righted. But the growth of interest and understanding by the company geologist continues and must continue as to both breadth of scientific base and mastery within his special field.

Compared with the scope appropriate for any other specialist in the geological domain, whether structural geologist, petrologist, physiographer or other, the mining geologist, even in a single district, is likely to be confronted with conventional problems in most of these subjects, and compelled to solve them as the essential foundation for effectively following known ore and finding new. And for him, this means to *solve*, not merely to find a temporarily plausible explanation; otherwise, crosscut or drill hole will be wasted or ore will be missed or the shaft will be located ineffectively or in treacherous ground. A good mine geologist is thus likely to find himself a rather busy person, both physically and intellectually.

It was wholly natural that company geological work should, at its outset, put prime emphasis on mapping of the underground geology. Not only the kind, boundaries and attitudes of the rocks and of the major structures, such as a general geologist would record on surface, but also the position, shape, nature, and structural characteristics of the ore. The underground map came not only to typify but largely to comprehend the mine geologist's work. To "keep the mapping up to date" was his prime job. Mines not previously using geology decided to hire or assign an engineer to "do the geology"; that is, the mapping. In skillful and ingenious hands, precision of location and observation and depiction of details improved notably. As more details, such as changing mineralogy of the ore, alteration margins, and minor structure were brought into the mapping record, first on the levels and then also in the stopes, map scales were increased appropriately. At present, many companies have elaborate files of geological maps and sections of very high perfection; and now, of course, most mine geologists have been technically trained especially for that work.

The tangible value derived from the geological mapping at first varied greatly from mine to mine, both because of the difference in intrinsic applica-

bility of the mapped record to the important problems of the given property, and also because of the varied effectiveness with which the full significance of the map was apprehended. In any case, here was something tangible, that could be checked against the evident facts and grasped by superior officers. In very many instances it has paid handsome dividends in ore found, in clean mining, and in reduction of useless work.

It is to be realized, however, that the typical mine map, even at the present time, is predominantly a *representation of structure;* and for probably the majority of mines its chief function is to emphasize *channelways*, actual or potential. Emphasis on structure in general and channelways in particular has likewise dominated most of the geological thinking of the mine geologist. This has tended to confirm the value of mapping and crystallize contentment with that aspect of geological effort.

Evolution of Theory

No one confronted with the problem of ore finding could remain oblivious, however, to the existence and the growth of theories of ore genesis and localization, as expounded especially by governmental and university geologists. Review of a few major changes and additions in theory during the present century will afford opportunity to gauge the mine geologist's role in utilizing and contributing to this core of principle and concept (compare ref. 16).

At the opening of the century the long controversy between the magmatists and the meteorists was in its final and most violent stage. The paradox that sometimes happens occurred in this case: i.e., that a theory is doomed by its most brilliant and explicit presentation—that is to say, when all that can be marshaled in its support has been brought clearly into view, its crucial shortcomings become manifest as never before. For the great family of ores now regarded as hydrothermal, the theory of rock leaching by meteoric water could not hold against contemporary factual and philosophical presentations favoring magmatic affiliation and ascension. Stampede to the magmatic viewpoint soon led to extremes. The concept of immediately local derivation of the ore from the intrusive body, spearheaded by acceptance of pneumatolitic origin for contact metamorphic ores while the adjoining igneous mass was still more or less molten, was carried to the extent of viewing each dike or sill as a potential source from which ore might have come.

We are now witnessing a recoil, as a result of wider experience and clearer reasoning. It is becoming manifest that the magmatic episode is long and complex; that even the ore-bearing magmas were not everywhere and from the instant of intrusion surcharged with ore stuff, which they belched

into whatever they touched; but that instead a considerable outer shell of the body had crystallized before the escaping volatile-rich fluid had acquired a sufficient proportion of metals and associated elements to effect at favored places that degree of concentrated deposition which constitutes a commercial ore body. We are left with the somewhat disconcerting presumption that we have never seen the specific source of any hydrothermal ore body—that particular nest where the ore fluid came into being and then started on its journey in quest of places for deposition. Widely differing views are consequently held as to the place, the dating, and the nature of such sources. Opinion is again in a state of flux.

So a new swing of the pendulum pushes the ore hearths down to great depths. Holmes[17] would draw the ores of lead, and presumptively other metals, from greater depth than that at which granitic and basaltic magmas originate and thus would make them nonmagmatic in the accepted sense. This stimulating conclusion, deduced by extreme extrapolation from a tiny "baseline" of isotopic differences, has since been materially weakened by corrected data. Still more recently, Hulin[18] proposes that the date of liberation of the ore fluid is so long after the emplacement of magma, and hence the place of liberation is so deep in the magma chamber, that "no idea of a direct genetic relationship between the ore deposits and the near-by intrusive body can be longer entertained." Instead, the characteristic association of ore deposits and intrusive masses "is recognized as resulting from structural control of the mineralized district." This thought-provoking paper, which builds on to views presented 40 years ago by Spurr, fits also as a further step in the author's well-known concepts of intramineralization fracturing and of ore derivation from basic magmas. It will doubtless receive the careful study it so clearly deserves. Interest will attach to the resulting discussion, which must eventually pass judgment on the relative soundness of this thesis and accumulated counterindications now widely accepted.

Rejuvenation and elaboration, in the '20s, of the venerable concept graphically called the "ore magma" and its product, the "vein dike," found many active supporters and not less numerous and emphatic opponents. The issue gradually subsided, presumably because of majority conviction that the evidences against it are too strong. But it still finds occasional advocacy; and something of the sort seems to be in the minds of those European writers who still allude to "injected" sulphides or ore "displacing" the country rock for examples which most American geologists would ascribe to the process of rock replacement effected by a dilute and tenuous solution.

The influence of physicochemical conditions on ore deposition, as propounded by Lindgren in 1906, the theory of ore formation as related to magmatic differentiation advanced by Spurr a year later, and the discussion

of primary downward changes by W. H. Emmons in 1924, contributed to the broad concept of vertical zoning to which allusion is now frequently made by scientific and practical workers. The realization developed that these successive zones, when visualized on a district scale, could be regarded as adjoining, not as a series of cylinders piled one above another, but rather as a succession of interfitting conical sheaths, the flaring bottom of each sheath thinning to zero at some distance above the corresponding bottom of the sheath representing greater intensity lying next below. It also became evident that the horizontal-concentric manifestation of zoning, such as displayed at Butte, could be regarded as merely a horizontal slice across the vertical stack of conical zones.

In accordance with this idealized image or model, the vertical line through the apices of the sheaths would mark the axis of major permeability and of the "hot center." If sound, the theory should afford, through the indicated intensity of the conditions attending ore deposition, an idea of the relative initial depth of formation of the observed ore. But independent check on depth of formation is commonly handicapped by uncertain reliability of estimates of post-ore erosion. In a few districts, however, such as Butte, Ouray and Casapalca, deep mine workings seem to confirm the order of change in mineral character with depth which the theory postulates; opposite order appears to have been nowhere encountered.

Obviously, judgment and restraint are needed to avoid overworking so alluring a picture; judgment and openmindedness are equally needed to avoid rejecting it hastily. It is certainly not yet justifiable to assume that every hypogene district must exemplify zonal distribution, nor that all zonal patterns must approximate the one outlined above. Unrest is wholesome to whatever extent it stimulates quest for a better theory. In the meantime, scattered evidences of a somewhat cynical distrust of the philosophy underlying the zonal theory seem more likely to represent sterile retrogression than the initial stirrings of something new and constructive.

Depth of Ore Persistence

On the economically important depth below present surface to which ores persist, views have oscillated markedly during the past 75 years. The early decades disclosed strongly contrasting ideas; those who knew of mines that failed at shallow depths inclined toward general pessimism, while promoters stressed the argument that the heavier the metal, the deeper, obviously, it would persist. Gradually, round the turn of the century, conscientious and capable men, in the face of speculative fervor, inclined toward very conservative views. Able geologists, like Gilbert and Van Hise, concluded that the inevitable constriction of openings with depth places a definite

bottom to the formation of ores (if formed, as they largely assumed, by waters of meteoric origin). Engineers of extended experience with many mines, like Rickard and Hoover, cited statistical implications that profit could be expected only rarely from depths greater than about 2000 feet.

Fortunate it is that these well-meant counsels were not heeded. The swing to belief in a magmatic origin for many ores lessened or nullified the theoretical denial of deep deposition; and realization that numerous mines of considerable depth and not yet "bottomed" were dealing with ores belonging in the middle depth range according to the zonal concept strengthened this reversal of the earlier theory. Fact also came to the support of the newer view; for mines continued to deepen and still make profits. Not all mines, of course. In the main, the hypogene deposits that have faded at modest depths below the present erosion surface have the characteristics ascribed by the zonal theory to "shallow-seated" formation, whereas those on which mining has persisted to 5000 or 8000-foot depths fall in "deeper seated" categories of the theory, which thus receives a further measure of pragmatic support.

At present it is regarded as probable that for many instances the downward limit of mining will be reached not because of actual decline in grade and/or quantity of mineralization but because rock pressures, temperature-humidity conditions and the increased distance of hoisting, pumping, ventilation, etc., will eventually raise costs to a figure where profits vanish. Because it has become clear that the world is going to need ore from the greatest depths that can feasibly be reached, postponement or lessening of the adverse effects of depth needs more attention than at present. Prophylaxis is possible even if not cure—for deep mines grow from shallow mines; and many of the difficulties encountered in the deep ones are aggravated because of neglect of precautions that should have been taken while the mines were shallow if the prospect of becoming deep had been adequately foreseen. Sound geology should be helpful in deciding, for mines of intermediate depth, to what extent the combination of zonal type and local structure may justify present steps that would improve conditions if the mine becomes deep.

Secondary sulphide enrichment had been sensed as to essence by many mine operators and engineers,[19] and when presented by geologists in the form of a clearcut hypothesis about 1900 was given widespread and confident acceptance. Yet quickly this fine, sound concept was carried too far. The hasty application to silver ores has proved in many instances not to fit; enrichment in nickel sulphide ores is relatively insignificant, and in gold ores probably little more so. Even for copper, for which its enormous importance is universally recognized, there exists a long-standing disparity of interpretation of chalcocite from deep levels. At Butte, where this question is notably

important, the Anaconda geologists feel convinced that the deep chalcocite is primary—hypogene; presentation of the results of their detailed studies is awaited with interest.

Extension of Geological Research

The foregoing examples of theoretical nodes in the broad problem of ore deposition only inadequately sample the total. The character of the ore-bearing fluids; the validity of direct magmatic segregation; the theoretical and practical status of contact-metamorphic ores; the role of colloids; the mechanisms of weathering as affecting both the occurrence of lateritic ores and the connection between weathered outcrops and what lies beneath—these are among additional subjects, partly theoretical, partly factual, as to which views have fluctuated markedly with time. All this clearly means that *majority opinion at any given time does not necessarily reflect the truth.*

Geologists may fervently wish for greater fixity and finality of geological theory; and managements may be puzzled or even rendered suspicious by the change and controversy evident. Yet neither must be disheartened; for only thus does a science grow. Because of the inherent inaccessibility in time and place of so many important geological processes, and particularly because of the limitation on *experimentation* in duplication of natural conditions, speculation has largely lacked the control so wholesome and productive in physics, chemistry and engineering. It has therefore been a natural reaction to utilize and value a type of geological procedure that is least speculative in nature.

This brings us back to the great wave of emphasis now placed on the subject of structural control. Structural study unquestionably has found more ore to date than all other phases of geological work combined. Undoubtedly, such study will continue to be highly productive, since so much ore is dependent for its importation and localization on some manifestation of permeability. But just as the arteries, veins and capillaries are no more important to the human system than is the character of the blood that flows through them, or than the subtle reactions of so many kinds that contribute to the total physiological process, so the attention to channelways, reopening and preparatory "ground-conditioning," to channelway details as by contouring attitudes or widths, to relative fracturability of different rocks, represents a most one-sided and partial approach to the problem as a whole. It is an unsound approach only in that it tends to neglect, if not indeed to discourage, other important and necessary adjuncts. Chemical, mineralogic, petrographic and mineralographic studies have as yet been pursued far more for the writing of articles than for the hunting of ore. To realize that the burden of justification for this lies strongly on the ore hunter, one need only

recall what chemistry, microscopy, X-rays and spectroscopy have done for modern metallurgy.

It is highly encouraging, therefore, to realize that company geological departments, like metallurgical departments before them, are becoming alert to the need and advantage of *research* in the modern sense. International Nickel, Anaconda, and Cerro de Pasco are among the companies that in recent years have established laboratories for geological research, equipped with modern instruments appropriate to a wide kind of investigation and staffed with men soundly trained not only to conduct the investigations but also to interpret their significance to the geological problems in hand. These laboratories are adding so notably to understanding of ore occurrence and ore controls that adoption of the same program by many other companies in the near future seems inevitable. The research right on the spot will achieve its optimum in effectiveness and satisfaction to the extent that the work and the men in the laboratory be most intimately integrated with the geological work and workers in the mines. The problems of ore occurrence are already too large to be handled masterfully by any single individual. By deliberately bringing into teamwork men of different backgrounds of training and experience, the larger geological departments can begin to realize something of the collective power and success that the great medical clinics have so notably acquired.

Prospecting of the Future

Even if this broadening and scientific enriching of geology in the mines soon becomes common practice with the stronger companies, it will come none too early to serve as foundation for the new body of knowledge required for the successful location of entirely new mineralized areas, whether in covered regions or with bedrock exposed. Present intellectual armament for attack on that great problem is decidedly inadequate, as even the best reflections thus far offered on the subject make plainly manifest. No consistent record of success in this challenging program can be expected from following any given hunch. Only a comprehensive and reasonably sound philosophy of ore deposition can hope to make more than chance, sporadic hits.

In this eventual grand campaign of ore hunting in the blind, geophysical and geochemical methods will certainly be employed. The conspicuous success in recent years of geophysical exploration for petroleum[20] gives some idea of what may be hoped for when methods, instruments and techniques become sharpened to suit the smaller bull's-eyes that ore bodies constitute.

Magnetometric methods, since they deal with a specific and wholly unambiguous response of certain substances, will doubtless continue to stand

at the top in reliability, and may be expected to be still further refined in sensitivity and expressiveness. The recent development of airborne magnetometry holds high promise of rapid and cheap reconnaissance of great areas, not only for locating magnetic "highs" but also, probably, for much areal mapping, since slight differences in magnetic quality from one rock type to another can now be detected from surface or from air, even under cover of vegetation, drift or water. The acme in magnetic usefulness will come if and when depth of the magnetic source can be positively determined. That end seems especially likely of attainment through airborne determinations at different elevations above the same area.

Spontaneous potential methods probably will continue to be more reliable than induced fields for ore occurrences in which a definite chemical process like oxidation is going on; and will become still more valuable if it becomes possible to recognize and eliminate responses from reactions probably not related to ore bodies. Because many ore bodies have notably higher density than ordinary rock, gravimetric methods may possibly be perfected to pick up responses from heavy masses of ore-body size. Seismic methods seem better suited, as to scale, for disclosing broad structural features favorable as loci for ore occurrence than for finding the ore itself.

Minute traces of telltale elements in rock outcrops, soils, ground waters and the ash of vegetation have received considerable attention in this and other countries[21] as clues to ore finding. If further trials demonstrate the economic utility of such geochemical inquiry, the hillsides may see, instead of prospector's burro, shovel and pan, a jeep with spectrograph and other modern instrumentation.

Present-day perfection of aerial photography is already an enormous aid in mapping for reconnaissance or detail. Frequent disclosure of rock structure unsuspected from the ground can undoubtedly be put to excellent productive use; in reconnaissance of virgin territory it may record prime successes. The helicopter is already far toward proving itself the answer to the geologist's dream. If reliability of performance, first cost and maintenance expense can all be brought to proper level, the craft's unequaled versatility will make it ideal for all kinds of country.

In the quest for blind ore, deep drilling obviously will play an even greater role than now. Relative lightness and flexibility, besides the advantage of pointing in any direction and of yielding core, indicate diamond drilling as most appropriate. Every improvement in cost, speed, core recovery and control of wedging or diversion will be welcomed.[22] If the "wire-line core barrel," which can be removed from the hole without pulling rods, and/or the method of "counter-flush continuous coring" become practical for hole diameters appropriate to diamond drilling, much time and expense can be

saved. Doubtless there will be wider employment of rapid, cheap drilling by diamond bits of the "blast-hole" type until the critical objective is neared, then changing to a coring bit—perhaps with an independently removable core barrel, or with continuous coring. With the rapid advances in interpretation of powered material under the microscope, it is entertainable that for certain purposes core drilling could be completely displaced by solid-bit drilling combined with careful collection and microscopical study and assay of the sludge; or perhaps followed by deflected short runs of core drilling starting just above where interesting material has been cut. The possibility of a synthetic product—a carbide?—of adequate hardness and toughness and materially cheaper than diamond may not be a wild vision in this era of metallurgical wonders.

This section may well be concluded by allusion to the difference in conceived function of mine geology by two men of wide experience and conspicuous success, much of whose work has lain in the same province, the Cordillera of North America. In "Mining Geology Today,"[23] Joralemon is at the disadvantage of writing first; in "Mining Geology Today and Tomorrow,"[24] Sales replies. Adequate summary of the papers is out of the question here; but a reader will be well repaid by this cross fire of philosophy on some of the basic problems of mining geology.

Reserves and Conservation

Seventy-five years ago, mining was proceeding, as of old, largely on faith from initial outcrop outward and downward. The long-accumulated experience that depth was most feasibly dealt with not by uninterrupted downward extraction but by a succession of spaced levels tended to increase evident ore supply by conspicuous periodic increments, even though anything approaching dependable measurement of the increments was uncommon. Since that time great changes have come about.

The gradual evolution of mining from a romantic adventure and gamble to a business involving recognized hazards, the expanding size of mining units, the rapid increase in outlay for equipment and plant with resulting requirement of knowing amortization period and rate, the need to raise large sums from the public through the appeal of frank information, the widespread growth of income taxation with recognition of mine depletion, and the mounting awareness by mine management of continuing responsibilities both to their shareholders and employees and to the dependent communities—these have brought to each mining unit throughout the industry a pronounced consciousness of ore reserves and mine life. As these topics involve predictions of what the rocks contain, they have naturally come into the domain of the mining geologist.

Next, the significance of quantity and duration of mineral reserves spread from the scale of the individual mine to the scope of the nation and of the world, through realization that wasteful methods are neither good company business nor good social policy, that individual mines and mining districts were dying, and that the rate of exhaustion of these nonreproducible resources was steadily accelerating. For the United States, conservation of natural resources was brought to the fore by President Theodore Roosevelt, who, in connection with a National Convention which he convoked in 1908 to consider the subject, called on the U. S. Geological Survey to estimate the country's reserves of economic minerals. The resulting data, though recognized as most imperfect, served nevertheless to affirm the importance of the subject. Even then it was predicted that lead would be the first of the country's important metal products to reach exhaustion.

The great demands of mechanized warfare in 1914–1918, and particularly in 1939–1945, focused still more conspicuous attention on national and world resources. These remain a vital topic in the considerations of peace. The simplest logic of arithmetic, that less remains than at the beginning, is confirmed by the increasing difficulty and decreasing rate of finding new supplies. But there simplicity ends. In the abundant present-day publication on ore reserves there is much contradiction and confusion. The turmoil serves to prevent complacence; but if quantitative estimates continue to be made, probably we shall continue for unknown decades ahead, as for decades in the past, to see estimates successively revised.

Hitherto, passage of time has required revisions upward. For example, in 1915 a recognized authority estimated the *total* expectable reserves of petroleum in the United States; 30 years later, the estimate solely for *proved* reserves was four times the 1915 figure, notwithstanding the enormous intervening production. Similarly, a competent expert in 1907 estimated the period during which the coal reserves of the United States would last; 40 years later, the estimated period is 20 times as long. Admittedly, more pertinent information for all mineral products is available now, both in this country and over the world, than was at hand 30 and 40 years ago. However, when one considers how difficult it is for those best informed to estimate the remaining reserves in a single, compact district of long history, the probable error in predicting eventual worldwide reserves known and as yet unknown should slow down the guessers' impetuosity.

The actual inroads on world reserves during the 75 years of the Institute's existence are approximately as indicated by the total production in column 4 of Table 2. In column 3 are shown the growth ratios; that is, the relative production at beginning and end of that period.

For the products that were mined on an important scale during the first

TABLE 2—*World Metal Production,*[a] 1870–1945

NEW METAL ONLY

IN TONS OF 2000 POUNDS EXCEPT AS OTHERWISE NOTED

Mineral	1 1870	2 Maximum Year	3 Ratio Col. 1 : Col. 2	4 Total 1871–1945
Gold[b]	5.95	41 (1940)	1:7	1,260
Silver[b]	49.5	276 (1937)	1:5.5	12,800
Copper	130	2,800 (1942)	1:21	74,000
Tin	31	282 (1941)	1:9	8,100
Iron	14,200	122,000 (1943)	1:8.6	4,140,000
Lead	315	1,870 (1940)	1:6	79,000
Zinc	148	1,820 (1943)	1:12	62,500
Mercury[c]	100*	275 (1941)	1:3	8,600
Nickel	0.45	156 (1943)	1:350	3,400
Manganese[d]	70	6,680 (1937?)	1:95	119,000
Antimony	1.5*	52 (1943)	1:35	1,600*
Cadmium (1882)	0.005*	5.3 (1943)	[1:1,000]**	70
Aluminum (1890)	0.2*	1,920 (1943)	[1:9,600]**	15,100
Chromium[d] (1895)	44*	2,170 (1942)	[1:49]	27,000
Magnesium (1896)	0.05*	284 (1943)	[1:5,600]**	1,200
Bismuth (1900)	0.009*	1.9 (1942)	[1:200]**	20*
Molybdenum (1901)	0.024*	34 (1943)	[1:1,400]**	240
Tungsten[e] (1905)	4*	44 (1939?)	[1:11]	740
Vanadium (1907)	0.003*	5 (1943)	[1:1,700]**	50*
Coal	258,000	1,915,000 (1942)	1:7.4	99,000,000
Petroleum[f]	5,800	2,625,000 (1945)	1:453	49,140,000

[a] Statistics derived from U. S. Geological Survey, U. S. Bureau of Mines, American Bureau of Metal Statistics, *Mineral Industry,* American Petroleum Institute, *Iron Age* and other sources.

Dates following name of metal indicate approximate beginning of significant production. Dates in col. 2 represent the year in which the indicated maximum production was obtained.

Productions marked by asterisk are approximations.

Ratios in brackets are for periods less than the full 75 years; those marked by ** are to be regarded as only rough indications because of smallness and uncertainty of the production in col. 1.

[b] Millions of fine ounces.

[c] Thousands of flasks of 76 pounds.

[d] Thousands of tons of ore.

[e] Thousands of tons of ore of 60 per cent WO_3 equivalent.

[f] Thousands of barrels of 42 U. S. gallons.

seven decades of the nineteenth century, shown in Table 1, comparison may be instituted with the growth ratios in column 3 of Table 2. The reasons for the variations in these ratios from product to product and from early period to late period are well known. It is interesting to note, however, that gold, lead, zinc, iron and coal, among the old standbys, have not held the same rate of growth in the last 75 years as in the preceding 70 years, whereas copper and tin have bettered their position, as also has silver because of its by-product status. But the really striking feature (resembling the behavior of zinc in the earlier period) is, of course, the growth of the metals with the newer uses: the alloy metals and the light metals.

As many have pointed out, the present century has witnessed greater inroads upon the world's supplies of metalliferous minerals and carbonaceous fuels than took place throughout all prior history. What fraction of the initial total still remains cannot even be guessed, since that depends probably as much on man's future ingenuity and on the prices civilization may find it possible to pay for the metals as upon the actual quantities contained in the rocks to depths that man can reach.

Factors that Affect Reserves

Reserves obviously are raised and conservation achieved by all improvements that lower production costs and increase recoveries of the major valuable component or components; and, also, to whatever degree recovery is extended to "rebellious" or rare components in an ore. Vast strides have been made regarding costs by mechanization and increased size of units. As physical metallurgy has developed uses for rare components (at least 40 of the metallic elements are now "commercial"), ore dressing and process metallurgy have kept abreast in recovering them from their source materials. Relatively little now escapes being caught in the by-product net, and for most elements further efforts are likely to show progressively diminishing returns. Increasing attention to the collection and reworking of scrap metals —already a most important industry—will probably repay the effort. In all these respects the mining, metallurgical, chemical and manufacturing industries have labored most earnestly and effectively.

Ore reserves, however, are much more sensitive and mobile quantities than most statisticians seem to assume. They vary on the scale of the individual property with the owner's direct activity, rising or falling as his ore finding exceeds or falls behind extraction, as his costs decline or mount and as his recovery efficiencies improve or regress.

Reserves also vary through industry-wide causes beyond influence of the individual mine: supply vs. demand, new uses vs. substitutes, and the in-

dustry-wide balance between exhaustion and replenishment of ores. This second group of influences is felt, for all save gold, through the factor of metal prices. Under natural and normal conditions, these broad influences, like the laws of physics and chemistry, work toward self-correction and equilibrium by automatically augmenting or shrinking the reserves in each and every occurrence, whether these reserves be in known mines or as yet wholly undiscovered, and also by encouraging or restraining ore hunting.

Both the mine-scale and the industry-scale influences have existed since mining could be regarded as an industry. Recently, however, through expanding governmentalism, wholly new factors have arisen, which profoundly affect ore reserves: crushing taxation, arbitrary and punitive restraints and controls, and governmental support—whether overt or covert—of demands for wages out of line with the economics of the industry or the times. Under reasonable governmental regulation, the mining industry had long demonstrated that it could produce metals from steadily declining grades of ores, and from ores drawn from greater depths and more remote localities, with increasing wage scales yet without substantial change from long-prevailing levels of metal prices. Legislators, political propagandists and labor leaders may well ponder whether more than this can be expected; in the long run, policies that cancel low-grade reserves are fully as dangerous and damaging to nations as to mine owners.

In recent years, hope for new supplies of ore have lain in two directions: (1) small bodies of moderate grade possibly commercial under modern techniques; and (2) great bodies of very low grade. As between these two groups, the latter is strongly favored under the conditions that have been brought into being during recent years. The small properties, with high requirement of labor per unit of output, are severely handicapped. And among the low-grade units only the very largest can hope to amortize the excessive capital requirements. Yet this tendency toward ever larger units is the direct opposite of the objective held by the dreamy ideology that has brought the causative conditions into force.

Let it not be forgotten that the recent war was won, above all else, by *production.* The totalitarian powers were astounded and the democracies jubilantly surprised by the productivity of the latter. Yet even the bounties of nature are to be effectively won only in a climate economically, socially and politically favorable. The fundamental conditions, objectives and policies that during the last century and a half have prevailed in Great Britain and the United States have not been mere accidental coincidence paralleling the attainment of greatness and prosperity by those nations; but instead, have been the sound and indispensable basis of these qualities which all nations of the world desire. Radical departure from those same objectives and poli-

cies can bring only disillusionment, retrogression and distress, however or by whomever the trial be made.

Because, at a few places where all conditions are especially favorable, ore in place averaging 0.5 per cent copper or 0.0002 per cent gold has been mined profitably, reference is often made to the vast low-grade deposits available to prolong metal supplies for a period beyond present anxiety. The thought has even been seriously proposed that for each reduction of one decimal place in grade accepted as ore, say from 3 to 0.3 per cent, from 0.3 to 0.03 per cent, etc., a new tonnage more than one decimal place greater is thereby made available. Those familiar with ore occurrence know that this simply is not true. For most metals, the abnormal local concentration that constitutes an ore deposit has real geometrical limits, beyond which the tenor more or less abruptly drops off to values far below anything entertainable as economic.

Of course, it is true that for ores like those of iron and aluminum, which, by current standards, average in the tens of per cent metal content, there is realistic prospect of gaining adequate supplies for a very long time into the future by utilizing materials of progressively lower grades; chromium and manganese are in a closely analogous category. Magnesium, in rocks and oceans, stands at the extreme of abundance. But for metals like copper, tin, nickel, for which present world-average grades of ore range from 2 per cent downward, there remains a much smaller leeway for ingenuity; gold and silver, except when recovered as by-products, are in a corresponding category. Zinc and possibly lead occupy a position somewhere between the iron-aluminum and the scarcer group.

Possibilities for the Future

Although the facts of the past have clearly shown the dangers in prophecy, it is necessary, nevertheless, to cast our sights ahead.

The period between 1871 and 1946 has disclosed no new land areas of first rank except in the south polar region. However, for great areas whose existence and major features were already known, there has been enormous increase in knowledge of detail of the kind pertinent to classification regarding suitability or unsuitability for ore occurrence. Much of this advance has come, of course, through specific and deliberate search for mineral wealth. Concurrently, the criteria for suitability have become much better understood. The general nature and distribution of rocks and their ages and structures are now known for most of the land surface. Islands of ignorance still remain; one such, Labrador, is just now in process of promising investigation. The frigid and tropical belts contain most of these blank areas.

Within the next quarter century or so, these scantily known regions

doubtless will have been brought pretty well within the fold of understanding, especially by aid of aerial reconnaissance, and above all if this includes the helicopter or equivalent means of grounding safely and at will in virgin terrain. During that period it is reasonable to expect new ore discoveries.

Thereafter, increments from deposits having visible surficial indications may be expected to fall to a new low; and thenceonward most new ore must come from exploring known districts more thoroughly laterally and mining them to greater depth, from wiser geological prediction of favorable but buried loci, and from the aid of geophysical and geochemical techniques. If anything like the past rate of advance in scientific understanding and technologic efficiency may be projected into the future, the common and most of the rarer metals may be counted on for a long time to come. On the other hand, if the sociopolitical climate is not conducive to metal hunting, neither will it be to metal using; then the standard of living will recede, and a new Dark Ages will reign until man regains his common sense and honesty. There is no guarantee that what happened to Egypt and Babylon, to Greece and Rome, will not happen in today's world, save the steadfast determination that it must not be.

Role of Atomic Energy

No consideration of conservation and no look into the future can ignore the amazing new reality, atomic energy. It is clear that research on this subject is proceeding feverishly on both sides of the Atlantic, and enough has been made public on this side to leave no doubt of great advances in scientific understanding. But in addition to what other nations may be doing, a vast pool of secrecy remaining in this country incites much superficial and emotional writing.

Most of the world fervently hopes that this supreme triumph of the human intellect may be turned from warlike to peaceful use. Many seem to take for granted that this outcome is most likely to be achieved by prompt application to industrial uses under rigid international control. Existing proposals before the United Nations imply such programs. And there is much near-official activity toward bringing them into being as rapidly as possible. Neglecting the wholly fantastic notions of columnists and others among the less informed, plans are being seriously discussed that envisage for the near future a consumption in the United States alone of 10,000 tons of metallic uranium annually; and of competing soon with the most efficient coal-burning power plants. An earlier, more official (Smyth) report phrases the situation thus:

> Early rough estimates, which are probably optimistic, were that nuclear energy available in known deposits of uranium were adequate to supply the total power needs of this country for 200 years (assuming utilization of U-238 as well as U-235).

Two considerations, however, warn of the need for caution in the contemplation of such plans. First, a growing number of thoughtful scientists have come to believe that, in the present turbulent state of the world, the enormous complexities and difficulties of international control of nuclear energy, if produced on a great industrial scale, combined with the tremendous temptation to circumvent this control, would constitute such extreme hazard to peace as not to be justified by the sum total of gains presently visualized from industrial use. The proposed alternative is international restriction to scientific research, a scale of use far easier of rigid control and enormously less tempting to evade. Second, there are unquestionably uranium and thorium deposits capable of yielding enough bombs to wreak unconscionable havoc over great areas of concentrated population, not only by immediate destruction but also by slower but wider-reaching radioactivity. *But there is yet no demonstrated certainty that there exist sufficient natural concentrations of these metals to support a long-continuing atomic-power industry.*

These two challenging considerations, moreover, have a possibly sinister interrelationship. If there surely were enough of these two metals to permit sustained extension of the benign effects of cheap nuclear energy to great masses of people hitherto energy-starved, this very factor might be hoped to ease present world tensions, and, combined with other earnest efforts toward peace, to reduce steadily with time the temptation of treacherous evasion of control and of resort to malign use. The longer peaceful production would continue, the less the probable chance of perversion. But if industrial plants established in many countries—as would naturally be demanded by these countries as condition of their acceptance of control—should after a period demonstrate that the supply of physically obtainable uranium and/or thorium metal would not last much longer, doubly compounded temptation might incite vicious leaders of an aggressive nation to make their evil strike before too late.

Conceivably, therefore, even if agreement on international control can be reached, much more may hinge on the available reserves of uranium and thorium than such mere practical questions as the possibility of economic competition with coal.

The easy detectability of uranium and thorium minerals by such device as the Geiger-Müller counter, when held *close* to a rock on surface, in mines or drill holes, promises unusually prompt discovery of new occurrences wherever such detailed studies are made; but similar detection at the distance appropriate to aerial reconnaissance seems beyond hope. As far as yet disclosed, no spectacular additions to reserves of a grade hitherto minable resulted from the feverish and extended searches by the Allied governments during the war years. Lower grade materials are known in several localities, but much

comment, even by insiders, about supplies for a great nuclear energy industry either rests on secret information or else is superlatively optimistic and naïve.

The requirements are worth brief inspection. Material containing 0.2 per cent uranium,* with an assumed overall recovery of 75 per cent, would have to be mined at the rate of over 6,000,000 tons per year to yield the mentioned 10,000 tons annually of uranium metal. If, as seems probable, such rate of exhaustion would make rapid inroads on world reserves of that tenor available to this country, resort would soon have to be taken to progressively lower grades. Considerable tonnages of shales are known containing roughly 0.02 to 0.002 per cent combined uranium and thorium. At these figures, again with 75 per cent recovery, to secure the expected annual 10,000 tons of metal, the higher grade would have to be mined at 60 million tons a year, or 200,000 tons a day, or the lower grade at 600 millions tons yearly; that is, equal to all the coal mines of the United States. Complacent reference to the occurrence of uranium and thorium to the extent of a few parts per million in ordinary rocks—i.e., about another decimal place lower still—misinterprets the manner of deriving as well as the significance of such figures, and also reveals an unrealistic appreciation of the limitations of metallurgical recovery.

However, even if enough of these rare metals could be found and produced to supply a peacetime energy industry for a term of economically justifiable duration, their exhaustion merely for ordinary competition with coal or petroleum would seem most inadvisable. A few superlatively urgent uses for energy in remote regions might be justifiable. On the other hand, schemes like pumping from wells to make the Sahara bloom seem likely to belong on the same shelf with Baron Munchausen's tales. Until it may be proved impossible, production of controlled supertemperatures for tomorrow's metallurgy and chemistry might be the most valuable use of these rare fissionable elements. If so, their exhaustion otherwise would be lamentable.

Assuming, however, that fissionable material from uranium and/or thorium is to be used on a considerable scale for either military or industrial purposes, certain consequences pertinent to the mining industry obviously will result. Besides stimulation of search for and production of these metals, doubtless under most rigid governmental or international control, there would be forced increase in production of metals naturally associated: vanadium, cobalt, selenium, radium, silver, molybdenum, nickel, chromium, tantalum, columbium, and rare-earth elements. There would also be increased need for certain elements used in the processing reactions: beryllium, boron, cad-

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* This is approximately the same as the average grade, 0.21 per cent, for the carnotite ores of the long-known deposits of Colorado and Utah, as given in the official report of extensive exploration during the war; the roscoelite ores of the same area are of much lower grade. Tonnages are not stated.[26]

mium, indium, rhodium, and gallium are potentially indicated. And as synthetic products of the fission reaction there would be substantial quantities of various elements lying in the middle range of atomic weights; some of these are rare, and of these certain ones in the form of stable isotopes are valuable. For the list of needed elements, the prices would tend to rise. For the elements naturally occurring with them, and thus made available as forced by-products, the previous prices would tend to be depressed, likewise the price for the rare products of fission. Beyond these very general influences, the economic consequences are now too vague to deserve further speculation.

Now that the binding energy of atomic nuclei has been brought within reach, derivation from commoner elements beckons alluringly—above all, if of such nature as not to be "chain reacting" and explosive. But all this is as yet too speculative for more than mention here.

If the present worldwide wave of greed for political power leads to perverted employment of this majestic new-found knowledge, may the Infinite Judge enter the charge against those grasping despots who lead their peoples by falsehoods, rather than against the earnest scientists who, almost without exception, hope and strive against such prostitution of all that science stands for.

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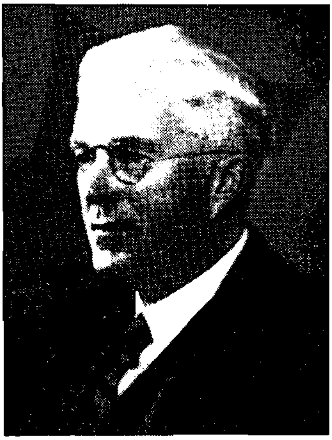
Seventy-five Years of Progress

Seventy-five Years of Progress in Mining Geology

BY L. C. GRATON

Civilization did not begin until metals became the material of tools, implements and machines.—
RICKARD, *Man and Metals.*

HISTORY is no more an end in itself than is a backsight the sum total of a survey. This Institute may view with satisfaction the remarkable development of the mineral industry since its founding three score and fifteen years ago, its own enlarging service to that industry, and the contribution thus made toward the enhanced welfare, opportunity and mutual understanding now in greater or less degree reaching and benefiting all peoples of the globe. But neither this professional society nor the dynamic mining industry as a whole wishes on this anniversary to direct its gaze chiefly toward the past. The foremost purpose of historical review should be to throw into clear perspective the strong points and the defects in the forward march thus far, primarily as the basis for conceiving and designing a still sounder progress henceonward.



L. C. GRATON

Professor of Mining Geology at Harvard University since 1912, Dr. Graton is a recognized authority on the principles of ore deposition and the development of geologic art as it relates to metalliferous ores. Various important corporations have engaged his services as consulting geologist; and he is the author of reports on the geology of mining districts in many parts of the world and of articles dealing with geologic subjects of national and international significance.

At various times since the Institute's founding, the *theories* of ore deposition have been considered from the historical viewpoint.[1–7] For the present occasion it seems fitting to lay prime emphasis on the *practice and utilization* of geology in its varied relations to the problems of the mining industry.

It is hoped that the reader will understand and accept the degree to which the whole is sampled by parts familiar to the present writer, and the disproportionate attention to thought and achievement within the United

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[1] References are on page 38.

States. Draughts have freely been made on the unwritten experience and conclusions of generous fellow workers, not only through direct appeal for the present purpose but acquired also in the course of numberless informal discussions during past years in diverse lands. Because of the many from whom the present article has thus gained, it is hoped that this collective acknowledgment will be accepted as assurance of the writer's grateful appreciation.

Geology the Offspring of Mining

Mining evolved from that blend of curiosity and self-interest that drove early man to seek and win selected components of the solid earth. Even in its primitive stages, the immediate problems of operation came to be attended by more subtle but no less important queries regarding these concentrations of useful metalliferous substances: *where? how?*—questions that lie at the very core of geologic genesis. About the middle of the sixteenth century the true complexity of the mining art became so manifest that its various subdivisions began to acquire entity. This was especially true in the already long-famous mining districts of Saxony, then the chief metal-producing center of the world. In the initial paragraph of his best known work, Agricola, a resident of that region, recites the wide range of qualifications of "the miner"; and first among the requirements are listed: knowledge of where prospecting is profitable and where futile, understanding of the veins, stringers and seams, and thorough familiarity with the rocks and minerals, the mineral-bearing solutions and their deposits. Thus in very truth was Geology sired by Mining.

More than one chronicler has implied that for a long period after publication of Agricola's seven large works interest languished in the geological aspects of ore occurrence, and even in geology generally. The truth is that Agricola was far ahead of his time. His explicit observations and rational conclusions, when once on record, undoubtedly discouraged much of the prior kind of superficial and speculative writings. But in the mines as well as in the broader aspects of the science, Agricola's views exerted a dominating and constructive influence on geological thought and method for two centuries.

With the eighteenth century began the establishment of the famous mining schools among the mining districts of Central Europe. The earliest, 1702, in the Saxon Erzgebirge, was reorganized in 1765 to become the renowned Freiberg Mining Academy. This close interrelation of mines and schools powerfully affected the development of all the major branches of the art. As will later appear, the course of geology, and particularly of mining geology, in the United States was profoundly influenced by the teachings and experience brought back from these European sources during the third quarter of the last century.

Geology still finds the mines to afford a most fruitful soil for its further growth—and more and more is the dependence becoming reciprocal, as progressive exhaustion of the world's ores requires specialized new talents and techniques for the finding of further supplies.

General Background Preceding 1871

Save for lingering imperfections here and there, the face of the earth could be regarded as known at 1871. The successive waves of exploration since the fourteenth century B.C. and the ensuing colonization and development that had yielded this geographical knowledge were actuated by a common aim—riches; and among these the metals were predominant.

METAL DISCOVERY AND PRODUCTION

Of the countless districts that had yielded metals to man during the five or six millennia of his use of them, surely a great number had left no memory behind. Others, like Ophir, had retained little more than a name. Only a very few continued known and productive on a scale proportionate to mid-nineteenth century needs. Most of the exploitable occurrences of metal to the end of the Medieval Era had been found wholly by chance; and the regions of the Old World that had long been inhabited by civilized races were not, at that time, replacing their exhausting mines by discovery of others. Even for the grander cycle of metal production that had opened with rapid exploration of the New World, it must not be forgotten that very important fractions came from long-accumulated stores in treasuries, temples and tombs of the natives whom the *conquistadores* subjugated and plundered. And most of the "discoveries" of actual mining places rested on the information freely proffered or forcefully wrung from the indigenous peoples whose forefathers had found and first worked these occurrences.

In the seventeenth and eighteenth centuries, discoveries of prime importance occurred in many lands. More and more, these were virgin finds, as prospecting extended and improved. In the meantime, sudden realization of the value in what had been the least prized products of the mines—namely, iron and coal—was chiefly responsible for the Industrial Revolution. Significantly, the steam engine, symbol of that new era, was first put to use in mine pumping. Expanding utilization of mechanical power enormously stimulated production of coal and the industrial metals. With manufacture, commerce and general trade mounting dizzily, new monetary requirements arose which fortunately were met by the spectacular gold discoveries in California and Australia; and these, in turn, brought forth a new and unprecedented cycle of search for ores of all kinds, which was in full vigor when the Institute was founded in 1871.

GEOLOGICAL THOUGHT AND PRACTICE

By 1871 geology had been recognized for three quarters of a century as an independent science. It possessed a substantial and expanding literature; it had become segregated into a number of accepted subdivisions, of which Economic Geology was one; and it embraced an integrated and growing group of professional workers. Besides the older schools of Freiberg, Clausthal, Paris and Cambourne, younger institutions in both Europe and America were offering instruction in geology as applied to mining.

Many of the grand principles of geological science were then in view, and more or less firmly established. But numerous questions second in importance only to these were in highly controversial state; examples relating to ore occurrence may be typified by the following:

> The broad concept of igneous intrusion was widely accepted in Europe, and the striking relation of many ore occurrences to the margins of intrusive bodies had already been emphasized; yet numerous geologists, notably in North America, urged that granite and other varieties had been produced by metamorphism of sediments.
>
> The common contrast in character between the parts of an ore body near the surface and those at greater depth, the bands of altered country rock marginal to veins, and the phenomenon of pseudomorphism were matters of common observation; nevertheless, the principle of replacement had not yet been enunciated with convincing clarity.
>
> That the great majority of ores had been transported and deposited by a water-rich solution had gained overwhelming acceptance; yet for great classes of deposits there was strong divergence of view as to whether the transport was from above or below, and whether the water was derived from rain or magma.
>
> Erratic shape and highly restricted localization of workable ores was the overwhelming experience of mining; yet ore minerals present in *part* of the areal extent of a sedimentary bed were urged by many as coeval—syngenitic—with the commingled unquestionably sedimentary sand, mud or calcium carbonate.
>
> Stream placers, the type of ore concentration longest known and worked, were accepted as a special product of sedimentary deposition; but active controversy persisted as to their subsequent "enrichment" and the "growth" of nuggets.
>
> Observers of equal competence held divergent views as to the downward persistence of various types of deposits; but there was common agreement that the "true fissure vein" bottomed below any possible reach by man.

The mobile and controversial state of the science, together with the speculative excitement attending new ore discoveries, afforded fertile ground for the charlatan and the unscrupulous promoter. On the other hand, the reliable geologists were fortunately supported by the mining engineers, mine superintendents and even metallurgists, who wisely reflected their close contacts with ores and ore deposits in contributions of authority and value.

The actual employment of geologists in connection with the mining industry at 1871 was virtually limited to teachers, members of the national and state geological surveys under either civil or military authority, and those

temporarily engaged for some given problem or project, not uncommonly involved with mine promotion. Perhaps the earliest important instance of engagement of a consulting geologist in the present-day sense was the retention of Baron Ferdinand von Richthofen by a group of the Comstock mines, beginning in 1864, to give counsel on the threatening decline of the ores with depth and upon the Sutro Tunnel project. His intelligent and realistic treatment of these problems did much to establish the dignity and value of the profession in the United States at a most opportune time in its mineral development, and without doubt influenced support for the establishment, in 1879, of the United States Geological Survey.

To the inroads that mining had already made upon the world's mineral resources, some of the wisest minds of the time were not oblivious. But the succession of great discoveries, the rapid industrial developments and all the resultant effects caused the industry to be mainly permeated by the same unbounded optimism that had fired the ancient searchers for the Golden Fleece. True perspective of the period is now to be had in the following approximate ratios of output of major products at the beginning and at the end of the seven decades preceding the founding of the Institute (compare with Table 2):

TABLE 1—*Relative World Production,* 1801–1871

Product	1801	1871	Product	1801	1871
Gold	1	10.6	Iron	1	17.4
Silver	1	1.9	Lead	1	15.0
Copper	1	7.1	Zinc	1	384
Tin	1	3.9	Coal	1	21.5

These ratios give more than a measure of the increase in discovery, extraction and consequent exhaustion. They imply also the increased difficulty of finding new supplies, a matter then given little serious concern but that nevertheless led to gradually increasing dependence on those adequately trained and experienced in the special domain of mineral deposits.

The Seventy-five Years 1871–1946

ROLE OF THE INSTITUTE

From its inception, the American Institute of Mining Engineers gave wholehearted haven to mining geology. Of the three signers of the proposal to establish such an organization, two are found among the contributors to the literature of geology. One fourth of the 68 charter members and 8 of the 18 original officers are in the same category. The first scientific paper

presented at the founding meeting in Wilkes-Barre and assigned to open Volume I of the Institute's Transactions treats of the geographic and geologic distribution of the mining districts of the United States, by that grand patriarch of the Institute, Dr. Rossiter W. Raymond; and 14 of the other papers in that initial volume deal with geological subjects. During its existence thus far, the presidency of the Institute has been accorded to eight geologists, and thirteen renowned geologists over the world have been elected as Honorary Members.

Through the years, the sympathetic environment and live discussion drew to the Institute's meetings oral presentation of the summarized fruits of investigation by leading mining geologists of this continent. The Transactions, of high technical excellence, afforded worldwide distribution of these and other contributions, and are among the most valued archives of the subject. Among its outstanding offerings may be cited the following, each of which, within its particular scope, has exerted a profound influence on the understanding of ore deposits:

	Volume
The Genesis of Certain Ore Deposits, by S. F. Emmons	XV
Structural Relations of Ore Deposits, by S. F. Emmons	XVI
The Genesis of Ore Deposits, by F. Posepny	XXIII
The Secondary Enrichment of Ore Deposits, by S. F. Emmons	XXX
Metasomatic Processes in Fissure Veins, by W. Lindgren	XXX
Some Principles Controlling the Deposition of Ores, by C. R. Van Hise	XXX
The Ground Waters, by J. F. Kemp	XXXVI
Ore Deposits at Butte, Montana, by R. H. Sales	XLVI
Relations of Metalliferous Lode Systems to Igneous Intrusives, by W. H. Emmons	LXXIV
Magmas, Dikes and Veins, by W. Lindgren, with extended reply by J. E. Spurr and discussion by many others	LXXIV

The Committee on Mining Geology, since its establishment in 1913, has effectively continued the early tradition of this subdivision of the Institute's activity by organizing broad and timely programs, which have drawn excellent attendance at sessions of the annual meetings. During recent years many of these sessions have been arranged jointly with the Society of Economic Geologists.

Special reference must also be made to the three special volumes devoted to mining geology, each issued in honor of an outstanding leader: the the Posepny Volume, in 1902; the Emmons Volume, in 1913; and the Lindgren Volume, in 1933. The first two assembled noteworthy papers previously published; the third embraced a carefully organized group of new contributions. All three had the common purpose of throwing added light on the genesis of ores. It is safe to say that no other three volumes yet printed

hold contributions on such fundamental aspects of this subject by so many authoritative specialists. The period they cover, 1886–1933, is peculiarly significant in the history of the subject—and perhaps never again will so brief a period yield so much for the future to build upon. Truly may the Institute take pride in this geological series, unapproached as it yet is in any other of its fields of interests.

ROLE OF GOVERNMENTAL AGENCIES

At 1871, the operating locus of most professional geologists was in either the educational establishments or some governmental organization. Several of the nations had already founded geological surveys; and a number of the states of this and other countries had established corresponding organizations. These had contributed much to the scientific foundation of general geology, with notable additions here and there to an understanding of ore deposits. But up to about 1870 metalliferous geology by governmental agencies had not attained great prominence.

With the discovery of gold in California and the rapid succession of important mineral disclosures in other western states and territories, mainly on lands of national ownership, the United States Government had increased the geological explorations in that great unfolding domain.

During the latter part of the '60s and through the '70s four official surveys were simultaneously engaged on western geology. One of these, the Geological Survey of the Fortieth Parallel, 1867–77, was the first important organization under any government to apply intensive geological investigation to ore deposits. Directed by Clarence King, and with J. D. Hague, Arnold Hague, and S. F. Emmons, alumni of Freiberg, as assistants, this unusually capable organization may fairly be said to have set a new standard in both general and economic geological work. Prompt recognition of this achievement led to the all-important next step.

Work of the U. S. Geological Survey

In 1879, all geological activities of the Federal Government were consolidated into the United States Geological Survey, with Clarence King as Director. In one of his first official acts, King established a Division of Mining Geology, under the joint supervision of S. F. Emmons and G. F. Becker. Their instructions were broad and challenging:

> You will make accurate, detailed and exhaustive studies . . . so that . . . the varied types of deposits in all important mining-districts will have been studied; and the many phenomena bearing upon the genesis of ore-deposits thus accurately determined should be sufficient for a new theory of ore-deposits, based on facts actually determined in the light of modern geology.

Merely to mention all those who in the succeeding years have worthily shared in execution of that central program would unbalance this review; it must suffice to typify all these by three leaders of the Survey's early middle years, Lindgren, Spurr and Ransome. Even more is it impossible to summarize the principal contributions to an understanding of ore occurrence made by Survey geologists, but the major objectives and methods of this greatest geological organization in the world merit consideration.

The production of an accurate topographic-geologic map of such area and scale as to reveal broad setting and close detail has almost invariably been the foundation of the Survey's studies in mining districts. Carried out under a scheme of supervision that, at least potentially, brings to bear on each special area the Survey's cumulative knowledge of stratigraphy, structure, and igneous history of the greater province in which the district lies; enriched and safeguarded by the ministrations at Washington headquarters of corps of specialists in paleontology, petrography, mineralogy, chemistry, etc; and reproduced with beauty and rare precision, these special maps of the mine fields stand in the eyes of the mining industry as symbol and acme of the Survey's work and contribution. This has remained true from the beginning; and every itinerant geologist knows that, whether in prospector's shack or the geological quarters of a large mine, the Survey's map of the local region is carefully preserved for constant reference long after the "main report" to which it was attached may have been lost or shelved.

In the earlier days, the detailed studies of such scholarly and penetrating specialists as those already mentioned were of great value to the local operators. Disclosure of district-wide relationships, details of underground geology, ore structure, and genesis, and broad inferences as to downward continuity and tenor—these represented rich contributions which the local companies were in no position to provide for themselves. Coupled with a fine record of dealing with confidential material, achievements of this kind in district after district brought enthusiastic support for the Survey while also further expanding its own scientific grasp and power. (Pending issuance of the elaborate official report, the concentrated essence of such studies has in many instances been presented before the Institute—see outstanding examples already cited—or in the pages of *Economic Geology*. They constitute veritable gems of the science.)

In more recent years, the background against which the Survey's work in mining geology is performed has materially changed, and in two somewhat contrasting directions.

In the first place, most mining companies of substantial size in this country now carry on their own geological work. Even in this the Survey has had important, if indirect, part: it set a general pattern of investigation which the

companies recognized as desirable to adopt; numerous able Survey geologists, entering corporate practice, have aided in adoption of the pattern; still other Survey men, joining university staffs, have expounded the pattern to those whom the mines are to employ. Elaboration and fitting modification of the Survey technique plus quite independent extensions in new directions have been achieved by the mine staffs themselves. As a result, many mines are now qualified in most respects to conduct their own geological investigations on a high plane of scientific reliability and practical utility.

Such advantages as inhere in total richness of staff and broad scientific background of the Survey have to be balanced against the constant and continuing attack of the mine staff on the ever-changing facets of the local problems, and the close integration of the geological with the other company departments and with the complex variations of the local economic picture. Moreover, in recent years the Survey has been obliged to secure its future leaders in a three-cornered competition with university faculties and mining companies for the best among the oncoming supply of young geologists; the while mounting administrative loads attending marked increase in Survey personnel have gravitated to its contemporary leaders, thus restricting their own productive contact with the realities of outcrop and stope and their opportunity in the presence of these realities to guide and inspire their younger colleagues.

As consequence, the flow of geological benefits is no longer in a single direction. In detailed mapping, on surface and underground, Survey practice in recent years has tended not so much to lead as to follow what has become conventional in the mines. Likewise, there has been effort to incorporate in the Survey's work in mining areas something of the basic quantitative approach the mines have been forced to develop. These and similar trends became highly accentuated and conspicuous during the recent war, when duties unprecedented in magnitude and kind were imposed on the Survey, as well as on the sister organization, the Bureau of Mines, and the several special war agencies for mineral development and acquisition at home and abroad (see the revealing summary by Bateman[8]). Now that the turbulent pressures and breathless haste are past and the Survey's fine contribution to the war effort is of record, realization that the effective future role for the Survey does not lie in duplication of or competition with the functions of company geology is plainly shared by the present Survey administration.

It would seem to follow, then, that the initial program of the Survey, which brought it so much of acclaim and support—namely, the intensive study of great mining districts—should no longer hold primacy in its future plans of activity in mining geology. This will be progression, not withdrawal. It will represent wise and satisfying recognition that the Survey's early

function of pioneering leadership in one great objective has now been so well discharged that it may safely leave further extension in that area to the private endeavors it has aided, taught and inspired; and that the Survey is thus freed to turn more fully to the subjugation of other problems where governmental attack is now as appropriate and necessary as was the study of Comstock and Leadville, Butte and Cripple Creek scores of years ago. Moreover, if leadership is to continue the Survey will expect again and again in the future to devise, perfect and eventually turn over to industry one fruitful program in order to attack a new one, in quite the same way that the research department of a great corporation feeds its findings to the production department.

The second great change brought by the years points to exploitation by the Survey of new concepts and methods as the effective means of present-day adherence to the initial lofty objective of scientific advancement and practical usefulness which time has so fully confirmed. For decades, the implication in the instructions handed to Emmons and Becker was sufficiently valid; namely, that the best keys to broad understanding of ore deposition are to be found in the individual mining districts. One by one, the districts have yielded up specific, fundamental secrets: Leadville (1882), replacement and certain aspects of structural control; Marquette (1893), structural barriers for descending solutions; Butte (1896), secondary sulphide enrichment; Seven Devils (1899), contact-metamorphic ores; Rico (1901), structural barriers for ascending solutions; Coeur d'Alene (1908), pre-ore faulting of vein structures; Goldfield (1909), alunitic alteration—to name but a few examples. But to perpetuate indefinitely this district program in the manner available to the Survey would, from the all-important standpoint of genetic understanding, almost surely lead toward diminishing returns. Concurrently, the tasks of ensuring (1) that the known major districts will in due time be scoured centrally, peripherally and vertically until they retain little ore that is worth getting, and (2) that districts now ascribed lower levels of promise will receive eventual thorough testing, are now properly becoming responsibilities of the mining companies. An example of the seriousness and effectiveness with which this corporate responsibility is being discharged is seen in a paper just published on the Michigan copper region.[9]

The outstanding unfilled need lying ahead is the discovery of *new* mineralized districts. Enough scattered effort has already been directed toward this objective to confirm that it is much more difficult and even more speculative than has been mine finding up to now. It is hardly debatable that this is precisely the type of endeavor in which government can and must take leadership. And there is widespread conviction both within and outside the Survey that here lies its own chief future role insofar as concerns metalliferous re-

sources. The present Director, W. E. Wrather, long in intimate touch with the Survey tradition and of extended experience in commercial geological practice, is fully abreast of these objectives, with definite plans for realizing them. Fortunately the chief requirements fit exactly with the Survey's greatest strengths of the past: precise mapping and fundamental research. Extension of aereal mapping and related study to regions not now productive but possessed of the lithologic and structural potentialities of ore concentration seems fully justified, and holds great promise of bringing to light numerous places for more localized and intensive exploration by mining companies. In recent addresses before groups of the mining industry, Dr. Wrather has advanced a most proper and reassuring policy for this branch of the Federal Government. The following paragraph is quoted from his address before the American Mining Congress at Denver in 1946:

> I believe the efforts of the Survey should be designed to supplement those of industry, that the Survey's work in exploration should leave off where industry begins. . . . Therefore, the activities of the Survey in the field of mineral exploration should presumably represent the public interest in undertaking work which (*a*) private groups either cannot undertake, (*b*) will not undertake, or (*c*) cannot do as well as a Federal agency.

On another occasion he outlined the Survey's contemplated program of fundamental research as embracing: (1) discovery and elaboration of basic geological principles, (2) interpretation of these principles as applied to specific regions and problems, (3) development of appropriate instrumentation and techniques for geological, geophysical and geochemical investigations.

Among the directions that would seem particularly fruitful is a continuation of systematic studies of the ore occurrence of large regions, such as those already made by Lindgren in New Mexico, by Butler, Loughlin, and Burbank in Utah and Colorado, and now in progress under Ferguson in Nevada. Also deserving of active attack are topical studies, like that on interpretation and appraisal of aureoles of hydrothermal alteration as clues to ore, currently being followed in given districts by T. S. Lovering and G. M. Schwartz. It is gratifying to see work of that nature placing such strong emphasis on investigation in the field as contrasted with the library. For special inquiries of this kind, a topic entrusted to an individual or small team could profitably be pursued in district after district to the exclusion of all other district features that do not bear significantly on the theme in hand.

Work of Other Nations

Problems of past and present similar to those discussed in the foregoing pages have faced and still face the corresponding Surveys of other nations. It is natural that the outstanding contributions to mining geology have come

from those countries most blessed with mineral resources; and on the whole it seems to be true that in these the governmental geological agency is more alert and productive than when geology for geology's sake mainly prevails. High place on the roster of attainment in studies of ores must be accorded to Canada and its Provinces, Mexico, Sweden, Norway, the Australian states and the Union of South Africa. The Canadian bureaus are particularly noteworthy in their active aid to mineral development by early field investigation and prompt publication.

EDUCATION IN MINING GEOLOGY

In the training of men for the worldwide mining profession, the mining schools of Europe were at peak influence in 1871. The Freiberg Academy in particular at that time drew many students from outside Germany, and sent even larger numbers as graduates far and wide. Among the considerable number of Americans trained in those schools, a noteworthy proportion chose a career in mining geology, and proved to play a most influential part in shaping the ideals and the course of that science as it developed in this country. Although these undoubtedly were men of marked inherent ability, it is indubitable that their eminence derived at least equally from the training and viewpoint they had absorbed abroad.

It was fortunate, as we now can see, that the ablest of these men, instead of taking up teaching, should have been drawn to a career of systematic field work in the West at a time when new discoveries gave need and opportunity for their best. Their studies and writings extended, vitalized and dignified the broad principles and revealing relationships that were to enrich future instruction in mining geology.

It is significant that the new wealth of truths regarding ore occurrence being brought to light especially by the U. S. Geological Survey was utilized by teachers of deep faith and extended experience in field study—such men as Kemp, Van Hise, Lawson and Smyth. In due time the universities called to their geological faculties a number of those, typified by Ransome and J. D. Irving, who had acquired experience in mining districts under those seniors, Emmons, Lindgren and others earlier mentioned. Lindgren, youngest of the mining geologists coming from European training, climaxed 30 years of active field studies with 25 more of teaching and writing of the most stimulating kind.

The basic writings and textbooks dealing with ore deposits at the beginning of the period under review were chiefly of European origin. Conspicuous among these were the papers of de Beaumont and the treatise by von Cotta; but a translation of the latter by Prime, one of the charter members of the Institute, and Whitney's Metallic Wealth were available in

English. Most of the texts appearing up to the '90s followed a common pattern. Imperfect efforts toward generalization and a groping for genetic understanding constituted a comparatively brief preliminary part; relatively uninspired descriptions of great numbers of individual mining districts occupied the major part of the book. By 1893, De Launay and, in particular, Posepny had presented substantial treatises in which the principles and general relationships were given dominance, with local descriptions introduced chiefly to illustrate the genetic features discussed. Posepny's work, presented through the medium of the Institute, made a profound impression on American thought. Scholarly and sane increments to a consistent philosophy of ore genesis are found in Stelzner's manuscript (edited and published by Bergeat, 1904), De Launay's three-volume work (1913), and Lindgren's successive editions (1913–1933). In all these cases, the high quality and insight seem to be intimately connected with the author's long-sustained contacts with ores in the field.

The emphasis given to mining geology in the colleges and universities in this country varies markedly, but has increased with time. At one extreme stands a single course, designated economic geology, which covers metallic and nonmetallic occurrences, water supply, soils, etc., given by a professor carrying other subjects also. Certain of the larger institutions emphasize one or more special branches, such as petroleum geology, engineering geology, or geophysical prospecting. At a few places two or more faculty members deal exclusively with various aspects of the geology of ores.

Certain generalizations are rather plainly deducible from this experience of three quarters of a century. The increasing dependence of the mines on geology, already so evident in the quantitative sense, must extend also in the sense of better quality if the accelerating exhaustion of known ores is to be offset. This improvement of quality and power must be attained both in the course of practical application and in the preceding educational preparation. Because the fundamental principles and relationships in geology itself and in the sciences on which it rests are increasing in number and complexity, it is already clear that both better teaching and longer study are required.

The mounting need to utilize more of physics, chemistry and mathematics in geological interpretation must be disclosed by the teacher rather than left for discovery by the student. The individual teacher will progressively lose power if he relies solely on a background of field experience acquired early in his career; continuing touch with the reality in its own habitat is indispensable. Worthy and valuable investigations are possible in laboratory and library; but exclusive restriction to these is unwise, since *ore* is a treacherous image when divorced from the dollar sign.

Steadily it is becoming more evident that successful ore finding is to be

achieved only by research in the highest sense, *conducted right on the ground.* As in other sciences, no one in geology is qualified for research until he has mastered its body of fundamental principles and relationships. For the student of mining geology who justifiably aspires to full stature in the profession, the conventional four-year undergraduate course no longer suffices. Decision as to whether to pursue graduate study at once or after acquisition of some practical experience depends on circumstances. But in any event, before his scholastic preparation can effectively function in use it must be integrated with the training and background to be had only in the mines. This can be achieved in part during the summer holidays by a sympathetic policy of cooperation and very modest remuneration extended rather generally by the mining companies. Better still are the carefully organized training programs already instituted by a few companies. In any case, it is clear that the mines that recognize and meet the necessity for the postcollegiate professional training of geologists will secure the pick of the young graduates. Fortunately, the number of mines in this category is growing. Results in these deserve watching.

GEOLOGY IN THE MINES

In the professional study of the geology of ores, the mining companies, strangely enough, were preceded by governmental officials and teachers primarily concerned with discovery and illumination of basic scientific principles. And before American companies came to adopt geology for the central purposes of finding ore or facilitating its extraction, less constructive intermittent use had been made of geological talent and prestige in mine promotion and mine litigation. By the '60s and '70s, however, mining engineers whose training had included courses in geology were dealing, either as regular employees or as retained consultants, with the geological problems arising in normal operation and in exploration.

Anaconda's Leadership

The first geological department of any importance established by a mining company—and perhaps the earliest on any scale—was that of the Anaconda company at Butte. The later record of this department is so noteworthy that the conditions of its initiation merit summary record here. Systematic study of the Butte deposits by the U. S. Geological Survey had begun in 1896 under the direction of S. F. Emmons and continued for several years. Controversy having arisen in 1898 over extralateral rights, D. W. Brunton (later a president of the Institute), as consulting engineer for Anaconda, advocated geological study of the ground in dispute, and engaged for

that purpose H. V. Winchell (himself later a president of the Institute), who organized a staff and began systematic underground mapping. Following the larger consolidation into the Amalgamated company, Winchell's staff was expanded; and in 1901, R. H. Sales, who had earlier worked in other of the mines and had been assigned to cooperate on part time with the Federal geologists, joined the company's geological department. In 1906 Sales became chief geologist, and has since directed Anaconda's geological activities at Butte and elsewhere.

In its early years, Anaconda's geological work remained closely concerned with the tensely contested problems of boundary rights. The underground study was therefore carried out with unprecedented care and detail to make the maps, sections and models express most effectively the exact conditions underground. Inasmuch as Butte is characterized by numerous strong, through-going veins of various attitudes, and by several sets of strong fault displacements, and since extralateral litigation involves primarily geometrical considerations, the geological work of those early years was concerned chiefly with interpretation and solution of the structural problems.

After consolidation of ownership of most of the Butte mines had practically ended the period of litigation, and the department had come to deal with the geological features on a collective, district-wide basis, two important developments arose. First, the accumulation of geological understanding was turned to the directly constructive service of normal mine operation and production. In particular, great proficiency was acquired in projecting the known pattern of intersecting veins and faults into contiguous unopened ground. It became standard practice to give the operating staff precise directions for appropriate procedure even before the fault had been cut—a rare achievement in those days.

Second, the nature as well as the geometry of the mineralization received consistent attention. Systematic variations in mineral character and texture and in kind and intensity of wall-rock alteration were gradually shaped into the now well-known zonal pattern. Sale's Institute paper of 1913, already mentioned (p. 6), made Butte one of the classic examples of mineral zoning, besides treating most revealingly of faulting, vein structure and other important features of one of the world's foremost mining districts. It stands as one of the great geological contributions made directly by a mining company.

For many years the largest and strongest of its kind, the Anaconda geological department trained a large number of workers in the procedures and techniques that had been developed at Butte; in particular, a standardized and effective method of geological mapping underground. In the course of time, many of these geologists took up work elsewhere over the world, so that underground observation and mapping according to the "Anaconda school"

is now in very wide use, being especially appropriate where persistent tabular loci are important factors in ore distribution.

Current Practice

Emulation of Anaconda's success came rather slowly, but where sympathetic officials, carefully chosen geologists and tough geological problems coincided, the value of company geology began to receive general recognition. The allocation of geological tasks to trained geologists was, indeed, but one exemplification of the rapid spread of specialization throughout the mining industry as size of operating unit and complexity of problems increased. At the present time, most mining companies of importance employ geology, some of the larger departments comprising up to 20 or more geologists. Even numerous small companies contrive to utilize geology on a scale commensurate with their resources. For it has become clear that among the reasons why properties of small and intermediate size so commonly gravitate into the control of larger companies is not merely the greater resources of the latter in funds and facilities but also the superior geological judgment of possibilities for ore.

The function of the geological department has considerably expanded in recent years.* Formerly, the geologists' maps and other records, together with appropriate explanation, were submitted to the operating department for such use as might be made by the latter in laying out exploratory and development work. More and more the direction of exploration in and about the mine, whether by open work or by drilling, has been delegated directly to the geological department. Also, geological counsel now enters automatically with respect to rock character and structure as affecting location of main workings and plant, prediction of heavy or bursting ground, methods of extraction and support, water hazards, and related questions.

With steadily declining grades of ore and narrowing margins of profit, the necessity for reliable underground sampling naturally increased. In contrast with ores of great monotony in composition and structure, there are many others in which conscientious mechanical precision is not enough to assure a true sample. In a growing number of mines the sampling crews now work under supervision of the geological staff.

Likewise, periodic census of ore reserves is gravitating increasingly to the geologists. Many feel that this introduces more specialized skill and more objectivity into the proper determination of cutoffs and average grades, the

* The organization of the Anaconda department as it was nearly 20 years ago is described by Sales.[10] Other illuminating discussions of geological procedure in representative mines, by McLaughlin, Sales, Linforth, Perry, Bjorge, Shoemaker and Billingsley, constitute chapter 12 of the Institute's Lindgren Volume, 1933. See also: J. D. Forrester.[11]

controls over dilution vs. clean mining, and the balance between extraction only vs. combined extraction and marginal exploration from the stopes, than where the responsibility for sampling and estimation as well as breaking of the ore is left to the operating staff. But whatever the division of responsibility, effective pooling of operating and geological information is essential.

Various incidental uses of geological experience are proving valuable to the mining companies. Microscopical study of the ore minerals and of the successive milling and metallurgical products has often aided in improved recoveries and lowered costs. Mine depletion and mine life as affecting rate of depreciation are important considerations in these days of heavy taxation. Several companies that operate custom smelters now afford geological service to the client mines as a cooperative assurance of maintained output of material in proportions for best smelting practice.

There are, of course, a few large companies and numerous smaller ones in which systematic geology is not yet employed. Obviously, in these ore still "comes easy." Presumably, for most of them a different outlook will eventually arise. The prosperous companies that work without geologists are less likely to understand the origin and controls of their deposits and are least likely, when their mine shall be exhausted, to meet the moral obligation of leaving for the future science and industry an enlightening record of the treasure they have destroyed.

EXPLORATION

Examination and appraisal of mines and prospects owned by others had long been entrusted to mining engineers. In the first two decades of this century, some of the most powerful mining organizations set up exploration subsidiaries for the more continuous and aggressive quest for new properties. In some of these, competent geological talent was engaged to join in the investigation and appraisal of the known ore and the possibilities of developing more. General Development Co. and Guggenheim Exploration Co. were in the latter category. Anaconda achieved the same end simply by assignments from its regular geological staff, which was increased accordingly. This latter practice has now spread, so that most geological departments carry the major responsibility for outside exploration.

The progressively increasing use of geology is interestingly revealed in the exploration that has yielded the largest number of great new mines in the last quarter century; namely, Northern Rhodesia. The rich copper deposits of the Katanga region to the north had been "discovered" by the standard method of gaining information from the natives combined with prospecting of the conventional kind. In the Rhodesian area, numerous copper-stained outcrops had for years teased prospectors and companies' representatives,

and at Bwana M'Kubwa an operation had been started—extravagantly extolled but soon fading. During the eight or ten years beginning with 1923, three important field groups, with strong London backing, explored this cupriferous region. The general philosophy, method and results of each may be briefly recalled.

The first group, under Raymond Brooks, mining engineer with extended experience in Katanga, "started out to find mines, wherever and however they occurred, having no preconceived ideas as to where they would be found or in what kinds of formations."[12] All facilities in the region were then most primitive. The scouting was organized in teams containing a prospector skilled in the African bush and the local dialects, and a young man with enough engineering training to keep track of locations and data. The native inhabitants were depended upon as the chief source of information. Locations were established by compass and wheel-odometer traverses. Promising exposures were probed by conventional shallow work, with a little drilling, done under difficulties. An important discovery was made at N'Changa, the Mufulira outcrop was located, Chambishi and N'Kana, which had already attracted attention, had been partly tested out, and several smaller deposits had been found before control changed hands; Roan Antelope was not in the ownership under the direction of Brooks. In what proved to be a rich region, this intelligent use of time-tried methods in an essentially virgin area accomplished much in the short period of its operation.

The second group, under J. A. Bancroft, geologist, took over in 1923 part of the area in which Brooks had started and added still further areas in its explorations. The program was designed to be essentially geological; and a very large corps of young geologists were central in it. Under this regime, each party consisted of a geologist, a native to push the odometer, and incidental helpers. Systematic, closely spaced traverses were run, with natives ranging the bush for fixed distances on either side to locate the sparsely scattered rock outcrops. As soon as an outcrop was found, it would be inspected by the geologist. On the basis of such outcrop data, boundaries of rock formations were deduced and thus geological maps were constructed; and from the interpretation of these, in turn, were deduced whatever ideas could be gained as to localities potentially promising for ore. The general geological relations of a large area were fairly well ascertained and ultimately published,[13] together with outline descriptions of such mines, previously located, as lay within the concessions studied. It may never be known whether the methods of this group, so lavish in geological manpower, would have been as successful in ore finding as those of their predecessor had the identical areas and the same priority of opportunity been involved.

In the meantime, a third group took over study of that restricted tract known as N'Kana Concession, on which some work under Brooks had already been done. Under R. J. Parker and Anton Gray,[14,15] this was primarily a geological enterprise. It had the advantages of the roads and other physical improvements just previously made, of more concentrated attack because of much smaller area covered, and of the clues to major ore control (within a single sedimentary formation) deducible from the environments of deposits already in evidence: Kansanshi, Bwana M'Kubwa, Roan Antelope, N'Kana, Chambishi, N'Changa and Mufulira. This control was strikingly confirmed and explained by the mapping (involving study of both outcrops and the residual soils), and the favored stratigraphic horizon in which great tabular dissemination of ore had been introduced was correlated with the "Série des Mines" of Katanga. Selection of the most promising smaller tracts and drilling of these led at the end of two years to the following major results: "three large mines were developed and an extension to a fourth property was found. These were: Mufulira, Chambishi, Baluba and Roan Antelope Extension." (N'Changa, Roan Antelope main mine and N'Kana were being concurrently developed under other auspices.)

The following general inferences seem deducible with respect to this sudden blossoming of one of the greatest known mining regions:

1. Intelligent prospecting of the conventional kind remains a powerful tool in virgin regions where distinguishing surface exposures are combined with an indigenous population that has mined them on a primitive scale; a corollary is that early arrival on the scene gives enormous advantage.

2. No intrinsic magic attaches to effort merely because designated geological; results will vary with the vision behind the geological procedures and the quality and leadership of the geological staff.

3. Geology is as yet probably best justified and most productive when conditions of time-competition and property control permit its application in a fairly intensive manner; this ordinarily implies tracts of moderate, not enormous size.

4. Since neither conventional prospecting nor scientific geology can succeed where no ore exists, final judgment of the relative merits of the two procedures can hardly be made while the district is so young; but the several "blind" occurrences thus far located by geological study, such as Baluba, West Extension and Chingola, suggest that more may follow. Conceivably geophysical methods will find more occurrences in the future.*

5. It is to be remembered that exploratory effort brought in such imposing tonnages so rapidly because of two important groups of conditions: (*a*) the region, of friendly climate, is a tableland of very gentle relief, open woods

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* Cf. the successful geophysical results of Lunsemfwa, page 85 of ref. 12.

and residual soil; all the major discoveries were made within 30 miles of an existing railway, which tapped abundant coal 500 miles to the south; (*b*) the copper deposits are tabular bodies conformable with the bedding at a fixed horizon, and maintain unusually consistent grade over long distances along strike and dip. These are highly favorable conditions, especially for the geological type of exploration. It may well be a long time before a new district of anything like such magnitude is opened so easily and quickly.

A method recently adopted by the Swedish Geological Survey for reconnoitering large undeveloped areas with sparse outcrops is noteworthy for its economy of funds and geological manpower. Experienced young woodsmen, after brief specialized training, are sent out individually to comb a given area, note the position and size of outcrops and collect specimens from them. When such a scout returns to base, his collections are given competent inspection and any deserving specimens are at once subjected to further investigation. Those deemed worthy of examination in situ are tabulated, and in due time the scout takes a geologist to the site of each tabulated specimen. The plan is regarded enthusiastically by Swedish geologists.

Courageous and highly effective application of geological principles and the indices of geological favorability to the search for mines is illustrated by Ventures Limited and other activities in which Thayer Lindsley is a moving spirit. It is to be hoped that he may be persuaded to put on record the essentials of his method of calibrating the geological yardsticks, his criteria of selecting areas for investigation and his procedure in appraising the merits of ground chosen for consideration.

TECHNIQUES, THEORIES AND TRENDS

The governmental geologist is assigned to study a district with the direct expectation that the product will be a report. This is fundamentally true whether the district be notable for ore occurrence or for other reasons. The geologist of a mining company, by contrast, is set to work in a district to find ore or promising places for exploration, or else to decide that ore hunting does not appear economically attractive. In either group, the conscientious geologist is fully aware that the one or the other of these objectives is his obligation as an employee,* and he acts accordingly. Invidious conclusions, of whichever complexion, that some incline to draw from these undeniable differences of purpose and condition are not likely to be constructive. But recognition that the differences exist and in large degree are inescapable is essential to clear understanding of the function and methods of the company

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* Field work of his own choosing by the college teacher ordinarily fits the pattern of the governmental worker, whereas the independent consultant in mining geology naturally approximates the company viewpoint.

geologist. Because the governmental geologist does ordinarily publish his findings in full, his general approach and technique are well known.

During the half century that company geology has been practiced, the trend has been toward reduction of the contrasts in methods and objectives of the two groups of workers; this has been especially manifest in recent years, as already noted in the section on governmental geology. Beyond the fact that man is inherently imitative, each group possessed something lacked by the other. So far as the United States is concerned, search for minerals during the war pressed governmental geology probably too far in the "practical" direction, an unbalance now apparently being righted. But the growth of interest and understanding by the company geologist continues and must continue as to both breadth of scientific base and mastery within his special field.

Compared with the scope appropriate for any other specialist in the geological domain, whether structural geologist, petrologist, physiographer or other, the mining geologist, even in a single district, is likely to be confronted with conventional problems in most of these subjects, and compelled to solve them as the essential foundation for effectively following known ore and finding new. And for him, this means to *solve*, not merely to find a temporarily plausible explanation; otherwise, crosscut or drill hole will be wasted or ore will be missed or the shaft will be located ineffectively or in treacherous ground. A good mine geologist is thus likely to find himself a rather busy person, both physically and intellectually.

It was wholly natural that company geological work should, at its outset, put prime emphasis on mapping of the underground geology. Not only the kind, boundaries and attitudes of the rocks and of the major structures, such as a general geologist would record on surface, but also the position, shape, nature, and structural characteristics of the ore. The underground map came not only to typify but largely to comprehend the mine geologist's work. To "keep the mapping up to date" was his prime job. Mines not previously using geology decided to hire or assign an engineer to "do the geology"; that is, the mapping. In skillful and ingenious hands, precision of location and observation and depiction of details improved notably. As more details, such as changing mineralogy of the ore, alteration margins, and minor structure were brought into the mapping record, first on the levels and then also in the stopes, map scales were increased appropriately. At present, many companies have elaborate files of geological maps and sections of very high perfection; and now, of course, most mine geologists have been technically trained especially for that work.

The tangible value derived from the geological mapping at first varied greatly from mine to mine, both because of the difference in intrinsic applica-

bility of the mapped record to the important problems of the given property, and also because of the varied effectiveness with which the full significance of the map was apprehended. In any case, here was something tangible, that could be checked against the evident facts and grasped by superior officers. In very many instances it has paid handsome dividends in ore found, in clean mining, and in reduction of useless work.

It is to be realized, however, that the typical mine map, even at the present time, is predominantly a *representation of structure;* and for probably the majority of mines its chief function is to emphasize *channelways*, actual or potential. Emphasis on structure in general and channelways in particular has likewise dominated most of the geological thinking of the mine geologist. This has tended to confirm the value of mapping and crystallize contentment with that aspect of geological effort.

Evolution of Theory

No one confronted with the problem of ore finding could remain oblivious, however, to the existence and the growth of theories of ore genesis and localization, as expounded especially by governmental and university geologists. Review of a few major changes and additions in theory during the present century will afford opportunity to gauge the mine geologist's role in utilizing and contributing to this core of principle and concept (compare ref. 16).

At the opening of the century the long controversy between the magmatists and the meteorists was in its final and most violent stage. The paradox that sometimes happens occurred in this case: i.e., that a theory is doomed by its most brilliant and explicit presentation—that is to say, when all that can be marshaled in its support has been brought clearly into view, its crucial shortcomings become manifest as never before. For the great family of ores now regarded as hydrothermal, the theory of rock leaching by meteoric water could not hold against contemporary factual and philosophical presentations favoring magmatic affiliation and ascension. Stampede to the magmatic viewpoint soon led to extremes. The concept of immediately local derivation of the ore from the intrusive body, spearheaded by acceptance of pneumatolitic origin for contact metamorphic ores while the adjoining igneous mass was still more or less molten, was carried to the extent of viewing each dike or sill as a potential source from which ore might have come.

We are now witnessing a recoil, as a result of wider experience and clearer reasoning. It is becoming manifest that the magmatic episode is long and complex; that even the ore-bearing magmas were not everywhere and from the instant of intrusion surcharged with ore stuff, which they belched

into whatever they touched; but that instead a considerable outer shell of the body had crystallized before the escaping volatile-rich fluid had acquired a sufficient proportion of metals and associated elements to effect at favored places that degree of concentrated deposition which constitutes a commercial ore body. We are left with the somewhat disconcerting presumption that we have never seen the specific source of any hydrothermal ore body—that particular nest where the ore fluid came into being and then started on its journey in quest of places for deposition. Widely differing views are consequently held as to the place, the dating, and the nature of such sources. Opinion is again in a state of flux.

So a new swing of the pendulum pushes the ore hearths down to great depths. Holmes[17] would draw the ores of lead, and presumptively other metals, from greater depth than that at which granitic and basaltic magmas originate and thus would make them nonmagmatic in the accepted sense. This stimulating conclusion, deduced by extreme extrapolation from a tiny "baseline" of isotopic differences, has since been materially weakened by corrected data. Still more recently, Hulin[18] proposes that the date of liberation of the ore fluid is so long after the emplacement of magma, and hence the place of liberation is so deep in the magma chamber, that "no idea of a direct genetic relationship between the ore deposits and the near-by intrusive body can be longer entertained." Instead, the characteristic association of ore deposits and intrusive masses "is recognized as resulting from structural control of the mineralized district." This thought-provoking paper, which builds on to views presented 40 years ago by Spurr, fits also as a further step in the author's well-known concepts of intramineralization fracturing and of ore derivation from basic magmas. It will doubtless receive the careful study it so clearly deserves. Interest will attach to the resulting discussion, which must eventually pass judgment on the relative soundness of this thesis and accumulated counterindications now widely accepted.

Rejuvenation and elaboration, in the '20s, of the venerable concept graphically called the "ore magma" and its product, the "vein dike," found many active supporters and not less numerous and emphatic opponents. The issue gradually subsided, presumably because of majority conviction that the evidences against it are too strong. But it still finds occasional advocacy; and something of the sort seems to be in the minds of those European writers who still allude to "injected" sulphides or ore "displacing" the country rock for examples which most American geologists would ascribe to the process of rock replacement effected by a dilute and tenuous solution.

The influence of physicochemical conditions on ore deposition, as propounded by Lindgren in 1906, the theory of ore formation as related to magmatic differentiation advanced by Spurr a year later, and the discussion

of primary downward changes by W. H. Emmons in 1924, contributed to the broad concept of vertical zoning to which allusion is now frequently made by scientific and practical workers. The realization developed that these successive zones, when visualized on a district scale, could be regarded as adjoining, not as a series of cylinders piled one above another, but rather as a succession of interfitting conical sheaths, the flaring bottom of each sheath thinning to zero at some distance above the corresponding bottom of the sheath representing greater intensity lying next below. It also became evident that the horizontal-concentric manifestation of zoning, such as displayed at Butte, could be regarded as merely a horizontal slice across the vertical stack of conical zones.

In accordance with this idealized image or model, the vertical line through the apices of the sheaths would mark the axis of major permeability and of the "hot center." If sound, the theory should afford, through the indicated intensity of the conditions attending ore deposition, an idea of the relative initial depth of formation of the observed ore. But independent check on depth of formation is commonly handicapped by uncertain reliability of estimates of post-ore erosion. In a few districts, however, such as Butte, Ouray and Casapalca, deep mine workings seem to confirm the order of change in mineral character with depth which the theory postulates; opposite order appears to have been nowhere encountered.

Obviously, judgment and restraint are needed to avoid overworking so alluring a picture; judgment and openmindedness are equally needed to avoid rejecting it hastily. It is certainly not yet justifiable to assume that every hypogene district must exemplify zonal distribution, nor that all zonal patterns must approximate the one outlined above. Unrest is wholesome to whatever extent it stimulates quest for a better theory. In the meantime, scattered evidences of a somewhat cynical distrust of the philosophy underlying the zonal theory seem more likely to represent sterile retrogression than the initial stirrings of something new and constructive.

Depth of Ore Persistence

On the economically important depth below present surface to which ores persist, views have oscillated markedly during the past 75 years. The early decades disclosed strongly contrasting ideas; those who knew of mines that failed at shallow depths inclined toward general pessimism, while promoters stressed the argument that the heavier the metal, the deeper, obviously, it would persist. Gradually, round the turn of the century, conscientious and capable men, in the face of speculative fervor, inclined toward very conservative views. Able geologists, like Gilbert and Van Hise, concluded that the inevitable constriction of openings with depth places a definite

bottom to the formation of ores (if formed, as they largely assumed, by waters of meteoric origin). Engineers of extended experience with many mines, like Rickard and Hoover, cited statistical implications that profit could be expected only rarely from depths greater than about 2000 feet.

Fortunate it is that these well-meant counsels were not heeded. The swing to belief in a magmatic origin for many ores lessened or nullified the theoretical denial of deep deposition; and realization that numerous mines of considerable depth and not yet "bottomed" were dealing with ores belonging in the middle depth range according to the zonal concept strengthened this reversal of the earlier theory. Fact also came to the support of the newer view; for mines continued to deepen and still make profits. Not all mines, of course. In the main, the hypogene deposits that have faded at modest depths below the present erosion surface have the characteristics ascribed by the zonal theory to "shallow-seated" formation, whereas those on which mining has persisted to 5000 or 8000-foot depths fall in "deeper seated" categories of the theory, which thus receives a further measure of pragmatic support.

At present it is regarded as probable that for many instances the downward limit of mining will be reached not because of actual decline in grade and/or quantity of mineralization but because rock pressures, temperature-humidity conditions and the increased distance of hoisting, pumping, ventilation, etc., will eventually raise costs to a figure where profits vanish. Because it has become clear that the world is going to need ore from the greatest depths that can feasibly be reached, postponement or lessening of the adverse effects of depth needs more attention than at present. Prophylaxis is possible even if not cure—for deep mines grow from shallow mines; and many of the difficulties encountered in the deep ones are aggravated because of neglect of precautions that should have been taken while the mines were shallow if the prospect of becoming deep had been adequately foreseen. Sound geology should be helpful in deciding, for mines of intermediate depth, to what extent the combination of zonal type and local structure may justify present steps that would improve conditions if the mine becomes deep.

Secondary sulphide enrichment had been sensed as to essence by many mine operators and engineers,[19] and when presented by geologists in the form of a clearcut hypothesis about 1900 was given widespread and confident acceptance. Yet quickly this fine, sound concept was carried too far. The hasty application to silver ores has proved in many instances not to fit; enrichment in nickel sulphide ores is relatively insignificant, and in gold ores probably little more so. Even for copper, for which its enormous importance is universally recognized, there exists a long-standing disparity of interpretation of chalcocite from deep levels. At Butte, where this question is notably

important, the Anaconda geologists feel convinced that the deep chalcocite is primary—hypogene; presentation of the results of their detailed studies is awaited with interest.

Extension of Geological Research

The foregoing examples of theoretical nodes in the broad problem of ore deposition only inadequately sample the total. The character of the ore-bearing fluids; the validity of direct magmatic segregation; the theoretical and practical status of contact-metamorphic ores; the role of colloids; the mechanisms of weathering as affecting both the occurrence of lateritic ores and the connection between weathered outcrops and what lies beneath—these are among additional subjects, partly theoretical, partly factual, as to which views have fluctuated markedly with time. All this clearly means that *majority opinion at any given time does not necessarily reflect the truth.*

Geologists may fervently wish for greater fixity and finality of geological theory; and managements may be puzzled or even rendered suspicious by the change and controversy evident. Yet neither must be disheartened; for only thus does a science grow. Because of the inherent inaccessibility in time and place of so many important geological processes, and particularly because of the limitation on *experimentation* in duplication of natural conditions, speculation has largely lacked the control so wholesome and productive in physics, chemistry and engineering. It has therefore been a natural reaction to utilize and value a type of geological procedure that is least speculative in nature.

This brings us back to the great wave of emphasis now placed on the subject of structural control. Structural study unquestionably has found more ore to date than all other phases of geological work combined. Undoubtedly, such study will continue to be highly productive, since so much ore is dependent for its importation and localization on some manifestation of permeability. But just as the arteries, veins and capillaries are no more important to the human system than is the character of the blood that flows through them, or than the subtle reactions of so many kinds that contribute to the total physiological process, so the attention to channelways, reopening and preparatory "ground-conditioning," to channelway details as by contouring attitudes or widths, to relative fracturability of different rocks, represents a most one-sided and partial approach to the problem as a whole. It is an unsound approach only in that it tends to neglect, if not indeed to discourage, other important and necessary adjuncts. Chemical, mineralogic, petrographic and mineralographic studies have as yet been pursued far more for the writing of articles than for the hunting of ore. To realize that the burden of justification for this lies strongly on the ore hunter, one need only

recall what chemistry, microscopy, X-rays and spectroscopy have done for modern metallurgy.

It is highly encouraging, therefore, to realize that company geological departments, like metallurgical departments before them, are becoming alert to the need and advantage of *research* in the modern sense. International Nickel, Anaconda, and Cerro de Pasco are among the companies that in recent years have established laboratories for geological research, equipped with modern instruments appropriate to a wide kind of investigation and staffed with men soundly trained not only to conduct the investigations but also to interpret their significance to the geological problems in hand. These laboratories are adding so notably to understanding of ore occurrence and ore controls that adoption of the same program by many other companies in the near future seems inevitable. The research right on the spot will achieve its optimum in effectiveness and satisfaction to the extent that the work and the men in the laboratory be most intimately integrated with the geological work and workers in the mines. The problems of ore occurrence are already too large to be handled masterfully by any single individual. By deliberately bringing into teamwork men of different backgrounds of training and experience, the larger geological departments can begin to realize something of the collective power and success that the great medical clinics have so notably acquired.

Prospecting of the Future

Even if this broadening and scientific enriching of geology in the mines soon becomes common practice with the stronger companies, it will come none too early to serve as foundation for the new body of knowledge required for the successful location of entirely new mineralized areas, whether in covered regions or with bedrock exposed. Present intellectual armament for attack on that great problem is decidedly inadequate, as even the best reflections thus far offered on the subject make plainly manifest. No consistent record of success in this challenging program can be expected from following any given hunch. Only a comprehensive and reasonably sound philosophy of ore deposition can hope to make more than chance, sporadic hits.

In this eventual grand campaign of ore hunting in the blind, geophysical and geochemical methods will certainly be employed. The conspicuous success in recent years of geophysical exploration for petroleum[20] gives some idea of what may be hoped for when methods, instruments and techniques become sharpened to suit the smaller bull's-eyes that ore bodies constitute.

Magnetometric methods, since they deal with a specific and wholly unambiguous response of certain substances, will doubtless continue to stand

at the top in reliability, and may be expected to be still further refined in sensitivity and expressiveness. The recent development of airborne magnetometry holds high promise of rapid and cheap reconnaissance of great areas, not only for locating magnetic "highs" but also, probably, for much areal mapping, since slight differences in magnetic quality from one rock type to another can now be detected from surface or from air, even under cover of vegetation, drift or water. The acme in magnetic usefulness will come if and when depth of the magnetic source can be positively determined. That end seems especially likely of attainment through airborne determinations at different elevations above the same area.

Spontaneous potential methods probably will continue to be more reliable than induced fields for ore occurrences in which a definite chemical process like oxidation is going on; and will become still more valuable if it becomes possible to recognize and eliminate responses from reactions probably not related to ore bodies. Because many ore bodies have notably higher density than ordinary rock, gravimetric methods may possibly be perfected to pick up responses from heavy masses of ore-body size. Seismic methods seem better suited, as to scale, for disclosing broad structural features favorable as loci for ore occurrence than for finding the ore itself.

Minute traces of telltale elements in rock outcrops, soils, ground waters and the ash of vegetation have received considerable attention in this and other countries[21] as clues to ore finding. If further trials demonstrate the economic utility of such geochemical inquiry, the hillsides may see, instead of prospector's burro, shovel and pan, a jeep with spectrograph and other modern instrumentation.

Present-day perfection of aerial photography is already an enormous aid in mapping for reconnaissance or detail. Frequent disclosure of rock structure unsuspected from the ground can undoubtedly be put to excellent productive use; in reconnaissance of virgin territory it may record prime successes. The helicopter is already far toward proving itself the answer to the geologist's dream. If reliability of performance, first cost and maintenance expense can all be brought to proper level, the craft's unequaled versatility will make it ideal for all kinds of country.

In the quest for blind ore, deep drilling obviously will play an even greater role than now. Relative lightness and flexibility, besides the advantage of pointing in any direction and of yielding core, indicate diamond drilling as most appropriate. Every improvement in cost, speed, core recovery and control of wedging or diversion will be welcomed.[22] If the "wire-line core barrel," which can be removed from the hole without pulling rods, and/or the method of "counter-flush continuous coring" become practical for hole diameters appropriate to diamond drilling, much time and expense can be

saved. Doubtless there will be wider employment of rapid, cheap drilling by diamond bits of the "blast-hole" type until the critical objective is neared, then changing to a coring bit—perhaps with an independently removable core barrel, or with continuous coring. With the rapid advances in interpretation of powered material under the microscope, it is entertainable that for certain purposes core drilling could be completely displaced by solid-bit drilling combined with careful collection and microscopical study and assay of the sludge; or perhaps followed by deflected short runs of core drilling starting just above where interesting material has been cut. The possibility of a synthetic product—a carbide?—of adequate hardness and toughness and materially cheaper than diamond may not be a wild vision in this era of metallurgical wonders.

This section may well be concluded by allusion to the difference in conceived function of mine geology by two men of wide experience and conspicuous success, much of whose work has lain in the same province, the Cordillera of North America. In "Mining Geology Today,"[23] Joralemon is at the disadvantage of writing first; in "Mining Geology Today and Tomorrow,"[24] Sales replies. Adequate summary of the papers is out of the question here; but a reader will be well repaid by this cross fire of philosophy on some of the basic problems of mining geology.

Reserves and Conservation

Seventy-five years ago, mining was proceeding, as of old, largely on faith from initial outcrop outward and downward. The long-accumulated experience that depth was most feasibly dealt with not by uninterrupted downward extraction but by a succession of spaced levels tended to increase evident ore supply by conspicuous periodic increments, even though anything approaching dependable measurement of the increments was uncommon. Since that time great changes have come about.

The gradual evolution of mining from a romantic adventure and gamble to a business involving recognized hazards, the expanding size of mining units, the rapid increase in outlay for equipment and plant with resulting requirement of knowing amortization period and rate, the need to raise large sums from the public through the appeal of frank information, the widespread growth of income taxation with recognition of mine depletion, and the mounting awareness by mine management of continuing responsibilities both to their shareholders and employees and to the dependent communities—these have brought to each mining unit throughout the industry a pronounced consciousness of ore reserves and mine life. As these topics involve predictions of what the rocks contain, they have naturally come into the domain of the mining geologist.

Next, the significance of quantity and duration of mineral reserves spread from the scale of the individual mine to the scope of the nation and of the world, through realization that wasteful methods are neither good company business nor good social policy, that individual mines and mining districts were dying, and that the rate of exhaustion of these nonreproducible resources was steadily accelerating. For the United States, conservation of natural resources was brought to the fore by President Theodore Roosevelt, who, in connection with a National Convention which he convoked in 1908 to consider the subject, called on the U. S. Geological Survey to estimate the country's reserves of economic minerals. The resulting data, though recognized as most imperfect, served nevertheless to affirm the importance of the subject. Even then it was predicted that lead would be the first of the country's important metal products to reach exhaustion.

The great demands of mechanized warfare in 1914–1918, and particularly in 1939–1945, focused still more conspicuous attention on national and world resources. These remain a vital topic in the considerations of peace. The simplest logic of arithmetic, that less remains than at the beginning, is confirmed by the increasing difficulty and decreasing rate of finding new supplies. But there simplicity ends. In the abundant present-day publication on ore reserves there is much contradiction and confusion. The turmoil serves to prevent complacence; but if quantitative estimates continue to be made, probably we shall continue for unknown decades ahead, as for decades in the past, to see estimates successively revised.

Hitherto, passage of time has required revisions upward. For example, in 1915 a recognized authority estimated the *total* expectable reserves of petroleum in the United States; 30 years later, the estimate solely for *proved* reserves was four times the 1915 figure, notwithstanding the enormous intervening production. Similarly, a competent expert in 1907 estimated the period during which the coal reserves of the United States would last; 40 years later, the estimated period is 20 times as long. Admittedly, more pertinent information for all mineral products is available now, both in this country and over the world, than was at hand 30 and 40 years ago. However, when one considers how difficult it is for those best informed to estimate the remaining reserves in a single, compact district of long history, the probable error in predicting eventual worldwide reserves known and as yet unknown should slow down the guessers' impetuosity.

The actual inroads on world reserves during the 75 years of the Institute's existence are approximately as indicated by the total production in column 4 of Table 2. In column 3 are shown the growth ratios; that is, the relative production at beginning and end of that period.

For the products that were mined on an important scale during the first

TABLE 2—*World Metal Production,*[a] 1870–1945

NEW METAL ONLY

IN TONS OF 2000 POUNDS EXCEPT AS OTHERWISE NOTED

Mineral	1 1870	2 Maximum Year	3 Ratio Col. 1:Col. 2	4 Total 1871–1945
Gold[b]	5.95	41 (1940)	1:7	1,260
Silver[b]	49.5	276 (1937)	1:5.5	12,800
Copper	130	2,800 (1942)	1:21	74,000
Tin	31	282 (1941)	1:9	8,100
Iron	14,200	122,000 (1943)	1:8.6	4,140,000
Lead	315	1,870 (1940)	1:6	79,000
Zinc	148	1,820 (1943)	1:12	62,500
Mercury[c]	100*	275 (1941)	1:3	8,600
Nickel	0.45	156 (1943)	1:350	3,400
Manganese[d]	70	6,680 (1937?)	1:95	119,000
Antimony	1.5*	52 (1943)	1:35	1,600*
Cadmium (1882)	0.005*	5.3 (1943)	[1:1,000]**	70
Aluminum (1890)	0.2*	1,920 (1943)	[1:9,600]**	15,100
Chromium[d] (1895)	44*	2,170 (1942)	[1:49]	27,000
Magnesium (1896)	0.05*	284 (1943)	[1:5,600]**	1,200
Bismuth (1900)	0.009*	1.9 (1942)	[1:200]**	20*
Molybdenum (1901)	0.024*	34 (1943)	[1:1,400]**	240
Tungsten[e] (1905)	4*	44 (1939?)	[1:11]	740
Vanadium (1907)	0.003*	5 (1943)	[1:1,700]**	50*
Coal	258,000	1,915,000 (1942)	1:7.4	99,000,000
Petroleum[f]	5,800	2,625,000 (1945)	1:453	49,140,000

[a] Statistics derived from U. S. Geological Survey, U. S. Bureau of Mines, American Bureau of Metal Statistics, *Mineral Industry*, American Petroleum Institute, *Iron Age* and other sources.

Dates following name of metal indicate approximate beginning of significant production. Dates in col. 2 represent the year in which the indicated maximum production was obtained.

Productions marked by asterisk are approximations.

Ratios in brackets are for periods less than the full 75 years; those marked by ** are to be regarded as only rough indications because of smallness and uncertainty of the production in col. 1.

[b] Millions of fine ounces.

[c] Thousands of flasks of 76 pounds.

[d] Thousands of tons of ore.

[e] Thousands of tons of ore of 60 per cent WO_3 equivalent.

[f] Thousands of barrels of 42 U. S. gallons.

seven decades of the nineteenth century, shown in Table 1, comparison may be instituted with the growth ratios in column 3 of Table 2. The reasons for the variations in these ratios from product to product and from early period to late period are well known. It is interesting to note, however, that gold, lead, zinc, iron and coal, among the old standbys, have not held the same rate of growth in the last 75 years as in the preceding 70 years, whereas copper and tin have bettered their position, as also has silver because of its by-product status. But the really striking feature (resembling the behavior of zinc in the earlier period) is, of course, the growth of the metals with the newer uses: the alloy metals and the light metals.

As many have pointed out, the present century has witnessed greater inroads upon the world's supplies of metalliferous minerals and carbonaceous fuels than took place throughout all prior history. What fraction of the initial total still remains cannot even be guessed, since that depends probably as much on man's future ingenuity and on the prices civilization may find it possible to pay for the metals as upon the actual quantities contained in the rocks to depths that man can reach.

Factors that Affect Reserves

Reserves obviously are raised and conservation achieved by all improvements that lower production costs and increase recoveries of the major valuable component or components; and, also, to whatever degree recovery is extended to "rebellious" or rare components in an ore. Vast strides have been made regarding costs by mechanization and increased size of units. As physical metallurgy has developed uses for rare components (at least 40 of the metallic elements are now "commercial"), ore dressing and process metallurgy have kept abreast in recovering them from their source materials. Relatively little now escapes being caught in the by-product net, and for most elements further efforts are likely to show progressively diminishing returns. Increasing attention to the collection and reworking of scrap metals —already a most important industry—will probably repay the effort. In all these respects the mining, metallurgical, chemical and manufacturing industries have labored most earnestly and effectively.

Ore reserves, however, are much more sensitive and mobile quantities than most statisticians seem to assume. They vary on the scale of the individual property with the owner's direct activity, rising or falling as his ore finding exceeds or falls behind extraction, as his costs decline or mount and as his recovery efficiencies improve or regress.

Reserves also vary through industry-wide causes beyond influence of the individual mine: supply vs. demand, new uses vs. substitutes, and the in-

dustry-wide balance between exhaustion and replenishment of ores. This second group of influences is felt, for all save gold, through the factor of metal prices. Under natural and normal conditions, these broad influences, like the laws of physics and chemistry, work toward self-correction and equilibrium by automatically augmenting or shrinking the reserves in each and every occurrence, whether these reserves be in known mines or as yet wholly undiscovered, and also by encouraging or restraining ore hunting.

Both the mine-scale and the industry-scale influences have existed since mining could be regarded as an industry. Recently, however, through expanding governmentalism, wholly new factors have arisen, which profoundly affect ore reserves: crushing taxation, arbitrary and punitive restraints and controls, and governmental support—whether overt or covert—of demands for wages out of line with the economics of the industry or the times. Under reasonable governmental regulation, the mining industry had long demonstrated that it could produce metals from steadily declining grades of ores, and from ores drawn from greater depths and more remote localities, with increasing wage scales yet without substantial change from long-prevailing levels of metal prices. Legislators, political propagandists and labor leaders may well ponder whether more than this can be expected; in the long run, policies that cancel low-grade reserves are fully as dangerous and damaging to nations as to mine owners.

In recent years, hope for new supplies of ore have lain in two directions: (1) small bodies of moderate grade possibly commercial under modern techniques; and (2) great bodies of very low grade. As between these two groups, the latter is strongly favored under the conditions that have been brought into being during recent years. The small properties, with high requirement of labor per unit of output, are severely handicapped. And among the low-grade units only the very largest can hope to amortize the excessive capital requirements. Yet this tendency toward ever larger units is the direct opposite of the objective held by the dreamy ideology that has brought the causative conditions into force.

Let it not be forgotten that the recent war was won, above all else, by *production.* The totalitarian powers were astounded and the democracies jubilantly surprised by the productivity of the latter. Yet even the bounties of nature are to be effectively won only in a climate economically, socially and politically favorable. The fundamental conditions, objectives and policies that during the last century and a half have prevailed in Great Britain and the United States have not been mere accidental coincidence paralleling the attainment of greatness and prosperity by those nations; but instead, have been the sound and indispensable basis of these qualities which all nations of the world desire. Radical departure from those same objectives and poli-

cies can bring only disillusionment, retrogression and distress, however or by whomever the trial be made.

Because, at a few places where all conditions are especially favorable, ore in place averaging 0.5 per cent copper or 0.0002 per cent gold has been mined profitably, reference is often made to the vast low-grade deposits available to prolong metal supplies for a period beyond present anxiety. The thought has even been seriously proposed that for each reduction of one decimal place in grade accepted as ore, say from 3 to 0.3 per cent, from 0.3 to 0.03 per cent, etc., a new tonnage more than one decimal place greater is thereby made available. Those familiar with ore occurrence know that this simply is not true. For most metals, the abnormal local concentration that constitutes an ore deposit has real geometrical limits, beyond which the tenor more or less abruptly drops off to values far below anything entertainable as economic.

Of course, it is true that for ores like those of iron and aluminum, which, by current standards, average in the tens of per cent metal content, there is realistic prospect of gaining adequate supplies for a very long time into the future by utilizing materials of progressively lower grades; chromium and manganese are in a closely analogous category. Magnesium, in rocks and oceans, stands at the extreme of abundance. But for metals like copper, tin, nickel, for which present world-average grades of ore range from 2 per cent downward, there remains a much smaller leeway for ingenuity; gold and silver, except when recovered as by-products, are in a corresponding category. Zinc and possibly lead occupy a position somewhere between the iron-aluminum and the scarcer group.

Possibilities for the Future

Although the facts of the past have clearly shown the dangers in prophecy, it is necessary, nevertheless, to cast our sights ahead.

The period between 1871 and 1946 has disclosed no new land areas of first rank except in the south polar region. However, for great areas whose existence and major features were already known, there has been enormous increase in knowledge of detail of the kind pertinent to classification regarding suitability or unsuitability for ore occurrence. Much of this advance has come, of course, through specific and deliberate search for mineral wealth. Concurrently, the criteria for suitability have become much better understood. The general nature and distribution of rocks and their ages and structures are now known for most of the land surface. Islands of ignorance still remain; one such, Labrador, is just now in process of promising investigation. The frigid and tropical belts contain most of these blank areas.

Within the next quarter century or so, these scantily known regions

doubtless will have been brought pretty well within the fold of understanding, especially by aid of aerial reconnaissance, and above all if this includes the helicopter or equivalent means of grounding safely and at will in virgin terrain. During that period it is reasonable to expect new ore discoveries.

Thereafter, increments from deposits having visible surficial indications may be expected to fall to a new low; and thenceonward most new ore must come from exploring known districts more thoroughly laterally and mining them to greater depth, from wiser geological prediction of favorable but buried loci, and from the aid of geophysical and geochemical techniques. If anything like the past rate of advance in scientific understanding and technologic efficiency may be projected into the future, the common and most of the rarer metals may be counted on for a long time to come. On the other hand, if the sociopolitical climate is not conducive to metal hunting, neither will it be to metal using; then the standard of living will recede, and a new Dark Ages will reign until man regains his common sense and honesty. There is no guarantee that what happened to Egypt and Babylon, to Greece and Rome, will not happen in today's world, save the steadfast determination that it must not be.

Role of Atomic Energy

No consideration of conservation and no look into the future can ignore the amazing new reality, atomic energy. It is clear that research on this subject is proceeding feverishly on both sides of the Atlantic, and enough has been made public on this side to leave no doubt of great advances in scientific understanding. But in addition to what other nations may be doing, a vast pool of secrecy remaining in this country incites much superficial and emotional writing.

Most of the world fervently hopes that this supreme triumph of the human intellect may be turned from warlike to peaceful use. Many seem to take for granted that this outcome is most likely to be achieved by prompt application to industrial uses under rigid international control. Existing proposals before the United Nations imply such programs. And there is much near-official activity toward bringing them into being as rapidly as possible. Neglecting the wholly fantastic notions of columnists and others among the less informed, plans are being seriously discussed that envisage for the near future a consumption in the United States alone of 10,000 tons of metallic uranium annually; and of competing soon with the most efficient coal-burning power plants. An earlier, more official (Smyth) report phrases the situation thus:

> Early rough estimates, which are probably optimistic, were that nuclear energy available in known deposits of uranium were adequate to supply the total power needs of this country for 200 years (assuming utilization of U-238 as well as U-235).

Two considerations, however, warn of the need for caution in the contemplation of such plans. First, a growing number of thoughtful scientists have come to believe that, in the present turbulent state of the world, the enormous complexities and difficulties of international control of nuclear energy, if produced on a great industrial scale, combined with the tremendous temptation to circumvent this control, would constitute such extreme hazard to peace as not to be justified by the sum total of gains presently visualized from industrial use. The proposed alternative is international restriction to scientific research, a scale of use far easier of rigid control and enormously less tempting to evade. Second, there are unquestionably uranium and thorium deposits capable of yielding enough bombs to wreak unconscionable havoc over great areas of concentrated population, not only by immediate destruction but also by slower but wider-reaching radioactivity. *But there is yet no demonstrated certainty that there exist sufficient natural concentrations of these metals to support a long-continuing atomic-power industry.*

These two challenging considerations, moreover, have a possibly sinister interrelationship. If there surely were enough of these two metals to permit sustained extension of the benign effects of cheap nuclear energy to great masses of people hitherto energy-starved, this very factor might be hoped to ease present world tensions, and, combined with other earnest efforts toward peace, to reduce steadily with time the temptation of treacherous evasion of control and of resort to malign use. The longer peaceful production would continue, the less the probable chance of perversion. But if industrial plants established in many countries—as would naturally be demanded by these countries as condition of their acceptance of control—should after a period demonstrate that the supply of physically obtainable uranium and/or thorium metal would not last much longer, doubly compounded temptation might incite vicious leaders of an aggressive nation to make their evil strike before too late.

Conceivably, therefore, even if agreement on international control can be reached, much more may hinge on the available reserves of uranium and thorium than such mere practical questions as the possibility of economic competition with coal.

The easy detectability of uranium and thorium minerals by such device as the Geiger-Müller counter, when held *close* to a rock on surface, in mines or drill holes, promises unusually prompt discovery of new occurrences wherever such detailed studies are made; but similar detection at the distance appropriate to aerial reconnaissance seems beyond hope. As far as yet disclosed, no spectacular additions to reserves of a grade hitherto minable resulted from the feverish and extended searches by the Allied governments during the war years. Lower grade materials are known in several localities, but much

comment, even by insiders, about supplies for a great nuclear energy industry either rests on secret information or else is superlatively optimistic and naïve.

The requirements are worth brief inspection. Material containing 0.2 per cent uranium,* with an assumed overall recovery of 75 per cent, would have to be mined at the rate of over 6,000,000 tons per year to yield the mentioned 10,000 tons annually of uranium metal. If, as seems probable, such rate of exhaustion would make rapid inroads on world reserves of that tenor available to this country, resort would soon have to be taken to progressively lower grades. Considerable tonnages of shales are known containing roughly 0.02 to 0.002 per cent combined uranium and thorium. At these figures, again with 75 per cent recovery, to secure the expected annual 10,000 tons of metal, the higher grade would have to be mined at 60 million tons a year, or 200,000 tons a day, or the lower grade at 600 millions tons yearly; that is, equal to all the coal mines of the United States. Complacent reference to the occurrence of uranium and thorium to the extent of a few parts per million in ordinary rocks—i.e., about another decimal place lower still—misinterprets the manner of deriving as well as the significance of such figures, and also reveals an unrealistic appreciation of the limitations of metallurgical recovery.

However, even if enough of these rare metals could be found and produced to supply a peacetime energy industry for a term of economically justifiable duration, their exhaustion merely for ordinary competition with coal or petroleum would seem most inadvisable. A few superlatively urgent uses for energy in remote regions might be justifiable. On the other hand, schemes like pumping from wells to make the Sahara bloom seem likely to belong on the same shelf with Baron Munchausen's tales. Until it may be proved impossible, production of controlled supertemperatures for tomorrow's metallurgy and chemistry might be the most valuable use of these rare fissionable elements. If so, their exhaustion otherwise would be lamentable.

Assuming, however, that fissionable material from uranium and/or thorium is to be used on a considerable scale for either military or industrial purposes, certain consequences pertinent to the mining industry obviously will result. Besides stimulation of search for and production of these metals, doubtless under most rigid governmental or international control, there would be forced increase in production of metals naturally associated: vanadium, cobalt, selenium, radium, silver, molybdenum, nickel, chromium, tantalum, columbium, and rare-earth elements. There would also be increased need for certain elements used in the processing reactions: beryllium, boron, cad-

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* This is approximately the same as the average grade, 0.21 per cent, for the carnotite ores of the long-known deposits of Colorado and Utah, as given in the official report of extensive exploration during the war; the roscoelite ores of the same area are of much lower grade. Tonnages are not stated.[26]

mium, indium, rhodium, and gallium are potentially indicated. And as synthetic products of the fission reaction there would be substantial quantities of various elements lying in the middle range of atomic weights; some of these are rare, and of these certain ones in the form of stable isotopes are valuable. For the list of needed elements, the prices would tend to rise. For the elements naturally occurring with them, and thus made available as forced by-products, the previous prices would tend to be depressed, likewise the price for the rare products of fission. Beyond these very general influences, the economic consequences are now too vague to deserve further speculation.

Now that the binding energy of atomic nuclei has been brought within reach, derivation from commoner elements beckons alluringly—above all, if of such nature as not to be "chain reacting" and explosive. But all this is as yet too speculative for more than mention here.

If the present worldwide wave of greed for political power leads to perverted employment of this majestic new-found knowledge, may the Infinite Judge enter the charge against those grasping despots who lead their peoples by falsehoods, rather than against the earnest scientists who, almost without exception, hope and strive against such prostitution of all that science stands for.

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History of the Institute

History of the Institute

By A. B. Parsons

Not every organization on reaching the relatively ripe age of three score and fifteen can say with truth that its purpose and objects remain precisely the same as prescribed by its founding fathers. Of course, constancy of purpose may be something else than unalloyed virtue. It could merely reflect slavish worship of tradition, intellectual stagnation, or sheer inertia. On the other hand, it could establish the fact that the founders were men possessed of broad outlook, of prophetic vision, and of an acute sense of direction. In addition to charting the course with precision, the founders of the A.I.M.E. surely showed a flair for expressing clearly in a few words what others might say obscurely in many words.

To quote verbatim from the "call" for the meeting, in 1871, the proposed organization was to have:

> "two great objectives:
> "First, the more economical production of the useful minerals and metals.
> "Second, the greater safety and welfare of those employed in these industries."

This text underwent some refining on several subsequent occasions but today the ultimate product, as set forth in the Constitution reads:

> "to promote the arts and sciences connected with the economic production of the useful minerals and metals and the welfare of those employed in these industries by all lawful means."

The original call was dated "Wilkes-Barre, Pa., April, 1871," and was signed by Eckley B. Coxe, of Jeddo, and by R. P. Rothwell and Martin Coryell, both of Wilkes-Barre, each of the three subscribing himself as "mining engineer." The authors proceeded to explain briefly just how it was proposed to achieve these objectives:

> "In European countries, where the arts of mining and metallurgy have long been the subject of the most careful study, no means have been found so effectual in attaining the end above proposed, as the free interchange of experience among those actually engaged in these industries; and this object has been accomplished mainly through the medium of 'Institutes,' 'Associations,' or 'Societies,' composed of those engaged in these occupations, and by the periodical publication of 'essays' or 'papers' communicated to such societies by their members.
>
> "It must be evident to all practical men that the interchange of the varied experience

> of those engaged in such occupations in this country, could not fail to advance very materially the desired objects; it is therefore proposed to establish an American Institute of Mining Engineers, which will hold its meetings periodically in the great mining and metallurgical centres, where works of interest, such as mines, machine shops, furnaces and other metallurgical works, can be inspected, and the members exchange their views, and consult for mutual advantages upon the difficulties encountered by each; these 'Transactions' or 'Proceedings' when published would form a most valuable, and greatly needed, addition to our professional literature."

After declaring that an organization meeting would be held at Wilkes-Barre either in April or May, the exact date to be fixed later, the call concluded:

> "Any one who may have devoted himself to a particular subject connected with either mining or metallurgy and who may be possessed of new facts in reference to it, would greatly aid in furthering the objects of the proposed association by preparing a paper giving the result of his experience, to be communicated at the first meeting. It is expected that the desire for the advancement of professional knowledge, combined with the attractions of a visit to the most beautiful of our coal fields—the Wyoming Valley—will insure a large attendance from all parts of the country."

Significantly, even in 1871, civic pride crept into this businesslike communication! It was published in several periodicals and widely circulated by letter; and the outcome was a meeting of twenty-two men on May 16, 1871; i.e.,

J. H. Bramwell	Dunbar, Pa.	R. C. Neal	Bloomsburg, Pa.
S. Harries Daddow	St. Clair, Pa.	Thomas Petherick	Scranton, Pa.
Henry S. Drinker	Philadelphia, Pa.	Rossiter W. Raymond	New York City
Thomas M. Drown	Philadelphia, Pa.	R. P. Rothwell	Wilkes-Barre, Pa.
E. Gaujot	Pottsville, Pa.	J. M. Silliman	Easton, Pa.
Ogden Haight	New York City	W. H. Sturdevant	Wilkes-Barre, Pa.
W. B. Hick	Wilkes-Barre, Pa.	W. R. Symons,	Pottsville, Pa.
Daniel Hoffman	Pottsville, Pa.	James Thomas	Wilkes-Barre, Pa.
Lewis S. Jones	Wilkes-Barre, Pa.	James A. Timpson	Wilkes-Barre, Pa.
Thomas S. McNair	Hazleton, Pa.	Willard P. Ward	New York City.
Fred Mercur	Wilkes-Barre, Pa.	T. M. Williams	Wilkes-Barre, Pa.

R. P. Rothwell was chosen as provisional chairman and Rossiter W. Raymond as provisional secretary of the opening session. It was decided that all those present, as well as those who had indicated by letter a desire to become members, would be admitted as Associates; and that at a meeting to be held the following August a committee headed by Mr. Rothwell would "report the . . . said persons in two lists, as Members and Associates." At the very start of the term "Member" was to be reserved for persons who enjoyed recognized professional standing and who were actively engaged in the engineering and technologic phases of the industry. Other "suitable persons desirous of being connected with the Institute and duly elected" would become Associates.

Significantly, metallurgy and metallurgists were emphasized in the call and in other announcements, but the word "Metallurgical" was not included in the name. Not until 1919 was the name of the Institute officially changed—whether for better or for worse being a question often argued but seldom settled to the satisfaction of all participating in the debate. All approve the objective of greater inclusiveness; but some fear that by implication important groups are excluded.

On the following day, May 17, the group met again and approved the credentials as Associates of 71 applicants, including themselves. Next they proceeded to elect the following officers of whom nine, including Mr. Thomas, as president, were not present:

President

David Thomas, Catasauqua, Pa.

Vice Presidents

Rossiter W. Raymond, New York City
E. B. Coxe, Drifton, Pa.
W. R. Symons, Pottsville, Pa.
W. P. Blake, New Haven, Conn.
J. F. Blandy, Philadelphia, Pa.
J. H. Swoyer, Wilkes-Barre, Pa.

Managers

R. P. Rothwell, Wilkes-Barre, Pa.
T. S. McNair, Hazleton, Pa.
G. W. Maynard, Troy, N. Y.
Raphael Pumpelly, Cambridge, Mass.
Thomas Petherick, Scranton, Pa.
T. M. Williams, Wilkes-Barre, Pa.
Thomas Egleston, Jr., New York City
E. Gaujot, Pottsville, Pa.

Fred Prime, Jr., Easton, Pa.

Secretary

Martin Coryell, Wilkes-Barre, Pa.

Treasurer

J. Pryor Williamson, Wilkes-Barre, Pa.

Thereupon, in the absence of Mr. Thomas, Rossiter W. Raymond, Vice-President, assumed the chair. After a recess of five minutes, "it was determined to receive verbally the purport of a paper prepared by R. P. Rothwell on 'The Waste of Coal in Mining.' " Thus on the second day of its existence the Institute started fulfilling its primary mission, "the reading and discussion of professional papers."

Next, on motion made and carried, "The Secretary was ordered to receive entrance fees until such time as the Treasurer should enter upon his duties." With provision made for this highly important function, the session was adjourned. On the following day three papers were presented, the last being an elaborate discussion entitled, "The Relation of the Speed of Stamps [in gold mills] to Their Effectiveness in Crushing Rock." Various resolutions of thanks and appreciation to the engineers of Wyoming Valley and to the managers of the mines and works that had been visited were adopted, and the first three-day meeting of the American Institute of Mining and Metallurgical] Engineers was concluded. It was a going concern with 71 potential Members (Associates) and an exchequer—albeit one of extremely modest proportions.

It is pretty well established that man has used metals for at least five thousand years. By numerical comparison the 75 years of the Institute's life is inconsequential; but on the basis of material progress—and such progress synchronizes with, if it does not depend mainly on, the growing use of minerals and metals—that 75 years can be described only by some such extravagant term as "colossal."

To give quantitative expression to the expansion in the production (with which consumption kept in close step) of minerals and metals, Table 1 has been prepared. It shows the annual production of 15 important mineral commodities in or about 1871 and the corresponding figures for the peak year for

TABLE 1—*Comparison of Production of Metals and Minerals in the United States in 1871 and "Record" Years*

Commodity	A 1871	B High Record	B Year	Ratio of Increase B/A
Bituminous coal, tons	21,000,000	610,000,000	1944	29
Anthracite, tons	15,600,000	89,500,000	1920	5.7
Petroleum, bbl	5,180,000	1,730,000,000	1946	334
Pig iron, tons	1,900,000	62,800,000	1944	33
Steel, tons	84,000	89,600,000	1944	1,070
Copper, tons	14,000	1,115,000	1943	80
Lead, tons	19,800	496,000	1942	25
Zinc, tons	7,000	768,000	1942	110
Aluminum, tons	None	918,000	1943	Infinite
Magnesium, tons	None	183,500	1943	Infinite
Gold, oz	2,104,000	4,870,000	1940	2.3
Silver, oz	17,800,000	74,900,000	1915	4.2
Portland cement, bbl	2,000	183,000,000	1942	91,500
Salt, tons	500,000	15,700,000	1944	31
Sulphur, tons	None	3,800,000	1942	Infinite

the respective items. The ratios of increase range from 2.3 for gold to infinity for several that today are of vital importance. These data are for the United States, but similar figures could be cited for the world; and several additions, such, as tin, nickel, manganese, nitrate and potash, could be made.

Foresight of the Founders

It would be idle to speculate on how accurately the founders of the Institute foresaw what the next 75 years would bring to pass in the way of production; but the following excerpts from an eloquent paper by a member of 1871—Edmund C. Pechin, steelmaster of Dunbar, Pa.—are prophetic:

> "We find, the world over, the most intense activity everywhere displayed in enterprises requiring prodigious quantities of iron. Railways of colossal magnitude are projected . . . This growing scarcity of timber is *compelling* the use of iron in buildings; bridges of wonderful size and strength; huge ocean steamships; barges and boats for lake and river traffic; churches; cars, and thousands of minor articles of every shape and size. . . .
>
> "The time has come when scientific research is to assume its true position—the day of 'sheer force and blind stupidity,' whose only protection is a high tariff, has gone forever . . . the physicist, the geologist and mineralogist; the chemist, the engineer, are as essential to success as the [blast] furnace itself . . . There is no merely practical man, no matter how varied may have been his experience, or how long his practice, that will not benefit from the results of scientific investigation. That there is a growing sense of the importance of having thoroughly prepared scientific men in every department of business is evidenced by the institutions [of learning] that are springing up in different quarters, provided with able teachers . . . We summon to our aid all that science can afford, mechanical ingenuity devise, money purchase, and energy and ability achieve, and when this is done, we fain must confess how little we have accomplished and how little we know compared with the vast possibilities that lie before us."

Mark that these words, freighted with amazing wisdom, were written in *1872;* they were intended to apply to the iron and steel industry, but they were no less appropriate for any other branch of the mineral industry.

Other papers in the first volume of TRANSACTIONS make fascinating reading; and a few random observations suggested by these articles and by the data in Table 1 may be useful, especially for more youthful readers, in setting a back-drop for the industrial and technologic scene in which the Institute was organized.

1. In general, the commodities having the smallest ratio of increase in the table were the most important in 1871: (*a*) coal (anthracite being relatively more important than bituminous); (*b*) pig iron; (*c*) lead; (*d*) salt; (*e*) gold; and (*f*) silver.

2. The petroleum industry was still an infant, although the famous Drake well, near Titusville, Pa., had been discovered 12 years earlier. The chief market product was kerosene to burn in lamps, for Edison's first incandescent electric bulb was 8 years in the future.

3. The light fraction from petroleum known as gasoline was something of a nuisance; and the refiners produced as little as possible. The devising of a horseless carriage was in the minds of various inventors; but the use of gasoline as its source of power was given scant consideration; and the few who toyed with the idea of a flying machine fueled with gasoline were visionary dreamers. Duryea's gasoline automobile came in 1892; and the airplane became practical about 20 years later.

4. Production of bituminous coal had passed that of anthracite a few years before 1871; but heating buildings was the principal use of both kinds of coal. This has continued to be true of anthracite; whereas the thirty-fold expansion by 1944 in bituminous coal came from increased use for industrial purposes—railroads, power generation, and coke manufacture.

5. The production of pig iron in 1871 was a fairly well-established industry. Most of the ores were magnetites from the eastern states; but iron ores of excellent quality had been found near Marquette in the upper peninsula of Michigan and these were coming down to the furnaces in increasing quantity by lake transportation. Incidentally, fuels used in the blast furnace included anthracite, coke, charcoal and bituminous coal. Coke had not yet won recognition as the premier fuel.

6. One of the most interesting figures is 80,000 tons of steel produced in 1871. A little steel had been made each year since the Civil War but it was still a novelty. One TRANSACTIONS author showed that the keen competition between iron and steel to make rails for the railroads had been resolved in favor of steel! As indicated in the quotation from Mr. Pechin, the country was just starting the tremendous extension of its railway system that was to be the backbone of steel consumption for many years.

7. In 1871, John A. Roebling had successfully swung a suspension bridge over the Ohio River at Cincinnati, and also had drawn plans for a much longer bridge to connect Manhattan and Brooklyn. For this bridge he decided to use steel (instead of iron) wire for spinning the main cables. This had never been done; and a lesser man than Roebling probably would not have taken the chance. As a matter of fact, the final specification called for an *all-steel* structure. Again a bow to Mr. Pechin!

8. The highest buildings in 1871 were eight and ten stories; the walls were massive structures of natural stone. Not until about 20 years later did the "skyscraper" era commence; but thereafter great quantities of steel were used to fabricate the mighty skeletons on which the walls and floors were to be hung.

9. Copper came almost entirely from Michigan's upper peninsula; but not much was needed. The practical development of the electric dynamo and motor was not to be achieved until about 1880 and the electric power industry

has been and still is the big user of copper. Butte was still a silver camp; and although prospectors were roaming Arizona, the Apaches made much trouble and production of copper was negligible.

10. Portland cement was manufactured for the first time in the United States in 1871 at a small plant near Allentown, Pa. This branch of the mineral industry turned out a product valued at $400,000,000 in 1942. Not only the famous roads of the United States but structures of all sorts today rely on adequate supplies of portland cement.

11. Table 1 contains three mineral products of which the output was nil (or negligible) in 1871. Sulphur, of course, was obtained in small quantity from pyrites; but the chemical industry, to which sulphur is vital, was of only minor importance at that time. The two light metals, aluminum and magnesium, were industrial—indeed laboratory—unknowns in 1871. As to their importance today no one has any doubt.

It is unlikely that the Founders of the Institute foresaw the extent of the growth of which the foregoing are illustrative; but, as suggested by the quotations from Mr. Pechin's paper, many of them were alive to the possibilities of the future. They realized the need for the best possible engineering and technology in probing the crust of the earth for ores and other mineral deposits; in removing crude minerals from the ground; in beneficiating and refining them; and, finally, in processing and utilizing them efficiently and economically.

Primarily, the Institute was an instrumentality for achieving these ends. Doubtless the Founders expected to develop pleasant associations with their fellows in the profession; but that would be merely a valuable by-product.

First Forty Years, 1871–1911

The history of the Institute can be divided conveniently and logically (for reasons that will appear presently) into two periods: (1) the first 40 years, 1871 to 1911, constituting the period of organization and foundation laying; and (2) the next 35 years, 1911 to 1946, the period of decentralization, expansion in activities, and growth in numbers. In 1911, the first Local Sections were formed; the first technical committees were organized; a Committee on Increase in Membership (the Membership Committee up to that time really had been an Admissions Committee) was formed for the first time; and the first Committee on Publications was established.

During the 40 years of the first period the Institute was dominated by an autocrat, a most able and likewise beneficent autocrat—Rossiter W. Raymond. Dr. Raymond was one of the founders; he was present at the first meeting in Wilkes-Barre. He was not the first president; but he filled out Mr. Thomas' unexpired term and then served three terms of his own. Anyone examining the minutes of the meetings of the Council and the reports of the technical meetings held prior to 1884 will find that the name Raymond seldom was missing from the list of attendees. He was on all sorts of committees, standing and special; he offered resolutions of many kinds; he read and presented more than his share of papers, and he discussed papers on almost every subject. His versatility was amazing. One explanation is that from 1868 to 1876 he served as U. S. Commissioner of Mining Statistics. In this capacity he made repeated visits to western mining districts, and his active mind absorbed details of geology, mine operation, and ore treatment.

Then, in 1884, Dr. Raymond became Secretary—a post he held for 27 consecutive years. In the Raymond Memorial Volume, published by the Institute in 1920, T. A. Rickard, dean of technical journalists, among other things, says:

> "As secretary of the Institute he performed divers duties; he invited written contributions and revised them before publication; he organized the meetings, he was the administrator. In course of time his ebullient personality so dominated the Institute that he was allowed a free hand to do as he thought fit. Presidents came and went; although nominally secretary, he exercised complete control. The personnel of the board of management, or 'council,' of the Institute changed from year to year, but Dr. Raymond managed its affairs, practically without let or hindrance. The Institute became identified with him. For a period longer than a generation he was the mainspring of the activities of the Institute, its presiding genius, its chief spokesman. Those who participated in the meetings of ten or twenty years ago will retain a vivid impression of the way in which Dr. Raymond stamped his individuality on the organization. Courteous and friendly to all, resourceful and tactful in steering the discussions, witty and eloquent whenever he rose to his feet, he was the managing director of the proceedings; he gave point and distinction to them; he infused them with his keen enthusiasm; he lighted them with the brilliance of his mind."

That this is not an exaggerated picture is testified by many other members who were active during that period. Some of them emphasize the point, however, that the Council at all times had among its members eminent engineers who were men of large affairs; that they gave careful attention to the business of the Institute; and that they accepted Dr. Raymond's leadership deliberately and knowingly rather than blindly. Time and again, in the minutes of the Council's meetings, appears an entry to this general purport: "The Secretary was authorized to invite and accept papers and make all necessary arrangements for a meeting to be held in . . . during the month of . . . ."

The impression should not be given that the nonexistence of "technical" committees, charged with the solicitation of papers in specific fields and the arrangement of programs, resulted in an unbalanced collection of papers in the TRANSACTIONS. Quite the contrary was true; for Dr. Raymond's interests and knowledge were as varied as the mineral industry is diversified. Prominent among the founders were the ironmasters and producers of anthracite. Naturally, the metallurgy of iron and steel as well as coal mining were well represented on the programs. But in addition to adequate coverage of these topics, the first volume of TRANSACTIONS contained these typical subjects:

Mines and Works of the Lehigh Zinc Company. By H. S. Drinker.
The Relation between the Speed and Effectiveness of Stamps. By Rossiter W. Raymond.
Smelting of Argentiferous Lead Ores in Nevada, Utah, and Montana. By O. H. Hahn, Anton Eilers, and Rossiter W. Raymond.
The Brown Hematite Ore Deposits of South Mountain, near the Cumberland Valley. By J. W. Harden.
The Importance of Surveying in Geology. By Benjamin Smith Lyman.
Method and Cost of Mining the Red Specular and Magnetic Ores of the Marquette Iron Region of Lake Superior. By Major T. B. Brooks.
Economical Results in the Treatment of Gold and Silver Ores by Fusion. By John A. Church.
The Hunt and Douglas Copper Process. By T. Sterry Hunt.
Extraction of Bismuth from Certain Ores. By T. Sterry Hunt.
A New Method of Sinking Shafts. By Eckley B. Coxe.
A New Occurrence of the Telluride of Gold and Silver. By A. Eilers.
The Probable Existence of Microscopic Diamonds with Zircons and Topaz, in the Sands of Hydraulic Washings in California. By B. Silliman.
Remarks on the Use of the Plummet-Lamp in Underground Surveying. By Eckley B. Coxe.
Contributions to the Records of Lead Smelting in Blast Furnaces. By A. Eilers.
Recent Improvements in Diamond Drills and in the Machinery for their Use. By William P. Blake.
The Origin of Metalliferous Deposits. By T. Sterry Hunt.

In Volume I, geology, metal mining, ore dressing, and nonferrous metallurgy all were adequately represented; and such representation always has existed. Up to 1911, forty volumes of TRANSACTIONS had appeared; and the set was generally recognized as constituting the most extensive and authoritative library extant on engineering and technology in the mineral industry.

Another interesting feature of the Raymond era was the dispersion of meeting places. In the first 40 years, 99 general meetings were held, most of them occupying several days and some of them a much longer period. Of the 99, only 12 were held in New York City. Canada was the scene of 7, ranging from Halifax, Nova Scotia, to British Columbia. The Institute met in Mexico in 1901, in London in 1906, and in the Canal Zone (Panama) in 1910. The other meetings were scattered all over the United States (see Table 6, p. 464).

Unlike Institute meetings of later days, these were "one-ring" performances; that is to say, no simultaneous sessions were scheduled. The attendance was not so large but that any medium sized city could accommodate the meeting. Invariably, combined with the technical sessions were visits of inspection to mines and quarries; to plants of all sorts, including concentrators, smelting works, rolling mills, oil refineries, navy yards and portland cement plants; to mining schools, research laboratories, and museums. On more than one occasion special boats or trains were arranged for the Institute party and extended excursions covered large regions.

Social amenities were not neglected and a product of these meetings was the development of good fellowship, better cooperation, wider acquaintance, and a professional solidarity that was invaluable to the members of the Institute.

At the time of the Centennial Exposition held in Philadelphia in 1876, the Institute raised a substantial fund to provide and staff a headquarters for members and others interested in the mineral industry, and particularly to aid members of the profession coming from abroad. Before the Exposition closed, some 500 letters of introduction had been written and many visitors had been provided with detailed itineraries for tours to mines and plants in all parts of the United States. Similarly, the Institute took an active part in the World's Columbian Exposition, held in Chicago in 1893. By voluntary contribution it raised a special fund to support the mining and metallurgical "Departments" of the World Engineering Congress held in conjunction with the Exposition.

Dr. Raymond, personally, was accorded high honors by several engineering societies in foreign countries. He visited Europe on more than one occasion and frequently contributed papers to engineering congresses and conventions held abroad. Because of his long tenure in the secretaryship his achievements and the distinctions he won reflected favorably upon the Institute and enhanced its position in the engineering world both at home and abroad.

In summary, what did Dr. Raymond do for the Institute in these 40 years? As has been indicated, he gave its publications a standing throughout the scientific and technologic world that has seldom been rivaled. He was more than a painstaking editor; he actually rewrote many manuscripts. Scores of inexperienced authors were surprised (and likewise pleased) at the scholarly papers that were printed under their names; but the result was that the TRANSACTIONS of the Institute attained exceptionally high standards of excellence. In 1908, at the Jamestown Ter-Centennial Exposition, the Institute was awarded a gold medal in recognition of the high quality of its publications during the preceding decade.

It is fair to say also that Dr. Raymond, because of the fine quality of his intellect, the charm of his manner, and the magnetism of his personality, attracted men of superior attainment and great distinction to membership in the Institute.

The Institute joined in 1904 with the American Society of Mechanical

Engineers and the American Institute of Electrical Engineers (the American Society of Civil Engineers became a participant in 1910) in establishing the United Engineering Society (now called the United Engineering Trustees), a corporate body through which the societies jointly own the Engineering Societies Building as a permanent home and also the Engineering Societies Library. Details of this important enterprise will appear later in this history.

Membership had increased with astonishing uniformity, as shown graphically in Fig. 2 (p. 436). The net gain had averaged just around 100 per year, making a total in 1911 of slightly over 4000 members. Of these, more than 30 per cent resided outside the United States; for example, more than 200 were from Great Britain alone. This, of course, was a reflection of the high esteem in which the Institute was held by engineers in foreign countries. The paid staff at headquarters numbered 11; and the annual budget for 1910 was about $60,000. Though it was smaller than two of the other three leading American engineering societies, it took second place to none in standing and prestige. When Dr. Raymond resigned as Secretary and became Secretary Emeritus on March 31, 1911, he had the satisfaction of knowing that the foundation he had laid was firm and sound.

Thirty-five Years, 1912–1946

Several courses are open to the historian in dealing with the second major era, 1912 to 1946, in the life of the Institute. It would be possible to discuss as a separate section the more important trends and events in the period coinciding with the tenure of each of the five secretaries that in chronological succession followed Dr. Raymond. Or the following periods might be chosen: (1) World War I; (2) the decline and recovery of the '20s; (3) the depression and expansion of the '30s; and (4) World War II. However, it seems that a more convenient and practical method—and one that should effect economy of the reader's time—is to select significant phases of the Institute's development and activities and to discuss each in a single section as relating to the whole period. Indeed, in some instances the "first 40 years" will be trespassed upon for the sake of a more nearly complete record. The following topics will be considered:

1. Local Sections
2. Technical Committees
3. Professional Divisions
4. Membership
5. Publications
6. Endowed Funds
7. Medals and Awards
8. Meetings of the Institute
9. Engineering Societies Building
10. Cooperative Activities—other Societies
11. Activities in Two Wars
12. Constitution and Bylaws
13. Institute as a Forum
14. Woman's Auxiliary to the A.I.M.E.

LOCAL SECTIONS

Just as it is today, the membership of the Institute in 1911 was widely scattered geographically. Only one or two states failed of representation on the roll; and half of them had a substantial membership. Although the practice of holding general meetings in different places was helpful, the participation of the great majority of the members in Institute affairs was limited to infrequent attendance at meetings and to the receipt of publications, including an annual volume of TRANSACTIONS, the BULLETIN (issued monthly, beginning in 1909), and a YEAR BOOK, as it was then called, containing the List of Members. Interest of the member is best held, and that of the potential member is best enlisted, by activity in which each may participate. In 1911 it appeared that the obvious way to make such activity possible was to organize Local Sections, whose main function would be to arrange meetings at appropriate intervals for the benefit of those members of the Institute residing in a relatively compact area. Today, 39 such Sections practically blanket the United States, as shown on Fig. 1.

In the minutes of the Council for May 1911, record is made of a communication from Luther Wagoner regarding the formation of a Local Section in his home town of San Francisco. The Council chose to regard this communication as an application for a "charter"; and formally voted to "grant permission" to organize a San Francisco Local Section. Had the plan materialized at once this would have been the first Section to be recognized. Apparently procrastination ensued around the Golden Gate and the plan lapsed; for the records now give June 26, 1913, as the date of the organization of the San Francisco Section.

However, 1911 saw the establishment of three Sections—New York, Boston, and Spokane (later changed to Columbia), which included in its area the Coeur d'Alene region of Idaho. During 1912, no new Sections were chartered, possibly because of preoccupation with the drafting of an entirely new Constitution and Bylaws for the Institute. These were adopted on February 18, 1913; and in them the functions, privileges, and obligations of a Local Section were defined at length. Besides San Francisco, the following Sections were established during that year: Colorado, Puget Sound (later changed to North Pacific), Montana, St. Louis, and Southern California. By 1920 there were 21 Sections; and others were organized as indicated in Table 2, which also lists the members who have been accorded the distinction of election as chairman of each Section.

Local Sections have elected their own officers and have been self-governing within the terms of the charter granted by the Board of Directors of the Institute. The Institute reserves first right to the publication of papers

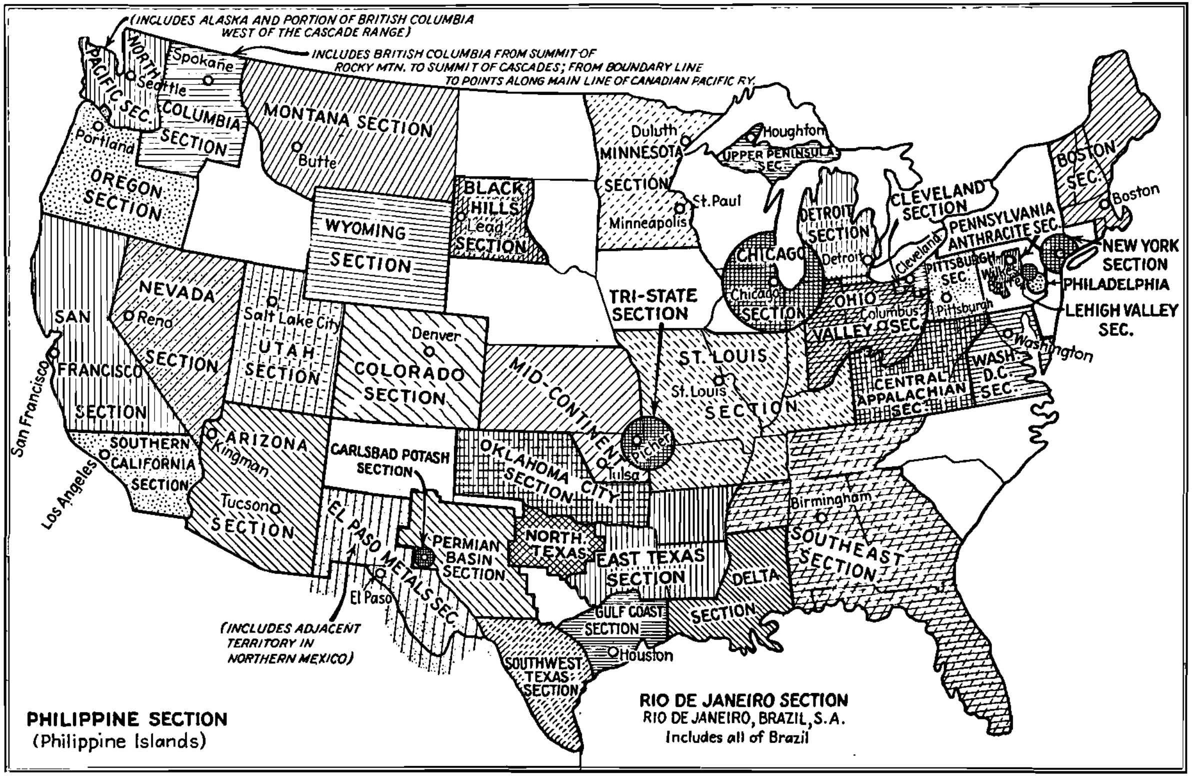

FIG. 1—*Territory covered by Local Sections of the American Institute of Mining and Metallurgical Engineers.*

The following two small areas in Kentucky are part of the Ohio Valley Section: (1) Newport, Covington and vicinity; and (2) Ashland and vicinity.

presented at Local Section meetings; and such meetings have been a source of a great many excellent contributions to the TRANSACTIONS and to the monthly magazine MINING and METALLURGY. In the Bylaws for 1913 occurs this statement: "It shall be the policy of the Board of Directors of the Institute to contribute from its funds for the necessary running expenses of each Local Section . . . but in no case exceeding the sum of $250 [in any year]." The upper limit was increased to $400 in 1938; but the maximum has been allotted customarily to only a few of the larger Sections. In 1946, an aggregate of $7,575 for all 39 Sections was appropriated. The basis of allocation between the Sections is the "need" as shown by "the extent of activities as reflected in the number and character of meetings and the attendance of members at such meetings," to quote from the "Statement of Principles" adopted by the Board in 1938. A number of the more active Sections collect modest annual dues and some derive funds from other sources, such as advertisements in a Local Section Directory.

Varying geographic conditions, diversity of technologic fields represented in their membership, and sundry other circumstances make the problems faced by the Local Sections very different indeed. Since about 1927, a feature of the Institute's Annual February Meeting has been a Conference of Local Section Delegates at which the conduct of Section affairs and other Institute activities have been discussed frankly and often at great length. The travel expenses of a delegate from each Section are defrayed from the general treasury of the Institute; and the fact that the chairman of the Section is expected to be the delegate, if he can attend, has added prestige to Section chairmanships.

One of the important functions of Local Sections has been to serve as host on the occasion of the Annual Regional Meeting. This meeting has been held in a different city from year to year; and, aside from the Annual February Meeting, has been the most important general meeting of the Institute.

For reasons that are apparent, the publication and circulation of papers must be conducted by the general organization. This leaves as the primary function of Local Sections "the holding of meetings for social intercourse and the reading and discussion of professional papers." Many of the Local Sections have emphasized social activities to the general satisfaction of their members. Healthy and active Local Sections have been a vital factor in promoting the vigor and growth of the Institute. As in any widespread organization, the grass-roots activity, exemplified by the work of the Local Sections, is all-important. A few of the Sections have not been particularly effective, but for the most part they have been a source of great strength to the Institute as a whole and have been a credit to their members and to their officers.

TABLE 2—*Past and Present Chairmen of Local Sections of the AIME*

	New York	*Boston*	*Columbia*
Year	Founded May 19, 1911	Founded Sept. 20, 1911	Founded Nov. 24, 1911
1911	B. B. Lawrence	R. H. Richards	Richard S. McCaffery
1912	George F. Kunz	R. H. Richards	Richard S. McCaffery
1913	Louis D. Huntoon	R. H. Richards	Richard S. McCaffery
1914	L. W. Francis	R. H. Richards	Francis A. Thomson
1915	L. W. Francis	Henry L. Smyth	Frank A. Ross
1916	David H. Browne	Henry L. Smyth	Stanly A. Eaton
1917	J. E. Johnson, Jr.	R. L. Agassiz	W. H. Linney
1918	Allen H. Rogers	Alfred C. Lane	S. S. Fowler
1919	Allen H. Rogers	Albert Sauveur	J. C. Haas
1920	E. P. Mathewson	Waldemar Lindgren	James F. McCarthy
1921	E. P. Mathewson	W. S. Hutchinson	Ivan de Lashmutt
1922	Robert Linton	W. S. Hutchinson	Rush J. White
1923	Bradley Stoughton	L. C. Graton	Raymond Guyer
1924	J. V. N. Dorr	Charles E. Locke	Fred W. Callaway
1925	John A. Church, Jr.	Roy B. Earling	Rowland B. King
1926	J. E. Spurr	C. R. Hayward	M. H. Sullivan
1927	John A. Church, Jr.	Edward C. Geither	Frank M. Smith
1928	Sidney Rolle	Galen H. Clevenger	Francis A. Thomson
1929	R. M. Roosevelt	Holcombe J. Brown	W. L. Zeigler
1930	R. M. Roosevelt	D. H. McLaughlin	R. K. Neill
1931	Landon F. Strobel	George B. Waterhouse	W. G. Woolf
1932	Sydney H. Ball	George A. Packard	R. T. Banks
1933	A. L. J. Queneau	Franklin B. Richards	Frederick Keffer
1934	H. T. Hamilton	Frederick K. Morris	John Wellington Finch
1935	Clinton Bernard	George W. Metcalfe	George A. Sonnemann
1936	William B. Heroy	Robert S. Williams	A. W. Fahrenwald
1937	Russell B. Paul	Edward E. Bugbee	Roy H. Clarke
1938	Felix E. Wormser	H. H. Lester	H. G. Washburn
1939	C. E. Arnold	Horace T. Mann	James L. Leonard
1940	Samuel Haskell	Daniel Cushing	Bliss Moore
1941	R. L. Hallett	F. Leroy Foster	Harold E. Culver
1942	James L. Head	Esper S. Larsen	P. E. Oscarson
1943	Walter P. Jacob	Carl F. Floe	Ross D. Leisk
1944	M. B. Gentry	Lucien Eaton	Philip J. Shenon
1945	George Blow	Warren J. Mead	J. B. Haffner
1946	E. C. Meagher	Russell Gibson	C. A. R. Lambly
1947	O. B. J. Fraser	William H. Graves, Jr.	J. Edward Berg

TABLE 2—(*Continued*)

	North Pacific	*St. Louis*	*Southern California*
Year	Founded March 28, 1913	Founded May 23, 1913	Founded May 23, 1913
1913	Chester F. Lee	Philip N. Moore	Theodore B. Comstock
1914	Joseph Daniels	H. A. Wheeler	Theodore B. Comstock
1915	I. F. Laucks	H. A. Wheeler	Theodore B. Comstock
1916	G. A. Collins	Arthur Thacher	Seeley W. Mudd
1917	Simon H. Ash	H. A. Buehler	C. C. Jones
1918	Henry Landes	Eugene McAuliffe	Ralph Arnold
1919	Henry Landes	F. V. Desloge	Ralph Arnold
1920	Percy E. Wright	J. A. Caselton	W. F. Staunton
1921	L. A. Levensaler	J. A. Caselton	Ralph Arnold
1922	Amos Slaters	B. O. Mahaffey	Harry R. Johnson
1923	Milnor Roberts	B. O. Mahaffey	Harry R. Johnson
1924	Harry Towsend	J. D. Robertson	Desaix B. Myers
1925	Melvin C. Butler	M. M. Leighton	Rush T. Sill
1926	Joseph Daniels	J. H. Steinmesch	Joseph Jensen
1927	Thomas Davis	J. H. Steinmesch	S. L. Gillan
1928	G. W. Evans	J. H. Steinmesch	Robert R. Boyd
1929	G. W. Evans	Carl G. Stifel	G. D. Robertson
1930	B. H. Bennetts	William Weigel	A. B. Menefee
1931	George T. Jackson	John T. Fuller	Van Court Warren
1932	Eugene A. White	P. A. Haines	H. Norton Johnson
1933	H. F. Yancey	P. A. Haines	H. Norton Johnson
1934	Russell J. Spry	W. H. Coghill	Emile Huguenin
1935	C. R. Corey	A. E. Stocking	Julian Boyd
1936	R. A. Wagstaff	H. S. McQueen	Robert Linton
1937	R. A. Wagstaff	H. S. McQueen	Robert Linton
1938	Jesse C. Johnson	P. H. Carpenter	Ernest K. Parks
1937	Paul T. Benson	L. L. Turley	G. A. Joslin
1940	Earl R. McMillan	Jean McCallum	Harry P. Stolz
1941	Charles R. Low	E. G. Robinson	V. H. Wilhelm
1942	J. B. Umpleby	E. G. Robinson	C. P. Watson
1943	Max R. Geer	H. R. Hanley	Walter D. Abel
1944	Axel E. Anderson	L. P. Davidson	E. G. Trostel
1945	Axel E. Anderson	L. P. Davidson	A. B. Campbell
1946	D. A. Somerville	Carl Tolman	E. O. Slater
1947	Willis H. Ott	Edward L. Clark	Thomas A. Atkinson

TABLE 2—(*Continued*)

Year	*Colorado* Founded May 23, 1913	*San Francisco* Founded June 26, 1913	*Montana* Founded Oct. 17, 1913
1913	William J. Cox	S. B. Christy	E. P. Mathewson
1914	William J. Cox	S. B. Christy	E. P. Mathewson
1915	Frank Bulkley	Herbert Hoover	E. P. Mathewson
1916	L. P. Hammond	T. A. Rickard	J. L. Bruce
1917	C. Loughridge	W. H. Shockley	W. C. Siderfin
1918	Charles M. MacNeill	A. C. Lawson	N. B. Braly
1919	R. J. Grant	F. W. Bradley	Frederick Laist
1920	W. W. Leonard	Corey C. Brayton	Theodore Simons
1921	Richard A. Parker	Frank L. Sizer	F. W. Bacorn
1922	J. C. Roberts	Albert Burch	William B. Daly
1923	C. N. Bell	L. Duschak	Reno H. Sales
1924	C. H. Wegemann	Robert A. Kinzie	Erle V. Daveler
1925	C. H. Wegemann	Abbot A. Hanks	L. V. Bender
1926	Horace F. Lunt	Frank H. Probert	George W. Roddewig
1927	John Wellington Finch	Wilbur H. Grant	Alexander Leggat
1928	J. C. Evans	E. A. Hersam	C. L. Berrien
1929	E. C. Reybold Jr.	E. A. Hersam	F. A. Linforth
1930	C. W. Henderson	David Atkins	J. D. MacKenzie
1931	Robert H. Sayre	Ira B. Joralemon	Murl H. Gidel
1932	H. A. Stewart	Lawrence K. Requa	Albert E. Wiggin
1933	H. A. Stewart	Wendell C. Hammon	Francis A. Thomson
1934	H. A. Stewart	Robert A. Kinzie	Samuel Barker, Jr.
1935	Clark B. Carpenter	Walter W. Bradley	R. B. Caples
1936	Clark B. Carpenter	C. M. Romanowitz	A. M. Gaudin
1937	Oscar H. Johnson	Worthen Bradley	E. A. Barnard
1938	H. L. Tedrow	Robert Hawxhurst	C. L. Wilson
1939	H. L. Tedrow	Edwin L. Oliver	A. S. Richardson
1940	R. H. Summer	Charles W. Merrill	E. S. Bardwell
1941	J. H. Johnson	W. S. Weeks	J. J. Carrigan
1942	J. H. Johnson	W. S. Weeks	S. S. Rodgers
1943	W. J. Coulter	Herbert A. Sawin	Morgan H. Wright
1944	W. J. Coulter	Charles A. Dobbel	E. M. Tittmann
1945	E. D. Dickerman	Walter Stalder	P. S. Weimer
1946	E. D. Dickerman	W. Spencer Reid	H. J. Rahilly
1947	E. D. Dickerman	Lawrence B. Wright	W. A. O'Kelly

TABLE 2—(*Continued*)

Year	*Pennsylvania Anthracite* Founded Feb. 17, 1914	*Chicago* Founded Feb. 26, 1914	*Utah* Founded Apr. 24, 1914
1914	R. V. Norris	H. W. Nichols	George D. Blood
1915	R. V. Norris	Robert W. Hunt	Robert C. Gemmell
1916	R. V. Norris	C. H. MacDowell	C. W. Whitley
1917	R. V. Norris	C. H. MacDowell	C. W. Whitley
1918	R. V. Norris	C. H. MacDowell	William Wraith
1919	R. V. Norris	C. H. MacDowell	C. W. Stimpson
1920	R. V. Norris	G. M. Davidson	G. T. Hansen
1921	R. V. Norris	L. V. Rice	G. T. Hansen
1922	R. V. Norris	A. D. Terrell	H. M. Adkinson
1923	R. V. Norris	A. D. Terrell	H. M. Adkinson
1924	R. V. Norris	John A. Garcia	A. B. Young
1925	R. V. Norris	William R. Wright	Robert S. Lewis
1926	R. V. Norris	C. C. Whittier	J. C. Dick
1927	R. V. Norris	A. C. Noe	Otto Herres, Jr.
1928	R. V. Norris	William A. Scheuch	Ernest Gayford
1929	Charles F. Huber	Wilfred Sykes	J. M. Boutwell
1930	Paul Sterling	G. E. Johnson	J. A. Norden
1931	Paul Sterling	E. T. Lednum	Robert Wallace
1932	Eli T. Conner	C. T. Hayden	G. W. Crane
1933	Eli T. Conner	J. R. Van Pelt, Jr.	B. L. Sackett
1934	E. E. Hobart	Gustav Egloff	C. T. Van Winkle
1935	B. H. Stockett	D. L. Colwell	W. J. O'Conner
1936	John C. Haddock	R. G. Bowman	E. A. Hamilton
1937	C. A. Gibbons	George Birkenstein	James W. Wade
1938	A. B. Jessup	W. E. Jewell	E. W. Engelmann
1939	R. Y. Williams	A. C. Carlton	W. R. Landwehr
1940	H. H. Otto	W. E. Brewster	Rollin A. Pallanch
1941	W. H. Lesser	T. B. Counselman	D. D. Moffat
1942	Wilmot C. Jones	B. E. Sandell	L. A. Walker
1943	S. H. Ash	H. M. St. John	Richard A. Wagstaff
1944	Evan Evans	George P. Halliwell	Adolph Soderberg
1945	L. D. Lamont	J. E. Drapeau, Jr.	Burt B. Brewster
1946	W. C. M. Butler	A. S. Nichols	Ernest Klepetko
1947	Harry W. Montz	Hjalmar W. Johnson	William H. H. Cranmer

TABLE 2—(*Continued*)

Year	*Arizona* Founded July 10, 1915	*Nevada* Founded Jan. 21, 1916	*Mid-Continent* Founded Dec. 28, 1917
1916	Gerald F. Sherman	J. W. Hutchinson	
1917	P. G. Beckett	J. W. Hutchinson	
1918	P. G. Beckett	R. E. H. Pomeroy	Alfred G. Heggem
1919	L. O. Howard	R. E. H. Pomeroy	J. J. Rutledge
1920	W. G. McBride	R. E. H. Pomeroy	M. J. Munn
1921	Charles A. Mitke	John J. Kirchen	M. M. Valerius
1922	Charles A. Mitke	John J. Kirchen	H. B. Goodrich
1923	Charles A. Mitke	R. A. Hardy	W. R. Hamilton
1924	Charles A. Mitke	R. A. Hardy	J. O. Lewis
1925	Charles A. Mitke	R. A. Hardy	John M. Lovejoy
1926	Charles A. Mitke	R. A. Hardy	Frank A. Herald
1927	Robert E. Tally	R. A. Hardy	A. W. Ambrose
1928	Robert E. Tally	J. A. Carpenter	C. V. Millikan
1929	E. P. Mathewson	J. A. Carpenter	L. G. E. Bignell
1930	E. P. Mathewson	J. A. Carpenter	H. H. Power
1931	E. P. Mathewson	J. A. Carpenter	Harry E. Wright
1932	E. P. Mathewson	J. A. Carpenter	Clarel B. Mapes
1933	E. P. Mathewson	J. A. Carpenter	H. H. Wright
1934	E. P. Mathewson	Ott F. Heizer	L. L. Foley
1935	E. P. Mathewson	Alfred Merritt Smith	L. A. Ogden
1936	E. P. Mathewson	Jesse A. Woolf	C. C. Robbins
1937	E. P. Mathewson	Walter S. Palmer	C. H. Keplinger
1938	F. A. Wardlaw, Jr.	W. I. Smyth	K. A. Covell
1939	F. A. Wardlaw, Jr.	William Vanderburg	A. W. Walker
1940	Brent N. Rickard	Roy A. Hardy	P. E. Fitzgerald
1941	Robert W. Thomas	Leonard Larson	H. F. Beardmore
1942	Robert W. Thomas	Percy G. Dobson	John A. McCutchin
1943	Robert W. Thomas	Paul J. Sirkegian	R. G. Hamilton
1944	Robert W. Thomas	R. S. Moehlman	Stanley W. Wilcox
1945	Robert W. Hughes	Paul Gemmill	Lloyd E. Elkins
1946	Charles R. Kuzell	Erich J. Schrader	W. B. Berwald
1947	Charles R. Kuzell	Charles W. Davis	P. P. Manion, Jr.

TABLE 2—(*Continued*)

Year	*Washington D. C.* Founded June 21, 1918	*Pittsburgh* Founded 1920	*Ohio Valley* Founded Nov. 19, 1920
1919	Herbert Hoover		
1920	Dorsey A. Lyon	Fred Crabtree	H. M. Boylston
1921	E. A. Holbrook	Fred Crabtree	H. M. Boylston
1922	Sidney Paige	Fred Crabtree	Zay Jeffries
1923	Tasker L. Oddie	Graham Bright	D. B. Quarrie
1924	George S. Rice	Graham Bright	H. M. Boylston
1925	George S. Rice	Graham Bright	H. M. Boylston
1926	Clarence T. Starr	Graham Bright	H. M. Boylston
1927	Frank L. Hess	Graham Bright	H. M. Boylston
1928	William M. Corse	W. A. Weldin	H. M. Boylston
1929	G. K. Burgess	W. A. Weldin	F. B. Richards
1930	Scott Turner	W. A. Weldin	C. B. Murray
1931	Howard I. Smith	James Aston	C. B. Murray
1932	Matthew van Siclen	James Aston	C. B. Murray
1933	Charles W. Wright	James Aston	Clyde Williams
1934	Myron K. Walker	James Aston	Clyde Williams
1935	J. H. Hedges	E. H. Dix, Jr.	H. E. Lewis
1936	J. Nelson Nevius	E. H. Dix, Jr.	H. E. Nold
1937	W. T. Schaller	K. C. Heald	Julian E. Tobey
1938	Julian D. Conover	K. C. Heald	Byron M. Bird
1939	John W. Finch	E. A. Holbrook	C. E. MacQuigg
1940	Samuel P. Hatchett	E. A. Holbrook	C. R. FonDersmith
1941	Robert H. Ridgway	Howard Scott	R. F. Stilwell
1942	Carl E. Julian	Howard Scott	Bruce W. Ganser
1943	William H. Wagner	Howard Scott	W. W. Heimberger
1944	Henry Curtis Morris	Henry C. Rose	S. L. Hoyt
1945	Albert W. Dickinson	Henry C. Rose	Byron M. Bird
1946	Elmer W. Pehrson	Henry C. Rose	Byron M. Bird
1947	Cloyd M. Smith	Linwood Thiessen	George W. White

TABLE 2—(*Continued*)

	Minnesota	*Upper Peninsula*	*Oregon*
Year	Founded Dec. 20, 1920	Founded Jan. 28, 1921	Founded Apr. 22, 1921
1921	W. R. Appleby	William Kelly	H. M. Parks
1922	W. R. Appleby	William Kelly	H. M. Parks
1923	W. R. Appleby	William Kelly	H. W. Elmer
1924	Samuel E. Atkins	William Kelly	George C.Hogg
1925	Frank Hutchinson	William Kelly	Frank W. Watson
1926	Harry C. Dudley	William Kelly	Frank W. Watson
1927	Harry C. Dudley	William Kelly	Charles E. Newton
1928	Hugh M. Roberts	William Kelly	Charles E. Newton
1929	E. E. Hunner	William Kelly	F. S. Cook
1930	W. R. Van Slyke	William Kelly	R. M. Betts
1931	J. A. MacKillican	William Kelly	William B. Dennis
1932	Carl Zapffe	William Kelly	Pierre R. Hines
1933	T. L. Joseph	W. O. Hotchkiss	J. H. Batcheller
1934	M. C. Lake	W. O. Hotchkiss	J. H. Batcheller
1935	W. W. J. Croze	W. O. Hotchkiss	J. H. Batcheller
1936	E. H. Comstock	R. S. Archibald	Herbert F. Byram
1937	W. L. Taylor	R. S. Archibald	F. W. Watson
1938	P. G. Harrison	R. S. Archibald	Ira S. Allison
1939	J. Murray Riddell	G. R. Jackson	Earl K. Nixon
1940	Odin A. Sundness	G. R. Jackson	S. H. Williston
1941	J. Wilbur Van Eversa	G. R. Jackson	L. W. Staples
1942	Robert D. Longyear	G. R. Jackson	F. W. Libbey
1943	S. E. Atkins	G. R. Jackson	John Elliot Allen
1944	Carl J. Calvin	G. R. Jackson	A. M. Dixon
1945	Russell H. Bennett	Rudolph Ericson	L. L. Ruff
1946	R. H. B. Jones	Rudolph Ericson	Mason L. Bingham
1947	R. W. Whitney	Waldemar A. Knoll	Ralph S. Mason

TABLE 2—(*Continued*)

Year	*Philadelphia* Founded 1922	*Lehigh Valley* Founded Mar. 27, 1924	*Tri-State* Founded May 27, 1926
1922	Henry S. Drinker		
1923	Henry S. Drinker		
1924	Henry S. Drinker		
1925	Richard Peters, Jr.		
1926	Richard Peters, Jr.	W. B. Plank	
1927	Richard Peters, Jr.	W. L. Cumings	
1928	Richard Peters, Jr.	W. L. Cumings	C. O. Anderson
1929	Richard Peters, Jr.	E. H. Bunce	C. N. Anderson
1930	Richard Peters, Jr.	B. L. Miller	George M. Fowler
1931	Richard Peters, Jr.	J. F. Magee	George M. Fowler
1932	Richard Peters, Jr.	W. M. Peirce	George M. Fowler
1933	Richard Peters, Jr.,	Allison Butts	L. G. Johnson
1934	Richard Peters, Jr.	A. H. Fay	L. G. Johnson
1935	Richard Peters, Jr.	E. A. Anderson	C. F. Williams
1936	Richard Peters, Jr.	H. A. Reichenbach	S. S. Clarke
1937	Richard Peters, Jr.	E. C. Waite	S. S. Clarke
1938	Richard Peters, Jr.	L. J. Boucher	H. H. Utley
1939	Richard Peters, Jr.	A. D. Shankland	S. S. Clarke
1940	Richard Peters, Jr.	J. W. Stewart	C. W. Nicolson
1941	Inactive	R. K. Waring	C. W. Nicolson
1942		Charles H. Herty	F. J. Cuddeback
1943		A. C. Callen	Victor C. Allen
1944		L. F. Witmer	G. E. Abernathy
1945	H. B. Allen	D. C. Jillson	A. J. Martin
1946	T. A. Read	J. H. Frye, Jr.	A. J. Martin
1947	Ralph W. E. Leiter	W. S. Cumings	O. W. Bilharz

TABLE 2—(*Continued*)

Year	*El Paso Metals* Founded Mar. 25, 1927	*Wyoming* Founded May 16, 1930	*Gulf Coast* Founded Dec. 13, 1935
1928	David Cole		
1929	David Cole		
1930	David Cole	Arthur S. White	
1931	Brent N. Rickard	Arthur S. White	
1932	Brent N. Rickard	J. E. Edgeworth	
1933	Earl R. Marble	F. V. Vicks	
1934	Earl R. Marble	F. V. Vicks	
1935	John F. Graham	W. T. Nightingale	
1936	John G. Barry	W. T. Nightingale	T. V. Moore
1937	John W. Kidd	Glen A. Knox	W. V. Vietti
1938	L. G. Hetrick	George B. Pryde	C. A. Warner
1939	W. P. Schumacher	George B. Pryde	M. T. Halbouty
1940	Homer C. Hirsch	George B. Pryde	Charles M. Langford
1941	E. M. Thomas	R. P. Hogan	J. U. Teague
1942	Frank P. Thomas	I. N. Bayless	Stuart E. Buckley
1943	Paul B. Lord	I. N. Bayless	James H. Bugbee
1944	William Knowles	V. D. Murray	Irwin W. Alcorn
1945	R. S. Beard	V. D. Murray	Morton T. Higgs
1946	R. D. Bradford	George B. Pryde	Mercer H. Parks
1947	A. A. Brown	H. C. Livingston	Harold Decker

Year	*Detroit* Founded Feb. 18, 1936	*Southeast* Founded Feb. 18, 1936	*Cleveland* Founded Apr. 17, 1936
1936	H. M. St. John	H. S. Salmon	
1937	H. M. St. John	C. L. Bransford	K. H. Donaldson
1938	H. M. St. John	Karl Landgrebe	Charles J. Junge
1939	E. B. Drake	A. J. Blair	Louis W. Kempf
1940	Alvin J. Herzig	J. R. Cudworth	M. D. Harbaugh
1941	Alvin J. Herzig	T. C. DeSollar	E. C. Knuth
1942	M. L. Frey	Richard L. Bowron	L. W. Eastwood
1943	Adam MacKenzie	Russell S. Poor	H. A. Schwartz
1944	Ernest Kirkendall	G. Ross Armstrong	W. P. Sykes
1945	George A. Timmons	John W. Hager	George Sachs
1946	George A. Timmons	Percy G. Cowin	W. F. Aylard
1947	D. Z. Dailey	Walter B. Jones	Edward J. Vargo

Table 2—(*Continued*)

	Rio de Janeiro	*Black Hills*	*Philippines*
Year	Founded Apr. 17, 1936	Founded Dec. 18, 1936	Founded Jan. 20, 1939
1937	O. H. Leonardos	E. G. Ross	
1938	O. H. Leonardos	J. P. Connolly	
1939	O. H. Leonardos	L. B. Eames	W. F. Boericke
1940	O. H. Leonardos	Nathaniel Herz	E. W. Ellis
1941	O. H. Leonardos	Bancroft Gore	Charles A. Mitke
1942	Inactive	N. P. Goodrich	A. F. Duggleby
1943		A. J. M. Ross	Inactive
1944		F. C. Lincoln	
1945		F. C. Lincoln	
1946		A. I. Johnson	
1947	E. de Macedo Soares S.	Edward L. Tullis	
	East Texas	*Central Appalachian*	*North Texas*
Year	Founded Apr. 18, 1940	Founded Oct. 17, 1940	Founded May 16, 1945
1940	N. N. Jones		
1941	N. N. Jones	Veleair C. Smith	
1942	A. S. Rhea	Robert H. Morris	
1943	R. W. Erwin	L. I. Cothern	
1944	John S. Bell	George E. Keller	
1945	Robert M. Hess	E. R. Price	
1946	Riley A. Aucoin	A. S. Shoffstall	John H. Murrell
1947	Thomas C. Frick	James A. Hagy	Gordon H. Fisher
	Permian Basin	*Carlsbad Potash*	*Delta*
Year	Founded Nov. 14, 1945	Founded Sept. 18, 1946	Founded Sept. 18, 1946
1946	Eugene Fisher		
1947	E. B. Armstrong	H. H. Bruhn	Dan L. Marshall
	Southwest Texas	*Oklahoma City*	
Year	Founded Sept. 18, 1946	Founded Feb. 18, 1947	
1947	Paul R. Turnbull	David L. Dooley	

TECHNICAL COMMITTEES

At the meeting of the Council on March 22, 1912, a special committee was appointed to consider the formation of an "Iron and Steel Section" of the Institute, and at the April meeting in that year the establishment was authorized of an "Iron and Steel Division . . . its business to be in charge of a committee upon which shall rest the responsibility of securing papers and discussions on iron and steel for the meetings of the Institute." Such a committee, under the chairmanship of Charles Kirchhoff, thereupon was appointed by President James F. Kemp.

Although the term "Division" was used, the agency actually had no organizational resemblance to the Divisions that later were established. On the other hand, in form and function, it was the prototype of the Technical Committees that soon were to become highly important in the Institute's affairs.

At the September meeting of that year a committee under the chairmanship of Benjamin B. Thayer was appointed to report on the desirability of establishing a separate committee "to cover the field of precious and base metals." A favorable recommendation, made at the meeting of the Council on January 23, 1914, was followed by the appointment of a committee with Charles W. Goodale as chairman. The Year Book issued on April 1, 1914, shows the following "standing" Technical Committees:

Committee (1914)	Chairman
Iron and Steel	Albert Sauveur
Precious and Base Metals (five subcommittees)	Charles W. Goodale
Mining Geology	James F. Kemp
Mining Methods	David W. Brunton
Nonmetallic Minerals	Heinrich Ries
Coal and Coke	H. M. Chance
Mining Law	Horace V. Winchell
Petroleum and Gas	Anthony F. Lucas
Use of Electricity in Mines	William Kelly

Incidentally, of the chairmen listed, four were destined to become presidents of the Institute; two were later to be made honorary members; and another was to have one of the Institute's major medals (Lucas Petroleum Medal) named in his honor. Also, it is highly significant that four of these committees eventually developed into Divisions: Iron and Steel, Nonmetallic Minerals, Coal and Coke, and Petroleum and Gas. In 1923, the following were on the roster:

Extraction and Refining of Precious Metals (Cyanidation)
Reduction and Refining of Zinc
Ground Movement and Subsidence
Mining Equipment
Industrial Relations—later abolished.

Technical committees, as shown in the Directory for 1947, are as follows:

1. Mining Methods
2. Mining Geology
3. Geophysics
4. Health and Safety in Mines
5. Reduction and Refining of Lead and Zinc
6. Reduction and Refining of Aluminum and Magnesium
7. Reduction and Refining of Copper
8. Reduction of Ferroalloy Ores
9. Milling Methods
10. Mineral Economics
11. Research
12. Eastern Magnetite Mining and Milling Methods

Briefly, the function and responsibility of a Technical Committee has been to follow carefully developments in the field that it represents; to post itself on new methods, new techniques, new processes, and new equipment; and to arrange for the writing of appropriate papers, by men competent to speak authoritatively, so as to provide a continuing record of significant progress in the art.

Primary responsibility for the programs at Annual and Regional Meetings and, consequently, for the contents of the TRANSACTIONS, rests with the Technical Committees, shared, of course, with the Professional Divisions. It should be noted that whereas the chairman of a Technical Committee does not enjoy authority to accept a paper for publication, it is his prerogative to place a paper on a program sponsored by his committee at annual or regional meetings; and that all papers thus presented are eligible for consideration by the Papers and Publications Committee for publication in the TRANSACTIONS.

The rosters of the technical committees have generally contained the names of the most competent and best recognized authorities in their respective fields. The Committees, as distinguished from Divisions, represent somewhat more than half of the Institute's membership classified on the basis of major technologic and engineering interest—the groups concerned with finding, winning, and treatment of metalliferous ores, and the economics of the metal industries.

PROFESSIONAL DIVISIONS

Article XVII of the Bylaws, as adopted on February 18, 1913, contained specific provisions for the functioning of "professional groups to be known as Divisions of the Institute and to be organized from its members." Section 1 of this article provided that "any member of the Institute may register for membership in any Division in which he is interested." However, it was not until 1918 that the first Division was formally organized under the terms of this article. The occasion was the absorption by the A.I.M.E. of the American Institute of Metals.

In 1907, a group of technical men in Philadelphia organized the American Brass Founders Society. Five years later the name was changed to the American Institute of Metals. The expressed purpose was "the advancement and dissemination of knowledge concerning the acts connected with the producing, founding, working and finishing of the nonferrous metals and their alloys," objectives that obviously paralleled, in general, some of those of the A.I.M.E. In 1918, an invitation was extended to the A.I.M. by the A.I.M.E. to join forces; and the procedure proposed was for the American Institute of Metals to become the Institute of Metals Division of the A.I.M.E.

Consummation of this program was authorized at the meeting of the Board on April 26, 1918; and thus was established the first Professional Division.

Each of the other five Divisions grew out of, and took over the functions of, an antecedent Technical Committee, the dates of establishment being indicated in Table 3, which lists the chairmen for the ensuing years. The technologic fields for which the respective Divisions have assumed responsibility are described briefly as follows:

Institute of Metals Division

Fundamental theory regarding nonferrous metals and alloys; the founding, alloying, fabricating, metallography and engineering uses of these metals and alloys.

Petroleum Division

Production engineering, production geology, geophysics, engineering research, refinery engineering, statistics and economics—all as related to petroleum and natural gas.

Iron and Steel Division

Production of pig iron and making of steel; the founding, alloying, fabricating, metallography and engineering uses of iron and its alloys.

Coal Division

Development and mining of coal deposits; engineering, mechanization, preparation, handling, and use of coal; "solid fuel" technology; and the economics of coal.

Mineral Industry Education Division

Educational problems relating to all branches of engineering and technology in the fields covered by the A.I.M.E.

Industrial Minerals Division

Development, mining, beneficiation, processing, utilization and economics relating to a large group of industrial minerals that includes all useful nonmetallic minerals other than the fuels.

Today the Bylaws of the Institute respecting Divisions are in essential respects identical with those formulated in 1913. Among other things, they provide that the Division shall be governed by a chairman, one or more vice chairmen, a secretary-treasurer, and an executive committee of which the officers shall be members *ex officiis*. All shall be elected annually by the Institute members that have indicated their desire to be members of the Division involved. Further provisions are:

> "A Division shall have the right to make rules for its own government, subject to the approval of the Board of Directors, not inconsistent with the Constitution and Bylaws of the Institute. The Board of Directors shall have the right to amend, annul, or add to these rules.

Until the end of 1945 the membership of each Division was regarded as being those who had signified their desire to obtain the TECHNICAL PUBLICATIONS (pamphlets, called T.P.'s) coming under the "classification" sponsored by the Division. These recorded "choices" provided the lists of members to

TABLE 3—*Past and Present Chairmen of Divisions*

Year	Institute of Metals Division	Petroleum Division	Iron and Steel Division	Coal Division	Mineral Industry Education Division	Industrial Minerals Division
1918	W. M. Corse					
1919	W. M. Corse					
1920	W. H. Bassett					
1921	W. H. Bassett					
1922	W. B. Price	Ralph Arnold				
1923	W. B. Price	E. DeGolyer				
1924	G. K. Elliott	E. DeGolyer				
1925	G. K. Elliott	F. Julius Fohs				
1926	Paul D. Merica	F. Julius Fohs				
1927	Paul D. Merica	John M. Lovejoy				
1928	S. Skowronski	A. W. Ambrose	Ralph H. Sweetser			
1929	S. Skowronski	J. B. Umpleby	G. B. Waterhouse			
1930	Zay Jeffries	C. V. Millikan	W. J. MacKenzie	H. N. Eavenson		
1931	Sam Tour	C. E. Beecher	F. M. Becket	H. N. Eavenson		
1932	C. H. Mathewson	Earl Oliver	F. N. Speller	Thomas G. Fear	C. H. Fulton	
1933	T. S. Fuller	W. E. Wrather	John Johnston	Eli T. Conner	C. H. Fulton	
1934	J. L. Christie	H. D. Wilde, Jr.	L. F. Reinartz	Eli T. Conner	T. T. Read	
1935	W. M. Peirce	Harry H. Power	A. B. Kinzel	John T. Ryan	T. T. Read	S. H. Dolbear
1936	E. H. Dix, Jr.	Hallan N. Marsh	Clyde Williams	E. McAuliffe	W. B. Plank	Oliver Bowles
1937	A. J. Phillips	M. Albertson	Francis B. Foley	J. B. Morrow	W. B. Plank	Chester A. Fulton
1938	R. F. Mehl	G. B. Corless	J. T. MacKenzie	Paul Weir	F. A. Thomson	J. R. Thoenen
1939	R. H. Leach	W. H. Geis	J. Hunter Nead	C. A. Gibbons	F. A. Thomson	M. M. Leighton
1940	E. M. Wise	T. V. Moore	F. T. Sisco	C. E. Lawall	W. R. Chedsey	W. M. Weigel
1941	D. K. Crampton	E. A. Stephenson	C. H. Herty, Jr.	Julian E. Tobey	W. R. Chedsey	Paul M. Tyler
1942	Carl E. Swartz	Harry P. Stolz	E. C. Smith	Newell G. Alford	A. F. Greaves-Walker	B. L. Miller
1943	Cyril Stanley Smith	C. A. Warner	Herbert W. Graham	C. Evans, Jr.	A. F. Greaves-Walker	Howard I. Smith
1944	Arthur Phillips	W. S. Morris	William A. Haven	A. W. Gauger	A. C. Callen	C. H. Behre, Jr.
1945	E. E. Schumacher	M. L. Haider	Erle G. Hill	L. A. Shipman	E. A. Holbrook	B. C. Burgess
1946	L. W. Kempf	H. F. Beardmore	W. E. Brewster	Henry F. Hebley	J. R. Cudworth	O. C. Ralston
1947	E. A. Anderson	Howard C. Pyle	T. S. Washburn	Evan Evans	J. R. Cudworth	J. L. Gillson

whom were mailed ballots, programs, and other communications directed to the members of any Division.

However, effective in 1946, the basis of distribution of T.P.'s was restricted so that the member was obliged to make an extra payment for "classifications" in excess of a prescribed maximum. Because of this circumstance and because some of the Divisions had requested it, a special poll, designed to determine the membership of the Divisions, was conducted, beginning in January 1946. The poll had a dual objective, to ascertain: (1) the primary or major technical interest of the member, whether this lay in the field of one of the Divisions or in the "un-Divisionalized" group; and (2) the Division or Divisions (as many as desired) with which the member chose to be affiliated.

In effect, the first poll showed the Division (if any) that the member would choose if he were strictly limited to a single major technologic field; the second poll showed the Divisions with which he desired affiliation even though his interest were secondary or casual. Table 4 shows the data, based on the poll.

Analyzing the figures in the second column, it is evident that about 20 per cent of the members are primarily interested in the work of the two Metals Divisions and at least 17 per cent in the field of the Petroleum Division. These data suggest why, in 1936, a new Assistant Secretary of the Insti-

TABLE 4—*Approximate Divisional Membership, 1946*

Division	Percentage of Total A.I.M.E. Membership	
	Based on "Multiple" Selections—All Interests	Based on "Single" Selection—Major Interest
Institute of Metals	28.9	7.8
Petroleum	19.0	17.1
Iron and Steel	17.4	11.3
Industrial Minerals	15.7	3.0
Coal	8.9	7.0
Education	6.7	0.5
Un-Divisionalized group—Mining Geology, Metal Mining, Ore Dressing, Nonferrous Smelting, and Hydrometallurgy		53.3
	96.6[a]	100.0

[a] This need not add to 100 because many members made no Divisional selections. On the other hand, many made two, three, or even more selections.

tute was engaged to devote most of his time to the two Metals Divisions; and why, two years later, a similar arrangement was made for the Petroleum Division. The occupants of these positions have been specialists in the technology of their particular fields; and they have contributed greatly to effectiveness of the work of the Divisions.

Two conflicting conceptions of the status of the Professional Division within the Institute have developed. These may be designated as (1) the "federation" and (2) the "instrumentality" conceptions.

Under the first conception, the individual is regarded as being primarily a member of Division M (for example). He owes allegiance first to his Division; but because Division M has some things in common with the other Divisions, they all participate in a sort of federated body called the A.I.M.E. Under the extreme view, the Division would collect its own dues, conduct its own meetings, manage its own finances, publish its own papers, and run its own office—in short, function as an independent organization with little in common with the other Divisions except that all would jointly elect a president of the Institute and cooperate in matters of broad common interest.

Under the second conception, the individual is regarded as being primarily a member of the A.I.M.E.; and to it he owes first allegiance. The Division is a convenient instrumentality through which the Institute performs, more effectively than it otherwise could, important functions in a specific technologic field. The Division elects its own officers, enjoys such autonomy as is needed to organize meetings and programs of various kinds and operates chiefly with funds from the general treasury and entirely within the framework of the general organization.

MEMBERSHIP

Although at the first meeting of the Institute, held in 1871, a distinction was drawn between "Members" and "Associates," based on the "professional" attainments of the individual in technology and engineering, it was not until 1928 that specific qualifications for the status of Member were written into the Bylaws. The "Rules" adopted in 1873 provided that:

> "The Institute shall consist of Members, Honorary Members, and Associates. Members, and Honorary Members shall be professional mining engineers, geologists, metallurgists or chemists, or persons practically engaged in mining, metallurgy or metallurgical engineering."

When the new Constitution of 1913 was adopted, the phraseology was improved somewhat and the last clause was amended to read "and all persons actively (instead of practically) engaged in mining and metallurgical engineering, geology, or chemistry."

Alleged laxity in interpreting or administering the "Rules," with the resultant enrollment as members of persons who they felt were not properly qualified professionally, led a small group of members to organize the Mining and Metallurgical Society of America, in April 1908. They declared that, "because of its catholicity and liberality in admitting members" A.I.M.E. had ceased to be a professional society! These protestants did not withdraw from the Institute; they simply set up a second society composed of what they frankly designated the "professional aristocracy"—the upper crust of the membership of the A.I.M.E. Many engineers of distinction declined repeated invitations to become members on the ground that the Institute could and should perform all necessary functions; and in its efforts to grow in size, the M. and M. Society dug far below the crust to obtain members. Several attempts to effect a merger or consolidation with the A.I.M.E. have been made. A joint committee representing both organizations deliberated on a proposal for "affiliation" late in 1912 and again in 1918. A detailed plan for reapproachment was developed in 1932; but nothing came of these negotiations and the Society, with 400 members, is active today. It is fair to say that the existence of the Society has had a wholesome effect on the membership standards of the A.I.M.E.

Qualifications for Member of the A.I.M.E., set forth in the Bylaws as revised in 1928 and still in effect, are as follows:

> "A person to be eligible for election or transfer into the class of Member must be at least 27 years of age and must have had at least six years' employment in the practice of engineering, mining, geology, metallurgy, or chemistry during at least three of which he must have held positions of responsibility in one or more of these fields."

On paper these qualifications are not as exacting as those required by some professional societies of comparable character in the United States and abroad; on the other hand, they are more rigid than those of many others.

Obviously, much depends on the attitude and policy of the Committee on Admissions—for example, the interpretation placed on the phrase "positions of responsibility" gives the Committee wide latitude. Particularly in recent years, the Admissions Committees have set high standards in this respect and the status of "Member A.I.M.E." is widely accepted as indicating broad experience and a high degree of competence as well as professional integrity.

The desirability of providing a place in the Institute membership for individual undergraduate students in mining or other mineral industry schools was recognized first in 1918. The Constitution, as amended on February 19, 1918, provided: "Junior Associates shall comprise all students in good standing in engineering schools who have not taken their degree." The phrasing is rather inept; it would be more sensible to say that all such students are eligible. However, during the succeeding 10 years several thousand students have enrolled as Junior Associates, incidentally paying dues of $5 per year. The arrangement did not meet the situation as well as had been hoped, and in 1929 Junior Associateship was abolished (those then on the roll being allowed to continue for a maximum period of six years) and two new classes were established: Student Associate and Junior Member.

Student Associateship is open to all "students of good standing in an approved school" and the individual can continue in this status during the full calendar year following the year in which he "ceases to be in University residence as a student." Student Associates are expressly excluded from the category of member; but they are listed individually in the A.I.M.E. DIRECTORY, they are supplied with specified Institute publications—usually MINING AND METALLURGY—and are accorded various other privileges, including that of purchasing all publications at special member prices. Dues for Student Associates are only $2 per year, a sum that does not cover the cost to the Institute of serving them. However, the money expended to subsidize Student Associates is regarded as being the best possible investment. Aptly, they have been called the "ore reserves" of the Institute; and from their number will surely come the bulk of future members. The greater the enrollment of Student Associates, the better the outlook for the Institute's future.

Junior Membership was established to provide an intermediate stage between Student Associate and Member. Few young men are able at the expiration of their last allowable year as Student Associate to meet the requirements of "full" membership. However, they can qualify as Junior Member—competent to "hold a subordinate position in engineering, mining, metallurgical, geological, or chemical work."

A Junior Member is permitted to continue as such for six years, or until he reaches the age of 33, without payment of any initiation fee and with annual dues of only $10. He enjoys every privilege of a Member except the right to vote. The purpose of making Junior Membership available was to provide a convenient and attractive transition, without imposing undue financial burden, from Student Associate to Member; and the results have been up to expectations.

In 1935, as the outgrowth of a special reciprocal arrangement with the Iron and Steel Institute and the Institute of Metals (both of Great Britain), the status of Junior Foreign Affiliate was created. It permits younger members of these two British institutes to enjoy limited privileges of the A.I.M.E. at the low rate of $5 per annum for a maximum period of six years.

Life Membership may be acquired by any member by paying a lump sum in lieu of future annual dues. In 1873, the cost was $100; in 1913, it was increased to $150; in 1923 to $225; and in 1941 to $300. Obviously, on an actuarial basis a life membership taken at the age of 27 is a pretty good purchase—and some of those who "bought" before 1900 and are still active are sure they got the bargain of their lives!

From 1871 to 1916 the dues of Members and Associates were $10 per annum. Effective in 1917 the dues of both Members and Associates were increased to $12 and effective in 1921 the dues of Members were increased to $15. Not until 1929 were the dues of Associates increased to match those of Members and both remain at this level to the present time.

Junior Membership was established in 1928 and the dues were then fixed at $10 per annum for the first six years to be increased automatically at the end of that time to $15 per annum. In 1944, the Bylaws were amended to provide that an increase from $10 to $15 be made either at the end of six years or upon reaching the age of 33, whichever came first.

An initiation fee was first established to take effect in 1904, the amount to be $10 for both Members and Associates. In 1921, the initiation fee was increased to $20 for both groups. At the start (in 1928) an initiation fee of $10 was fixed for Junior Members. However, in 1934, it was provided that a Junior Member who paid the initiation fee would be credited with $10 on account of his initiation fee of $20 for which he would become liable on change of status from Junior Member to Member. In 1944, the initiation fee of Junior Members was abolished. It was likewise further provided that the Junior Member who had paid dues continuously for 10 years, either as a Student Associate or as a Junior Member (or both), would be exempt from any initiation fee upon change of status to Member.

Upon reaching the 50th anniversary of their joining the Institute—provided they have paid dues regularly—members have automatically joined the A.I.M.E. Legion of Honor. The insignia of the Legion are a handsome gold pin and a suitably engraved certificate. To date this honor has been accorded to 275, of whom nearly half still survive.

Honorary Membership, regarded by many as the highest recognition within the gift of the Institute, has been bestowed on 80 men of preëminent distinction in the engineering profession, many of them coming from foreign countries. First to be selected to honorary membership was the first president, David Thomas. Today, the procedure for nomination and election is formalized in detail; and precipitate action is not possible. Unanimous action by the Committee on Honorary Memberships and by the Directors present at the Board meeting that considers the Committee's recommendation is necessary. The maximum number of living Honorary Members is 20; the entire list appears on page 437.

Fig. 2 is a chart showing the trend of membership from 22 in 1871 to 14,119 at the end of 1946. Junior Associates and Student Associates are shown separately because their inclusion in the figures would distort the graph.

The reason for the sharp drop in Student Associate enrollment, from more than 4000 before World War II to only about 1000 in 1945, is that war service claimed thousands of young men who otherwise would have been enrolled in "mineral engineering" schools, and this left only meager student bodies to draw upon.

The sharp climb commencing in 1913 was the result of the activity of the first Membership Committee, appointed in 1911 with Charles Kirchhoff as chairman, the function of which "pertained solely to securing new applications for members," to quote the minutes. The peak reached in 1922 is generally attributed to enthusiasm generated by the presidency (of the Institute) of Herbert Hoover in 1920. A great many that became members in that year soon resigned or allowed themselves to be suspended for delinquency in dues. The decline that started in 1932 was caused by the "great depression." By 1936 "times" were better, and there started an expansion that has continued ever since. Also, in 1936, R. C. Allen, as Chairman of the Committee on Membership (Increase), introduced the idea of a very large committee with membership spread over the country; and Ralph H. Sweetser joined the paid staff of the Institute to serve as Secretary of the Committee for the first

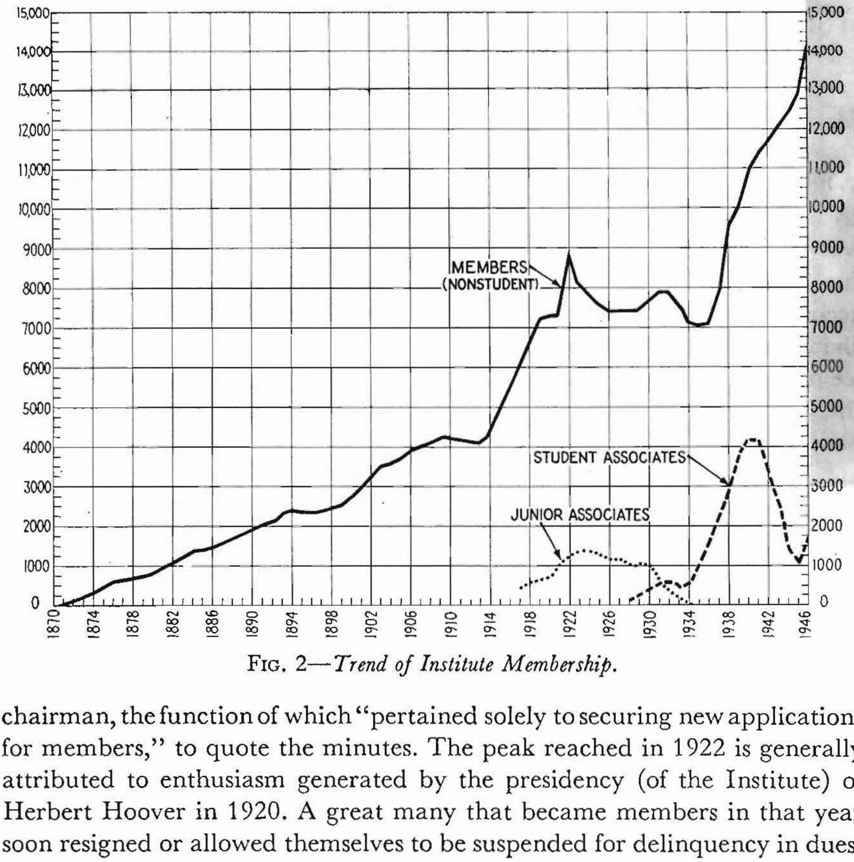

FIG. 2—*Trend of Institute Membership.*

HONORARY MEMBERS OF THE INSTITUTE

Year of Election		
1944	Walter Hull Aldridge	New York, N. Y.
1946	Peter M. Anderson	Johannesburg, South Africa
1946	Charles Camsell	Ottawa, Ont., Canada
1946	Charles Augustus Carlow	Fife, Scotland
1946	Cecil H. Desch	London, England
1946	William Fraser	London, England
1917	Herbert Hoover	New York, N. Y.
1941	Daniel Cowan Jackling	San Francisco, Calif.
1939	Henry Krumb	New York, N. Y.
1942	Essington Lewis	Melbourne, Vic., Australia
1921	C. McDermid	London, England
1944	Walter C. Mendenhall	Washington, D. C.
1942	Paul Dyer Merica	New York, N. Y.
1913	Ezequiel Ordoñez	Mexico City, Mexico
1938	A. M. Portevin	Paris, France
1937	George S. Rice	Washington, D. C.
1934	T. A. Rickard	Victoria, B.C., Canada
1946	John R. Suman	Houston, Texas
1946	Wong Wen-hao	Chungking, China

Year of Election		Year of Decease
1913	Frank Dawson Adams	1942
1876	Richard Akerman	1922
1909	Richard Beck	1919
1872	Sir Lothian Bell	1904
1944	Selwyn Gwillym Blaylock	1945
1921	William C. Blackett	1935
1923	Gelasio Caetani	1934
1905	Andrew Carnegie	1919
1938	Sir H. C. H. Carpenter	1940
1892	A. Del Castillo	1895
1902	Manuel Maria Contreras	1902
1929	Takuma Dan	1932
1888	A. Daubrée	1896
1888	Haton de la Goupilliere	1927
1935	Guillaume Daniel Delprat	1937
1906	James Douglas	1918
1920	Henry Sturgis Drinker	1937
1884	Thomas M. Drown	1904
1933	Karl Eilers	1941
1921	Ferdinand Foch	1929
1890	Moritz Gaetzschmann	1895
1922	Federico Giolitti	1946
1873	L. Gruner	1883
1906	Sir Robert A. Hadfield	1940
1928	John Hays Hammond	1936
1921	Frank William Harbord	1943
1888	Hans Hoefer	1924
1921	Heinrich O. Hofman	1924
1919	Robert W. Hunt	1923
1915	James Furman Kemp	1926
1891	Bruno Kerl	1905
1905	Henri LeChatelier	1936
1895	Joseph Le Conte	1901
1891	J. P. Lesley	1903
1931	Waldemar Lindgren	1939
1929	John Markle	1933
1899	Floris Osmond	1912
1890	Adolph Patera	1890
1935	Robert Peele	1942
1886	John Percy	1889
1888	Franz Posepny	1895
1909	Alexandre Pourcel	1934
1911	Rossiter W. Raymond	1918
1937	John V. W. Reynders	1944
1911	Robert H. Richards	1945
1884	Theodor Richter	1898
1899	Sir W. C. Roberts-Austen	1902
1933	Albert Sauveur	1939
1891	H. C. Emil Schroedter	1928
1890	Albert Serlo	1898
1880	C. William Siemens	1883
1906	John E. Stead	1923
1909	James M. Swank	1914
1872	David Thomas	1882
1928	William Boyce Thompson	1930
1902	Dimitry C. Tschernoff	1921
1873	Peter R. von Tunner	1897
1910	Tsunashiro Wada	1920
1907	Charles D. Walcott	1927
1885	Hermann Wedding	1908

year. The essential features of the plan have been continued and this fact no doubt has contributed to the steady growth.

PUBLICATIONS

The primary function of the A.I.M.E. is to provide a continuing, authoritative, and up-to-date printed record of technologic, engineering, and economic progress in all branches of the mineral industry. Members as individuals write the record; collectively, as an organization, they publish it.

In a sense, the major purpose of holding meetings is to stimulate the preparation of papers of the highest quality for publication. Other Institute activities are designed to increase its prestige in the profession and in the industries that engage the services of its members—but one of the important reasons for building prestige is to attract the best and most significant papers for publication.

Transactions and Technical Publications

As already indicated, the A.I.M.E. TRANSACTIONS had earned a world-wide reputation prior to 1911. Technologists and engineers everywhere esteemed them not only for their excellent physical format and outstanding editorial standards but for the superior quality of their content. A problem of those who succeeded Dr. Raymond was to maintain the standards of excellence that he had established.

Despite the expansion in scope and variety of technologic fields, and in volume of material, the publications of the Institute today rank among the best in the engineering world. The files of the Secretary's office contain many letters, particularly from foreign scientists and engineers, that attest this statement.

A fundamental requirement for maintaining high publication standards is an impartial and competent jury to pass upon papers, whether they be submitted voluntarily or as the result of solicitation. Incidentally, the two functions—solicitation and appraisal—always have been separated, for obvious reasons.

On September 24, 1911—the year marked by many procedural "reforms"—a Committee on Publications, consisting of 18 prominent members under the chairmanship of the Secretary of the Institute, Joseph Struthers, was appointed to consider and pass judgment on the acceptability of papers for publication.

The Bylaws of February 18, 1913, prescribed a procedure whereby each paper was to be referred to one or more "'Readers' most competent and available to pass upon it," selected from the members of the Committee, which was increased in size to about 50.

The so-called "Reader Routine" in use today is essentially the same procedure somewhat elaborated; the principal difference is that the Readers usually are chosen from outside the Committee, though not necessarily so. Every paper is automatically referred to at least two qualified readers. A significant difference in their opinions, as reported, is followed by reference to additional readers; and finally all comment and recommendations, prepared on printed forms, are put before the Committee as a basis for its disposition of the paper.

One important innovation in the work of appraising papers was adopted in 1942. At that time the committee consisted of 60 members. Normally about half attended monthly meetings and considered individually a long list of papers, including some in each of a dozen specialized fields. The procedure was cumbersome; responsibility was diluted; and results were haphazard. Under the new plan, seven subsidiary Publications Committees were appointed by the Board of Directors, one for each of the six Professional Divisions and a seventh to deal with papers on geology, metal mining, ore dressing, and smelting. The objective is decentralization on the basis of both geography and technologic field. The focal point for the seventh committee is Salt Lake City, where its meetings are held; the Coal Division group meets in Pittsburgh; the Industrial Minerals group in Washington, D.C.; and the Petroleum group in Tulsa, Oklahoma. These loci are, of course, subject to change at any time at the pleasure of the Board.

The subsidiary committees, having before them the "reader comment" have full authority to reject a paper; but a recommendation for acceptance must be approved by the "main" Papers and Publications Committee, now consisting of 15 members instead of 60. Lodging final authority in this single committee has as its purpose the maintenance of uniformity of standards and an equitable balance in the allotment of publication space and financial resources to various groups.

Up to 1927 all papers eligible for the TRANSACTIONS were published in "general" volumes. The first, appearing in 1873, contained papers for the two preceding years. Thereafter one volume was published each year until 1912, when the quantity of material made it desirable to divide it and issue two volumes. From that time until 1927, the publication program called for from two to four volumes annually; but they were still "general" volumes and no systematic attempt was made to segregate the material on the basis of the technologic fields to which the papers related. Every member was provided with all the volumes. In paper binding, they cost nothing above dues; but an extra charge of $1 per volume was made for half-morocco binding.

In 1927, a somewhat radical change was made, for which the main reasons were:

1. The rapid expansion in the flow of high-quality material from the fields covered by the Institute of Metals Division and the Petroleum Division, both of which were well established by that time; and from the Iron and Steel group, which was to expand from a Technical Committee to a Division in 1928.

2. The feeling that it was wasteful to send to all members a large quantity of published material dealing with subjects in which only a small proportion of them had more than a casual interest.

The plan evolved to meet these conditions was to segregate the material according to subject matter and to publish four, five, or six separate volumes each year. (Seven were published in 1934.) Since then there has been an annual volume each for the Petroleum, Institute of Metals, and Iron and Steel Divisions. During most of the time it has been the practice to publish a Coal volume in alternate years. Volumes containing the remaining material have been published at intervals, the length of which depended on the rapidity with which material accumulated. The list in Table 5 shows the operation of the plan.

Each member was privileged to receive his choice of one TRANSACTIONS volume each year without any payment beyond his regular dues; and to purchase a "first" copy of additional volumes at the member price of $2.50—the nonmember price being $5. Coincidentally, a procedure was adopted whereby the member could obtain without cost every published paper in the form of a pamphlet called a TECHNICAL PUBLICATION (T.P.). On the assumption that the typical member would have no desire to get all of the T.P.'s but would be content to receive regularly those dealing with a single technologic field, or perhaps two or three, the following classes were established:

Class	Subject
A	Metal Mining
B	Milling and Concentration
C	Iron and Steel
D	Nonferrous Metallurgy (Smelting and Refining)
E	Institute of Metals (Working, fabrication, properties, uses of nonferrous metal)
F	Coal
G	Petroleum (including Petroleum Geology)
H	Industrial Minerals (Nonmetallic Minerals)
I	Mining Geology
J	Mineral Industry Education
K	Mining Administration
L	Geophysics

At the beginning of the year each member would indicate the class or classes that he desired to receive, and all T.P.'s published under those classes would be mailed to him automatically as issued. A selective distribution was the result; but at the same time no member was deprived of getting a printed copy of any paper that he desired. Some designated practically the entire list, but the average was not more than two.

From the start in 1873, it has been the practice to run off a small supply of separate pamphlets, each containing one paper, for distribution at meetings, to facilitate and to encourage oral and written discussion. These separates, called "preprints," were superseded in 1928 by the T.P.'s.

TABLE 5—*Non-Divisional Transactions Volumes*

Year	Volume Number	Title
1928	79	Flotation Practice
1929	81	Geophysical Prospecting
	85	General
1930	87	Milling Methods
	91	General
1931	96	General
1932	97	Geophysical Prospecting
	102	General
1933	106	Copper Metallurgy
1934	109	Metal Mining and Nonmetallic Minerals
	110	Geophysical Prospecting
	112	Milling Methods
1935	115	Mining Geology
1936	121	Metallurgy of Lead and Zinc
1937	126	Mining Geology and Metal Mining
1938	129	Industrial Minerals
1939	134	Milling Methods
1940	138	Geophysics
	141	Metal Mining
1941	144	Mining Geology
1942	148	Industrial Minerals
1943	153	Metal Mining and Milling Methods
1944	159	Reduction and Refining of Nonferrous Metals
1945	163	Mining Practice
	164	Geophysics
1946	169	Milling and Concentration

In 1934, a further important step in the development of the present-day publication program was taken by establishing METALS TECHNOLOGY, a periodical magazine issued twice quarterly and consisting of current T.P.'s sponsored by the Institute of Metals Division, the Iron and Steel Division, and the Technical Committees that cover the reduction and refining of nonferrous ores. It was sent to those members who had designated classes C, D and E in the T.P. Series.

Two advantages of the plan were that the distribution of the T.P.'s was accomplished at regular and frequent intervals; and that some economy was effected, first in the Institute's shipping department by obviating the necessity of "picking up" and "enveloping" a large number of separate pamphlets; and second by obtaining the lower postage rates that apply to second-class matter.

So satisfactory was the experience with METALS TECHNOLOGY that three similar periodicals are now published:

MINING TECHNOLOGY—bi-monthly, established in 1937; containing T.P.'s in classes A, B, H, I, and K, and some in class L.

PETROLEUM TECHNOLOGY—bi-monthly, established in 1938; containing T.P.'s in class G and some in class L.

COAL TECHNOLOGY—quarterly, established in 1946; containing T.P.'s in class F.

Beginning with 1946, a significant change was made in the basis of distributing the TRANSACTIONS and TECHNOLOGYS, necessitated by the radical increases in publication costs of all kinds.

Prior to that time each member was entitled to "subscribe" to as many of the TECHNOLOGYS as he desired without cost, just as he had been accorded the privilege of an unlimited choice of T.P.'s. However, in 1946, following passage of an enabling amendment to the Bylaws, the plan described in the following paragraphs was put into effect:

Each Member, Junior Member or Associate, in addition to MINING AND METALLURGY, may have his choice of the year's subscription to one TECHNOLOGY, or, alternatively, a "first" copy of one volume of TRANSACTIONS. Additional subscriptions or additional "first" copies will cost $3. In order that the member can, without extra cost, receive everything published in at least one major technologic field, two changes in practice were necessitated:

1. Prior to that time some papers regarded as having less permanent value were published as T.P.'s but were not included in any TRANSACTIONS volume; under the new plan, every T.P. is assured publication in at least one TRANSACTIONS volume.

2. Formerly written discussion had been published only in TRANSACTIONS; the new plan provides that it appear in at least one of the TECHNOLOGYS.

It might be remarked that the amendments to the Bylaws did not make mandatory the restrictions on "free" distribution that have been outlined. Each December, the Board of Directors must prescribe the terms for the following year; and, if conditions warrant, a more liberal basis no doubt will be authorized.

The "Bulletin" and "Mining and Metallurgy"

Essential to the health and vigor of any membership organization is an organ—a periodical publication of some sort as a medium for letting the dues payers (or other financial supporters) know at reasonably short intervals what is going on. Chambers of Commerce, church societies, and labor unions find this to be true; and professional societies are not exceptional.

Recognition of this fact was the principal reason for establishing the A.I.M.E. BULLETIN in 1905. At the outset it was issued bi-monthly but beginning in 1908 it became a monthly. In addition to the technical or professional papers published by the Institute, each issue contained news reports and proceedings of meetings; lists of newly elected members and of candidates for membership; and various announcements and notices of general interest to members. The subscription fee to nonmembers was $10 per year; and to public libraries, educational institutions, and members, $5. However, with respect to members, this was a "book-keeping" charge in the form of an allocation from the regular dues. Naturally, the BULLETIN went to every member.

One other element not to be ignored in this connection is the financial revenue that can be derived from advertising in a periodical circulating among a group of representative engineers. For example, in January 1911 the BULLETIN contained 27 pages of advertising, including four pages of professional cards. In that year the income from advertising was $9,834.50!

In October 1919, the monthly BULLETIN was succeeded, nominally, by MINING AND METALLURGY, but the issue of January 1920 actually marked the establishment of a "regular" monthly magazine. Three significant departures were:

1. The format was changed from 6 by 9 inches to 8½ × 11½ inches, so as to accommodate standard advertising plates and otherwise to appeal to advertisers.

2. The technical papers that formerly constituted 95 per cent of the content of the BULLETIN were printed as separate pamphlets, still 6 by 9 inches, for distribution to members desiring them, and for subsequent publication in the TRANSACTIONS.

3. The editorial content of MINING AND METALLURGY was to consist largely of specially written articles that would not reappear in the TRANSACTIONS. The plan was to rely in large measure on papers presented at Local Section meetings. Many of these, deserving wide circulation, were "lost" under the former plan. The editorial announcing the "new" MINING AND METALLURGY concluded:

> "Although the plans for MINING AND METALLURGY are ambitious, it is not the intention to duplicate efforts or publications of others or attempt to do anything that any other paper is doing and doing well. The services of the Institute to its members are increasing and it is felt that this new magazine will add to these in number as well as detail. There is now but one of the Founder Societies publishing its Bulletin in the old inconvenient and inadequate 6 by 9 inches size devoted entirely to its technical papers and intra-society affairs."

MINING AND METALLURGY as a magazine has had a rather exciting career. It has been a bone of contention, and it has presented a difficult publishing problem, particularly since the Divisions have grown in size and in specialized importance.

Despite the policy expounded in the editorial just quoted, the magazine aspired at the start to compete aggressively for advertising with the *Engineering and Mining Journal* and the *Mining and Scientific Press* (of San Francisco, until it was purchased by the McGraw-Hill Company and combined with *Engineering and Mining Journal* in 1922). T. A. Rickard, as editor of the *Mining and Scientific Press*, complained bitterly that the competition with "private" publishing enterprise was unfair. He contended that the Institute should discontinue the soliciting of advertising for MINING AND METALLURGY—a contention that was almost equivalent to advocating that the periodical be killed. However, the increase in the number of successful society periodicals in the '20s and the general acceptance of them was an effective, if not a logical, answer to this argument.

In 1943, serious consideration was given by the Institute itself to abolishing MINING AND METALLURGY and to developing the three TECHNOLOGYS (COAL TECHNOLOGY did not then exist) into full-fledged magazines, each to contain news of the industry and the profession, editorials and "general interest" material of the kind published in MINING AND METALLURGY, together with technical articles in its special field and advertising related to that field. A special committee, composed of C. H. Mathewson, Erle V. Daveler and Paul D. Merica, gave long and earnest consideration to this proposal and to others involving the future of the magazine.

The conclusion reached, and later adopted by the Board, was to continue the publication of MINING AND METALLURGY as the *one* periodical that would go to every member of the Institute. It was felt that the publication of separate magazines for separate groups of members would tend to develop an unhealthy cleavage between them. MINING AND METALLURGY was described as providing "a cement or binder for the diverse technologic groups." The report recommended that the editorial policy of the magazine then in effect be reaffirmed and intensified. That policy had been formulated by the Committee on MINING AND METALLURGY, under the chairmanship of John M. Lovejoy; and is set forth in the following excerpt from an editorial in the magazine for August 1942:

> "On several occasions the functions of this magazine, as prescribed by the standing Committee on Mining and Metallurgy and approved by the Board of Directors, have been outlined in these columns; but, even so, members repeatedly raise questions indicating their misapprehension as to editorial policy and aim. The magazine is not a technical publication nor does it essay to give the current day-to-day news of the diverse industries in which the members of the Institute are engaged.

> "Stated as concisely as possible, the function is to provide a common intellectual meeting place for all groups. To achieve this, material must be published that is potentially of interest to all, or at least to a large majority. A common denominator must be found. Specifically, this requirement is met by news of the Institute: the movement of individuals, the work of the Local Sections, the activities of the technical Divisions, the actions of the Board of Directors, and reports of meetings. In addition, the Committee feels it desirable to include a certain number of general articles and sundry comment written by members of the Institute staff. It is prescribed that these contributions shall, as an ideal, be of such broad and general interest that they will appeal to a substantial majority of Institute members. Technical information and news of broad significance may be used; but only in a way so general that the appeal will be to persons in other technical fields as well as the particular one involved."

Aside from the Secretaries of the Institute, who served *ex officiis*, MINING AND METALLURGY has had three editors. The first was Percy E. Barbour, who served from 1920 until 1926. When he retired, the Board of Directors passed a resolution assigning to him a major part of the credit for establishing the magazine and making of it a "going concern." Thomas T. Read followed him and continued on a part-time basis even after he became Professor of Mining at Columbia, until he was succeeded early in 1932 by E. H. Robie. Each of the three was an Assistant Secretary of the Institute, though Dr. Read relinquished that post during the last year of his editorship.

Not only the editors of the magazine but the advertising manager have faced unusual problems arising from the wide range of technologic interest among the members. In the '20s, advertisers were not as "scientific" in selecting "media" as they became after the depression that began in 1929. During each year of the first decade of its existence the magazine realized substantial revenue from advertising, the maximum being about $60,000 in 1925. It was derived mostly from companies desiring to reach purchasers of equipment and supplies needed for mining, milling, and smelting ores, that being by far the largest homogeneous group of members.

In the early '30s advertising income shrank almost to the vanishing point —in 1934 it totaled only about $10,000. Thereafter, the trend has been uniformly upward; and in 1947 about $70,000 should be realized—still from the same type of advertiser that used the magazine in the '20s. Increased rates per page, based on increased circulation (membership), have helped, of course. A basic change in editorial content might easily double advertising income but the magazine should not (and does not) exist primarily to produce the maximum revenue. Rather it exists to perform a definite and necessary function with respect to the membership as a whole.

Articles of the kind required by the present editorial policy are difficult to write: to prepare them well requires a degree of journalistic expertness that cannot be expected of the average competent engineer or technologist. Nevertheless, it is generally agreed that the magazine is steering in the right direction and that it has been improving steadily in recent years. Unless there is a radical change in basic policy, it will continue to serve as an integrating and unifying instrument—the *one* tangible thing that all A.I.M.E. members have in common.

Year Book and Directory

One of the most valuable publications of the Institute—some would omit the qualification "one of"—has been the List of Members, giving name, address, and professional connection of each individual on the roll. It is looked upon by many as the only authentic roster of men who have attained standing in the profession. There are competent and reliable engineers engaged in the mineral industry who are not members of A.I.M.E., but the number is so small that, in the words of an often used expression, "nonmembership puts the burden of proof on an individual who aspires to be recognized professionally."

Nearly all of the first 15 volumes of the TRANSACTIONS contain the entire membership list. During the next 15 years, the complete list appears only at intervals of several years, although the newly elected members are listed in the intervening volumes.

In 1901, a separate 118-page book was published containing the membership lists alphabetically and geographically arranged, a list of meetings, and the "Rules"—as the laws of the Institute were still called. In 1908, the term YEAR BOOK was given to the membership list, and from time to time additional material was incorporated. In 1920, the name was changed to DIRECTORY. In that year, it contained photographs of current officers, lists of Local Section officials, representatives on various outside organizations, and the committees of the Institute itself. Except for one year, the list of members under one name or another has appeared annually ever since. Included in the current volume (1946) is a list of members alphabetically and geographically arranged; the Constitution and Bylaws of the Institute; officers and committeemen of the Local Sections, the Professional Divisions, the Woman's Auxiliary and the Affiliated Student Societies; lists of standing and special committees, and of representatives on joint activities; official Institute reports for the year; and information concerning medals and awards, as well as technical lectures.

From 1934 to 1938, a small separate volume called the YEAR BOOK was published annually as a section of the periodical MINING AND METALLURGY, which consisted principally of abstracts and an index of all TECHNICAL PUBLICATIONS (T.P.'s), and TRANSACTIONS papers issued during the preceding year. Prior to that time material of this character had been published in the general volume of the TRANSACTIONS but with the discontinuance of a volume that went automatically to every member the YEAR BOOK seemed desirable. When it was discontinued in 1938, a list of all publications issued during the preceding year was incorporated in the DIRECTORY.

The DIRECTORY is generally recognized as the "Who's Who" or Blue Book of technologists and engineers in the mineral industry.

Special Volumes

Over the years, the Institute has published or in one way or another has sponsored the publication of various excellent volumes other than the TRANSACTIONS. These special volumes have dealt in a comprehensive and organized way with a single broad subject, and usually have been financed by sales to members who are especially interested.

Perhaps most notable among the early publications of this type was a work on "The Genesis of Ore Deposits," by Franz Posepny. A first edition of 265 pages, published about 1895, was followed in 1901 by an 820-page edition containing new material in the form of discussion by many distinguished geologists. A 400-page volume entitled "The Evolution of Mine Surveying Instruments," consisting of a collection of papers by Dunbar D. Scott and pertinent discussion by numerous authorities, was published in 1904. In 1913, there appeared a special volume entitled "Ore Deposits," edited by Dr. S. F. Emmons, who finished the task just prior to his death in 1910. The papers, written by eminent geologists, totaled about 1000 printed pages, most of them having appeared in the TRANSACTIONS from 1900 to 1910. Each of these outstanding volumes was sold to A.I.M.E. members and to the public in sufficient numbers to cover the cost of producing them.

However, the publication of special volumes assumed major importance for the first time in 1931, when a volume called "Technical Writing," by T. A. Rickard, was published through an endowment called the Seeley W. Mudd Memorial Fund. Since then about 25 publication projects, most of them financed by the Mudd Fund or by the Rocky Mountain Fund, have been completed. Details will be found in the next section of this history.

ENDOWMENT FUNDS

The regular activities of the Institute have been financed mainly by income derived from members' dues, from proceeds or advertising in MINING AND METALLURGY, and from the sale of publications to the public. In addition, certain collateral activities and special projects, each year since 1919, have been financed by means of income from endowed funds controlled and administered by the Institute. In the aggregate, the amount of these endowments totals more than $706,900.

With a few exceptions, the Funds have been established by friends or relatives in memory of some distinguished member of the Institute. They have been instrumental in greatly increasing the usefulness of the A.I.M.E. to the public, to the mineral industries, and to the profession.

James Douglas Library Fund

In 1919, the executors of the estate of James Douglas, past president and honorary member, made a gift of approximately $100,000 to the Institute with the specific provision that the income (only) be used to defray a portion of the A.I.M.E. share of the current cost of operating the Engineering Societies Library. The library is owned and operated jointly by the four Founder Engineering Societies and is mentioned later in this history.

Rocky Mountain Fund

A group of men interested in the West—and, naturally, "mining men" were predominant—in 1907 organized the Rocky Mountain Club, with the intention of erecting a clubhouse in New York. Headquarters were established at the old Waldorf-Astoria on 34th Street, a site was purchased, and a good start was made toward accumulating a building fund, the largest contributors being John Hays Hammond, William Boyce Thompson and Edward H. Clark. However, during the first World War the money in the fund was spent to aid various worthy patriotic causes. Later, when the idea of raising a new fund appeared to be impractical, the building site was sold—incidentally, at a profit—for about $115,000.

Many proposals were made as to appropriate disposition of the proceeds; but nothing was done until 1927, when Charles F. Rand, A.I.M.E. Treasurer, suggested that the funds might well be used for the benefit of the Institute, particularly because so many mining men belonged to both organizations. The records show that Henry Krumb, J. V. W. Reynders and George Otis Smith were mainly responsible for obtaining the approval, in principle, of Messrs. Hammond, Thompson, and Clark.

The plan finally developed was to consolidate the two organizations. Members of the Club that were not directly interested in mining were granted a special limited form of A.I.M.E. membership and were designated Rocky Mountain Members. At first there were 150 such members; but by 1947 the Grim Reaper had shrunk the number to 70.

Upon conclusion of the merger, $109,754 was turned over to the Institute. A special trust was established, the income of which is available for use "for any object which in the judgment of the Directors shall be for the benefit of the consolidated corporation, but preferably to further the interests of the western mining states."

Henry Krumb was made chairman of the Rocky Mountain Income Committee, charged with the responsibility of recommending ways to use the income. He has continued as chairman ever since; and his policy has had for its objective conservation of the income in prosperous times and use of it in "hard" times for projects that otherwise would be a drain on the Institute's regular budget. For example, in the following list of projects will be noted five TRANSACTIONS volumes. Except for the Rocky Mountain Fund, either these volumes would have been much smaller—if published at all—or other vital activities would have been curtailed. At present the principal and accumulated income of the fund exceed $140,000. Following is a list of nine major projects involving an expenditure of about $70,000. Part of the expenditure was recovered to the Fund through the sale of publications:

1. A Reverberatory Furnace Conference was held at Salt Lake City in 1930; and the report of proceedings was published by the Rocky Mountain Fund.
2. In July 1933, "The Porphyry Coppers," the first of a new set of books to be known as the Rocky Mountain Fund Series, was published under the sponsorship of the Fund. The volume, containing 600 pages, was written by A. B. Parsons.
3. In November 1933, the second volume in the Rocky Mountain Fund Series, entitled "Ore Deposits of the Western States," came from the printer.
4. In 1933, TRANSACTIONS Volume 106, on "Copper Metallurgy," was published.
5. In 1934, TRANSACTIONS Volume 112, on "Milling Methods," under which head were included ore dressing, concentration, and the cyaniding of gold and silver ores, was financed.
6. In 1936, TRANSACTIONS Volume 121, on "Metallurgy of Lead and Zinc," was made possible by the Fund.
7. Late in 1934, $7,500 was appropriated to finance the publication of a special volume on "Mine Plant" and subsequently $7,500 was added. B. F. Tillson was the author of this uniquely valuable book.
8. In 1939, TRANSACTIONS Volume 134, on "Milling Methods," was published.
9. In 1940, TRANSACTIONS Volume 141, on "Metal Mining," was a Fund book.

Seeley W. Mudd Memorial Fund

A generous gift to the Institute of $103,000, by several members of his family, was used to establish in 1929 the Seeley W. Mudd Memorial Fund. Colonel Mudd had served the Institute as Director, as Vice President, and as a member of many important committees. His long career of distinguished professional and public service was fittingly commemorated by this fund. The income, according to the deed of gift, is to be expended

> "for the advancement of the sciences of mining and metallurgy by the encouragement of research and the dissemination of knowledge and for the promotion of the welfare of engineers engaged in the professions of mining and metallurgy. Inasmuch as Mr. Mudd was more closely identified with nonferrous mining and metallurgy and always sought by his counsel and interest to guide and encourage the younger men of the profession, the donors express the wish, but without imposing any restrictions, that the Institute will give preference to research within the nonferrous field and which will be of particular benefit to young engineers."

For reasons that are entirely sound, the Committee that recommends disposition of the income to the Board of Directors has established a policy somewhat at variance with that of the Rocky Mountain Income Committee. Projects that have been supported have been outside of what might be called normal scope of Institute activity: the aim has been to make available to the members and to the profession an "overplus" of published material. Although they are not restricted to publication, the successive committees have found that this is the most fruitful and most practical field. That they have found ample opportunity is suggested by the lists of volumes already issued, or now in the course of preparation.

The two series of books sponsored by the Fund may be described briefly. The A.I.M.E. Series consists of relatively small volumes designed to appeal primarily to the Junior Member, not as textbooks but as background reading for a young man starting his professional career. Since 1932, a selection of these volumes—always including "Technical Writing"—has been sent to each newly enrolled Junior Member with the compliments of the Seeley W. Mudd Fund. The list follows:

1. Choice of Methods in Mining and Metallurgy, containing chapters by various engineers.*
2. A History of American Mining. By T. A. Rickard.*
3. Mineral Economics, containing a series of lectures delivered at the Brookings Institution.*
4. Examination of Prospects, a new edition of the book of C. Godfrey Gunther, revised by R. C. Fleming.*
5. Technical Writing. By T. A. Rickard.
6. Modern Uses of Nonferrous Metals. Edited by C. H. Mathewson.
7. Coal Through the Ages. By Howard N. Eavenson.
8. Mineral Valuations of the Future. By C. K. Leith.

The Seeley W. Mudd Series consists, in general, of larger and more elaborate volumes financed on a sort of revolving-fund basis. The cost of publication is paid by the Fund; and the volume is then sold to both nonmembers and members of the A.I.M.E., the latter being accorded substantially lower prices. Proceeds of sales revert to the Fund and are available for later use. The net cost to the Fund of some of the books has been almost nothing because of the large volume of sales, particularly to nonmembers; and today the available money in the income account amounts to $25,000. Second editions of several of the volumes have been printed; and a completely rewritten edition of "Industrial Minerals and Rocks" is in preparation.

The list that follows shows the variety of subject matter in the Seeley W. Mudd Series:

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* Now discontinued.

1. Industrial Minerals and Rocks, published in 1937, is a 950-page volume prepared by a special editorial board under the chairmanship of Samuel H. Dolbear. The volume is a carefully organized series of articles dealing with all of the important nonmetallic minerals—resources, production, utilization, and marketing.
2. Elements of the Petroleum Industry, published in 1940, was prepared under the guidance of an editorial board, of which E. DeGolyer was chairman. This volume covers all phases of the industry, and is addressed to the engineer who is not directly connected with the oil industry as well as to the petroleum engineer, executive, or economist.
3. The Development of Mineral Industry Education in the United States was published in 1941. The author, Thomas T. Read, was Vinton Professor of Mining at Columbia University before his death in May 1947.
4. De La Pirotechnia, of Vannoccio Biringuccio, translated by Cyril Stanley Smith and Martha Teach Gnudi, was published in 1942. The original work is a classic of the sixteenth century and the translation is a scholarly contribution to the history of mining and metallurgical art.
5. Coal Preparation, an 850-page volume on crushing, sizing, washing, concentrating, and dedusting coal, was published in 1943. Chapters in it were written by leading authorities in their respective fields.
6. Steelmaking by the Open-hearth Process was published in 1944. The Committee on Physical Chemistry of Steelmaking of the Iron and Steel Division, A.I.M.E., sponsored the volume.
7. Mechanical Loading and Haulage in Underground Mines (authorized project) will not overlook coal mines but will stress metal and nonmetallic operations. Cadwallader Evans, Jr., is chairman of the Editorial Board and Lewis E. Young has been named editor.
8. Health and Safety in Mining (authorized project) will deal primarily with mines producing metals and the so-called nonmetallic ores rather than with coal mines. W. B. Plank is editor and Clarence M. Haight is chairman of the Editorial Advisory Board.

Several minor publications include two brochures titled: "Careers in the Mineral Industries" and "Manual for Student Associates and Affiliated Student Societies."

According to Harvey S. Mudd, his mother and the others who joined him in establishing the Fund feel that the yield, in personal pleasure and satisfaction, has been greater than that of any other benefaction with which they have been connected. The Institute and the profession have profited tremendously.

Endowment Fund X

In December 1938, a donor, whose identity was disclosed only to the Treasurer of the Institute, established a special fund, which was designated Endowment Fund "X." Each year since, additional contributions have been made, so that the value of the fund now approximates $115,000. Under the terms of the gift, the income may be used "for any purpose which is for the benefit of the Institute." The donor specifically states that such income can be used to defray current expenses and expresses the preference that it be used in times of economic depression, so that the Institute will not be compelled to curtail its activities when income from other sources shrinks. The only limitation is that the principal and income must be used "exclusively for scientific, literary or educational purposes of the Institute." To date, no use has been made of the income from the fund; but there is comfort in the knowledge that it will be available on a rainy day.

Charles Hayden Memorial Fund

Through the trustees of the Charles Hayden Foundation, the sum of $50,000 was given to the Institute in 1939 to establish the Charles Hayden Memorial Fund. By the terms of the gift, the income is to be used by the Directors of the Institute "in furtherance of the technical education of the Student Associates of the Institute through the preparation and circulation of technical publications." The Hayden Foundation has for its express object the promotion of the interests and welfare of youth, and this project fits well into that program. Income has been used to help defray the cost—over and above the fees paid by the students—of supplying publications.

Robert C. Gemmell Memorial Fund

A gift of $25,000 was made in 1940 by Mrs. Belle C. Gemmell for the purpose of establishing a memorial to her late husband, Robert C. Gemmell. The fund is to be administered by the Board of Directors of the Institute and the income is to be used

> "to promote the welfare of the mineral industries by sponsoring researches in technologic and engineering phases of mining and metallurgy; by affording financial support through scholarships, fellowships, or otherwise to researches relating to the mineral industries; and by sponsoring or assisting the collection, publication, and distribution of records of scientific and technical progress for the benefit of engineers engaged in the mining and metallurgical industries."

Karl Eilers Memorial Fund

In November 1941, following the death of Karl Eilers, who had served the Institute for 14 years as Treasurer and Board member, the Directors approved a proposal to establish the Karl Eilers Memorial Fund, and to invite contributions from friends and admirers. Income can be appropriated by the Board of Directors for any purpose that in its judgment will promote the welfare of the Institute. At the end of 1944 total subscriptions were approximately $25,000 from more than 325 members.

Henry L. Doherty Memorial Fund

The Cities Service Company in 1945 contributed $5,000, and a similar amount in 1946, as a nucleus for an A.I.M.E. fund that is expected to constitute a memorial to Henry L. Doherty. The monies in the Fund are to be used "to promote the art and science of petroleum engineering." On the recommendation of a committee composed of John M. Lovejoy, Chairman, E. DeGolyer and Warren A. Sinsheimer, publication has been authorized of a special volume on Petroleum Conservation, to be sponsored by the Fund and to be dedicated to Mr. Doherty.

Provision was made in 1946 for the publication of the annual Petroleum Production Symposium (Statistics) in a volume separate from the Petroleum TRANSACTIONS volume, by means of a subsidy from the Fund.

MEDALS AND AWARDS

Medals, whether of gold, silver, or bronze, like other awards (even a mere certificate) bestowed by learned and professional societies derive their value in the last analysis from: (1) the standing and prestige of the organization that sponsors the award; (2) the caliber of the men upon whom the honor has been conferred in the past. Personal popularity and "political" considerations are poor criteria for choosing medalists to recognize outstanding achievement; and a few inferior selections do much to depreciate the value of an award.

Those who have the responsibility of choosing recipients for A.I.M.E. honors are aware of this; and medalists of outstanding distinction have been the result. The following facts regarding the four major medals that are under the direct authority of the Board of Directors are significant:

The Board on April 18, 1940, adopted a resolution providing that "no person who has been awarded any one of the four medals—Douglas, Saunders, Lucas, and Rand—is eligible for consideration for any other of the four medals." Later in the year the rules for the award of these four medals were revised and, so far as practicable, made uniform. The medalists are elected by the Board of Directors, on recommendation of special standing committees of award, appointees on which serve four-year terms and are identified closely with the branch of industry represented by the respective awards.

Under the new rules only members of the committees of award are eligible to propose candidates for the nomination. Members of the Institute desirous of bringing possible candidates before one of the committees of award may communicate with any member of the appropriate committee. The method of voting is by letter ballot; and two thirds of the entire membership of the committee must vote affirmatively to select a candidate for transmission to the Board of Directors.

Following are a few data regarding the A.I.M.E. medals and awards with lists of the recipients to date.

Charles F. Rand Memorial Medal

Admirers of Charles F. Rand, President of the Institute in 1913 and Treasurer from 1922 to 1927, contributed in 1930 about $10,000 to a fund that would be a memorial to Mr. Rand, under the auspices of the A.I.M.E. A Foundation was established with the provision that income from the fund should be used at the discretion of the Board of Directors to "promote the general welfare of the Institute." It was also provided that the "Charles F. Rand Memorial Medal" might be established to recognize "Distinguished Achievement in Mining Administration." The formal establishment of this medal was announced in 1932; and coincidentally the term "mining" was specifically defined to include metallurgy, petroleum, or any other "field" of the mineral industry.

Pursuant to the original program, several relatively modest appropriations from the income have been made to finance small but worthy publication projects; but the most significant activity of the Rand Foundation Committee has been the award of the Rand Medal to three outstanding industrialists, as follows:

1940	Robert Crooks Stanley
1944	Cornelius Francis Kelley
1947	George Magoffin Humphrey

James Douglas Medal

Established in 1922, the James Douglas Gold Medal does honor to Dr. James Douglas, twice President of the Institute, and recognizes distinguished achievement in "nonferrous metallurgy." The term is interpreted to include ore dressing, smelting, refining, alloying and utilization of nonferrous metals. Awards of the medal have been made as follows:

1923	Frederick Laist
1924	Charles Washington Merrill
1925	William Hastings Bassett
1926	John Michael Callow
1927	Zay Jeffries
1928	Selwyn G. Blaylock
1929	Paul Dyer Merica
1930	John Van Nostrand Dorr
1931	William H. Peirce
1932	Champion Herbert Mathewson
1933	James O. Elton
1935	George Cameron Stone
1938	Hal Williams Hardinge
1940	Louis D. Ricketts
1942	Arthur Smith Dwight
1945	Robert Franklin Mehl

William Lawrence Saunders Medal

The William Lawrence Saunders Gold Medal, established in 1927, through a gift by Mr. Saunders, recognizes "distinguished achievement in mining," in which is included the production of metals, coal, and other solid nonmetallic minerals. Awards of the medal have been made as follows on page 455.

1927	David William Brunton
1928	Herbert Hoover
1929	John Hays Hammond
1930	Daniel Cowan Jackling
1931	Francis William Maclennan
1932	Frederick W. Bradley
1933	Walter Hull Aldridge
1934	Pope Yeatman
1935	James MacNaughton
1936	Clinton Hoadley Crane
1937	Erskine Ramsay
1939	Louis Shattuck Cates
1941	Herman C. Bellinger
1944	George Bates Harrington
1946	Fred Searls, Jr.
1947	LeRoy Salsich

Anthony F. Lucas Medal

The Anthony F. Lucas Medal, established in April 1936, was based on a capital fund to which the original contributions were made by anonymous donors in 1922. Provision is made for the use of the income of the fund in excess of that required for such medals as may be awarded from time to time, for the granting of scholarships and for other purposes designed to promote the welfare of petroleum engineers and technologists.

The medal is to be awarded to recognize "distinguished achievement in improving the technique and practice of finding and producing petroleum." Awards of the medal have been made as follows:

1937	J. Edgar Pew
1938	Henry Latham Doherty
1940	Everette Lee DeGolyer
1941	Conrad (posthumously) and Marcel Schlumberger
1943	John Robert Suman
1944	Charles VanOrmer Millikan
1946	James Ogier Lewis
1947	William Noble Lacey

Robert W. Hunt Medal and Prize

Partners and employees of Robert W. Hunt, desiring to commemorate his great contributions to the steel industry, established in 1920 a fund to provide the award of a gold medal and prize, under A.I.M.E. auspices.

The award may be made each year to the person or persons, not necessarily members of the Institute, that contribute to the Institute the best original paper or papers on iron and steel.

Recipients are nominated by the Iron and Steel Division but are elected by the Directors of the Institute.

The award may be a gold medal, a silver medal, and/or a sum of money; each to be accompanied by a certificate of award. The money prize shall not be awarded to anyone over 40 years of age.

Awards of the Hunt medal and certificate have been made as follows:

1920	Robert Woolston Hunt
1926	Charles Lewis Kinney, Jr.
1928	John A. Mathews
1929	Edgar Collins Bain
1930	James Aston
1940	Axel Hultgren and Gösta Phragmén
1943	Marcus A. Grossmann
1944	Clarence David King
1945	Edwin Chester Wright
1947	Harry K. Ihrig

Awards of the Hunt certificate, with or without a money prize, have been made as follows:

1928	C. H. Herty, Jr.
1929	William E. Griffiths
1931	Edmund Sharington Davenport
1932	Howard Scott
1933	Clarence E. Sims and Gustaf A. Lilliequist
1934	Cyril Stanley Smith and Earl W. Palmer
1936	C. C. Henning
1937	William Floyd Holbrook and Thomas L. Joseph
1938	Thomas S. Washburn and John Hunter Nead
1939	Kenneth Charles McCutcheon and John Chipman
1941	Alden B. Greninger and Alexander R. Troiano
1941	George E. Steudel
1942	Harold K. Work

J. E. Johnson, Jr. Award

In 1923, Mrs. Margaret Hilles Johnson established an award in memory of her husband, J. E. Johnson, Jr. The intent of the donor is to encourage young men in creative work in the metallurgy or manufacture of pig iron. The award cannot be made to persons more than 40 years old. The Iron and Steel Division of the Institute recommends to the Board of Directors of the Institute qualified persons to receive the award. Recipients of the award have been as follows:

1923	Alexander L. Feild
1926	Selwyne Perez Kinney
1927	Thomas L. Joseph
1928	P. H. Royster
1930	William S. Unger
1932	Ora E. Clark
1933	Hjalmar W. Johnson
1934	Benjamin J. Harlan
1935	Francis Marion Rich
1936	Francis Hearne Crockard
1937	John M. Hassler
1938	Roy Alexander Lindgren
1940	P. V. Martin
1941	Carl F. Hoffman
1942	Louis F. Sattele
1943	James M. Stapleton
1944	Leonard A. Tofft
1945	Carl G. Hogberg
1946	John J. Alexander
1947	Kurt Neustaetter

B. F. McKune Memorial Award

In 1940 the Open Hearth Steel Committee of the Iron and Steel Division established an award in memory of Frank B. McKune, who for 40 years was open-hearth superintendent for the Steel Company of Canada, Ltd., and a faithful and active pioneer in the work of the Open Hearth Steel Committee. The award is made annually, to the man not more than 35 years of age, who submits by January 1, for presentation at the Spring Open Hearth Conference, the best paper of not more than 5000 words on open-hearth practice. It consists of $200 and a suitable certificate. The prize has been awarded as follows on page 457.

1941	Henry F. Forsyth
1942	H. B. Emerick and S. Feigenbaum
1943	E. G. Wigfield
1944	James W. Halley and George L. Plimpton, Jr.
1945	Albert M. Kroner
1946	A. P. Woods and C. R. Taylor
1947	E. B. Hughes

Rossiter W. Raymond Memorial Award

Early in 1945, there was established the Rossiter W. Raymond Memorial Award, at the instigation of Frederick Roeser. He contributed $2,000 to a special fund, the income of which is to defray the cost of an annual prize for the best paper published by a member of the Institute under 33 years of age. Not only the technological content but the proficiency of organization of the material and the literary style are criteria for judging the papers. This award has been made as follows:

1946	John H. Hollomon
1947	William A. Johnson

Institute of Metals Division Annual Award

The Institute of Metals Division in 1933 established an annual award of an engraved certificate to recognize the author or authors of the paper that in the opinion of the award committee represents the "most notable contribution to metallurgical science among the papers that have been published by the Institute within the three years preceding the date of award." Certificates have been awarded as follows:

1934	Robert F. Mehl and Charles S. Barrett
1935	E. A. Anderson, M. L. Fuller, R. L. Wilcox and J. L. Rodda
1936	Cyril Stanley Smith and W. Earl Lindlief
1937	Arthur Phillips and R. M. Brick
1938	William L. Fink and Dana W. Smith
1939	Frederick N. Rhines and Robert F. Mehl
1940	Alden B. Greninger
1941	S. F. Maddigan and A. I. Blank
1942	Frederick N. Rhines
1943	J. D. Hanawalt, C. E. Nelson, and J. A. Peloubet
1944	A. H. Geisler, C. S. Barrett, and R. F. Mehl
1945	William M. Baldwin, Jr.
1946	P. W. Bakarian and C. H. Mathewson
1947	W. A. Anderson and R. F. Mehl

Howe Memorial Lecture

The Howe Memorial Lecture, honoring Henry Marion Howe, Past President of the Institute, was established in April 1923. An address is delivered annually by invitation under the auspices of the Institute, by an individual of recognized and outstanding attainment in the science and practice of iron and steel metallurgy or metallography. He is chosen by the

Board of Directors upon recommendation of the Iron and Steel Division. Following are the Howe lecturers for the years indicated:

1924	Albert Sauveur
1925	John A. Mathews
1926	William Campbell
1927	Bradley Stoughton
1928	Henry D. Hibbard
1929	John Howe Hall
1930	Zay Jeffries
1931	Francis F. Lucas
1932	Edgar C. Bain
1933	George B. Waterhouse
1934	F. N. Speller
1935	E. C. Smith
1936	H. F. Moore
1937	Paul D. Merica
1938	Frederick M. Becket
1939	H. W. Gillett
1940	Charles H. Herty, Jr.
1941	Alfred V. deForest
1942	John Johnston
1943	Leo F. Reinartz
1944	James T. MacKenzie
1945	Marcus A. Grossmann
1946	T. L. Joseph
1947	H. W. Graham

Institute of Metals Lecture

An annual lectureship was established in 1921 by the Institute of Metals Division, and delivery of the lecture has come to be an important function of the annual meeting. Selected by the Directors of the Institute, on nomination of the Division, a number of distinguished men from the United States and abroad have delivered this lecture. The roll is quoted herewith:

1922	Wilder D. Bancroft
1923	Walter Rosenhain (Great Britain)
1924	Zay Jeffries
1925	Carl Benedicks (Sweden)
1926	Paul D. Foote
1927	Cecil H. Desch (Great Britain)
1928	C. H. Mathewson
1929	Ulick R. Evans (Great Britain)
1930	S. L. Hoyt
1931	Arne Westgren (Sweden)
1932	Paul D. Merica
1933	Georg Masing (Germany)
1934	L. W. McKeehan
1935	C. A. Edwards (Great Britain)
1936	R. F. Mehl
1937	R. S. Hutton (Great Britain)
1938	P. W. Bridgman
1939	Daniel Hanson (Great Britain)
1940	Edgar H. Dix, Jr.
1941	George Sachs
1942	W. R. Webster
1943	V. K. Zworykin
1944	W. M. Peirce
1945	Charles S. Barrett
1946	William Hume-Rothery (Great Britain)
1947	Albert J. Phillips

MEETINGS OF THE INSTITUTE

For some reason the A.I.M.E. always has avoided the word "convention" in designating its larger gatherings. A "coming together" may last for several days; it may comprise many sessions for the presentation of technical papers, social functions of various sorts, plant inspections, business meetings, Section Delegates meetings, Directors meetings, and committee meetings: but all are wrapped up in a package and called by some such name as St. Louis Regional Meeting, Annual Meeting, or Coal Division Meeting.

The single thing that never is omitted is a technical program, though occasionally the time devoted to the reading of technical papers is negligible. Examples were the San Francisco Meeting in 1911 and the meeting in Mexico in 1936, which will be mentioned presently. Having scheduled a meeting to be held at a given place, the sponsors feel obliged to organize some technical sessions and to solicit suitable papers in order to justify and rationalize the meeting, even though the primary object is to "see the sights," to enjoy good fellowship, and otherwise to have a pleasant time. A special characteristic of nearly all Institute meetings is that the womenfolk (usually under the auspices of the Woman's Auxiliary) participate actively in the social functions.

A somewhat different slant on the relation between technical papers and meetings is this: a meeting affords authors the occasion to communicate their papers orally and to derive the benefit of discussion by fellow practitioners in their special technologic field. One purpose is to enable the author to revise and perfect his final manuscript for publication.

In any event, the holding of meetings always has been a fundamental part of the activities of the Institute. Five general classes of meetings can be mentioned as follows: (1) Annual Meeting, (2) Regional Meeting, (3) Divisional Meeting, (4) Special "Conferences," (5) Local Section Meeting.

Annual Meeting

From the start the Institute has held one "meeting" each year of which an essential part was the annual business meeting for the induction of newly elected officers. For a time the May Meeting was designated for this purpose; but beginning in 1879 this was changed to the February Meeting and since then the "Annual February Meeting" has been a fixture as the principal meeting of the year. As indicated in Table 6, the meetings were held in all parts of the country during the first 40 years (p. 464).

From 1912 to 1943 the Annual Meetings were conducted in the Engineering Societies Building in New York City, except that the social functions and a small overflow of committee meetings and a few sessions were held at near-by buildings and at hotels. By 1944, the Meeting had grown to such proportions that the Engineering Societies Building could not begin to accommodate it; and the entire "show" was taken to the Waldorf-Astoria Hotel in New York City. The next year, because of a "convention ban" imposed by wartime shortages, only a skeletonized meeting was attempted; but in February 1946 a full-scale meeting with every feature was held at the Palmer House in Chicago, the Chicago Section playing host in a way that earned high commendation. The accompanying statistics indicate the way the Meeting has expanded, both in attendance and in the number of technical sessions. Because of the multiplicity of simultaneous sessions requiring separate meeting rooms, only a few hotels in the United States can accommodate the entire meeting.

Attendance	1919	1931	1944
Total (including ladies)	950	1,680	2,890
Banquet	450	775	1,300
Smoker	400	600	700
Number			
Technical sessions	10	31	56
Technical papers	59	160	279

At the banquet, which normally is scheduled for Wednesday night of "meeting" week, medals and other awards are presented and the new president is formally inducted. A ball lasting well into the following day concludes the function. Special mention should be made of the fact that the New York Section of the Institute in its capacity as host Section has organized and conducted the social functions in connection with the Annual Meetings, and has, in fact, provided financial subsidy to a substantial extent.

The Annual Meeting for 1947 was held in conjunction with the 75th A.I.M.E. Anniversary Celebration during the week of March 17–21, at the Waldorf-Astoria Hotel, New York City. Attendance was more than 3,000 and at the banquet were 1,415 diners.

Regional Meetings

As far as the records disclose, the first meetings to be designated as "Regional" were held in the fall of 1926; one at Denver, Colorado, and a second at Spokane, Washington. In the same year a meeting held in Pittsburgh was classed as a General Meeting. From 1927 to 1935, one Regional Meeting was held each year; but except for that in San Francisco, in 1929, these were not accorded numbers in the general meeting series. To complete the record, they are listed in their appropriate chronological place in Table 6.

Essentially, Regional Meetings have been organized and conducted in the same way as the out-of-New York general meetings of earlier years. The technical programs naturally have revolved around the industrial activities that predominate in the locality of the meeting place; visits of inspection have constituted an important part of the program; and local members of A.I.M.E. have acted as hosts to the visitors. With one exception, none of the meetings since 1926 has been held east of Chicago or St. Louis: the objective is to provide a general meeting without excessive travel for members residing in the West.

A few notes on three of these meetings will indicate how all are organized and conducted. Though they were of longer duration than the usual meeting, the arrangements are fairly typical.

The San Francisco Meeting of 1911 (General Meeting 101) started from the Dearborn Street railway station in Chicago on Saturday evening, September 30, in "one of the most complete and luxurious [special trains] ever placed at the disposal of the Institute." On the 10-day journey to San Francisco the party visited the Grand Canyon of the Colorado; Los Angeles, where three days were spent under the chaperonage of a large local committee visiting near-by attractions, including Hollywood and Catalina Island; Santa Barbara; Paso Robles; and Del Monte. Arriving in San Francisco, excursions were scheduled to Stanford University and the University of California; and on Friday, October 13, a large party visited the gold-dredging operations in the Sacramento Valley. Things wound up on Sunday with a barbecue luncheon and an outdoor concert in the famous Grove of the Bohemian Club.

Four technical sessions were held, the last being in the impressive Greek Theatre at Berkeley. It is to be noted, however, that the official account of each of these sessions reads: "The following papers were presented in brief oral abstract!" However, more than a score of outstanding papers "made" the TRANSACTIONS. Robert W. Hunt, Past President of the Institute, substituted in the proceedings for President Charles Kirchhoff, who unfortunately could not arrange to leave New York.

When Herbert Hoover was President of the Institute in 1920, the 122nd Meeting was held in the Lake Superior region during the period August 20 to September 3. A group of members, starting from Buffalo, traveled by boat, via Detroit, to Houghton, Michigan, where Mr. Hoover and others joined the party. The itinerary, part of it accomplished by special train, included Marquette and Iron Mountain, Michigan; St. Paul, Minneapolis, Duluth, and the Mesabi Range in Minnesota. Copper and iron mines and plants were visited; technical sessions were held at the Michigan College of Mines, at the University of Minnesota, and at Hibbing, Minnesota. Luncheons and dinners abounded. Mr. Hoover and others made dozens of speeches; and special social functions were provided all along the way for the ladies in the party. In all, 1100 members and guests participated in the proceedings at some stage of the tour.

Sixteen years later, during the presidency of John M. Lovejoy, the 146th General Meeting was held in Mexico City and its environs, on the invitation of a group of members in Mexico headed by Dr. Ezequiel Ordoñez, Honorary Member of the Institute. Two special trains mobilized at St. Louis and conveyed 200 members and guests to Mexico City, via Dallas and San Antonio. This group was joined by others who had driven from the United States by automobile, and by many members residing in Mexico. A busy week followed, with an excursion by automobile to Pachuca and Real del Monte and an overnight visit to Cuernavaca and Taxco. Shorter tours were made to many delightful places closer to Mexico City. The Secretary of Foreign Relations for the Government of Mexico, and many other officials, as well as U.S. Ambassador Josephus Daniels, participated in the proceedings and gave them an international aspect. Probably for the only time in history, a meeting of A.I.M.E. Directors, with a quorum present, was held outside of the United States. Two not-too-well-attended technical sessions were held at which papers were read by title. As a matter of fact, with a relentless round of social functions, Jai-Alai, concerts, golf, and a bull fight on Sunday, business and technology received scant attention. As usual at A.I.M.E. meetings, the ladies were active participants and good fellowship was a keynote in the meeting.

Divisional Meetings

One reason for the expansion in the scope of the Annual February Meetings since 1920 has been the establishment of six Divisions and the practice of these Divisions of holding sessions in February. In addition, however, each has held at least one meeting in the fall. The Petroleum Division has scheduled regularly two fall meetings, one of them in Los Angeles. In addition to technical sessions, business meetings and a dinner have been part of the "standard" program. The list of meetings held in 1946 as shown in the following table is typical:

Division	Place	Dates	Approximate Registration
Petroleum	Galveston	Oct. 3–5	385
Petroleum	Los Angeles	Oct. 24–25	275
Industrial Minerals	Los Angeles	Oct. 24–25	75
Industrial Minerals	Columbus, Ohio	Oct. 23–24	75
Coal (Joint Fuels Conference)	Philadelphia, Pa.	Oct. 24–25	320
Iron and Steel and Institute of Metals	Atlantic City, N. J.	Nov. 18–20	450

Iron and Steel Division "Conferences"

One group of meetings that has developed remarkably in size and importance is the so-called "Conferences," of which there are three, all sponsored by the Iron and Steel Division. The first of these—the Open Hearth Conference—was established in 1925 with the blessing of J. V. W. Reynders, who that year was President of the Institute. Leo F. Reinartz was the leading spirit from the start and for 20 years he served as Chairman of the Open Hearth Committee. The meetings take the form of informal but carefully planned and organized discussions of the practical problems of the men who operate the furnaces that produce the bulk of the world's steel! Held each year in an important steel-plant center, recent Conferences have drawn as many as 800 registrants. Two days of sessions are followed by a "fellowship" dinner with a distinguished speaker; and a third day usually is devoted to plant inspections. Attendance is not confined to members of the Institute; but the *leaders* are drawn from the Iron and Steel Division, A.I.M.E.

The Open Hearth Conference held at Birmingham, Ala., April 7–8, 1937, was participated in by the Blast Furnace and Raw Materials group, represented by a commttee of the Iron and Steel Division, then under the chairmanship of Ralph H. Sweetser. Since 1937, the two groups have met contemporaneously each year; but have maintained their separate entities. The Blast Furnace and Raw Materials Conference has drawn about 200 registrants.

Inspired by the success of these two groups, an Electric Furnace Steel Conference was organized to meet for the first time in Pittsburgh, Pa., October 1 and 2, 1943. C. W. Briggs, Chairman of the Committee at that time, patterned the conduct of the meeting after that of the Open Hearth Conference. This third Conference has been a success from the start, the annual meetings recording an attendance of about 550 people.

Each conference has published its proceedings in an annual volume that contains advertising. Revenue from advertising, plus registration fees from those who participate and small contributions from the steel-producing companies, help finance the work of the Conferences. The fact that the companies are willing to give financial support is one indication of the fundamental value of these activities.

One of the most significant developments has been the gradual change of policy whereby several leading steel companies not only have permitted, but have encouraged, their operators and metallurgists to exchange technical data and information without reservation. There was a time when frank and open disclosure of such information was rare. The change has been a big help to all concerned; and unquestionably has contributed to the high quality of steel-plant practice in the United States.

Local Section Meetings

Holding of Local Section meetings started soon after the organization of the New York Section in 1912. In recent years from 175 to 225 meetings have been scheduled annually by the Sections. Usually they are in the evening, but several of the Sections have held all-day meetings with technical sessions and a group luncheon and dinner.

Procedure varies greatly with the different Sections, both as to the frequency and type of meetings. The Chicago Section pioneered the plan of arranging and publishing a complete program of ten meetings a year in advance, with the dates, topics and, when possible, the speaker definitely announced. Other Sections find it profitable to arrange meetings on short notice, so that they can take advantage of visiting engineers who can speak to them. Too much emphasis cannot be given to the opportunity that Local Sections afford members for social intercourse and for professional association in an ideal environment. Local Section meetings have been a vital force in the growth and health of the Institute.

TABLE 6—*List of General Meetings of the A.I.M.E. from Organization to April 1, 1947*

No.	Place	Date
1	Wilkes-Barre, Pa	May, 1871
2	Bethlehem, Pa	Aug., 1871
3	Troy, N. Y	Nov., 1871
4	Philadelphia, Pa	Feb., 1872
5	New York, N. Y	May, 1872
6	Pittsburgh, Pa	Oct., 1872
7	Boston, Mass	Feb., 1873
8	Philadelphia, Pa	May, 1873
9	Easton, Pa	Oct., 1873
10	New York, N. Y	Feb., 1874
11	St. Louis, Mo	May, 1874
12	Hazleton, Pa	Oct., 1874
13	New Haven, Conn	Feb., 1875
14	Dover, N. J	May, 1875
15	Cleveland, Ohio	Oct., 1875
16	Washington, D. C	Feb., 1876
17	Philadelphia, Pa.*	June, 1876
18	Philadelphia, Pa	Oct., 1876
19	New York, N. Y	Feb., 1877
20	Wilkes-Barre, Pa	May, 1877
21	Amenia, N. Y	Oct., 1877
22	Philadelphia, Pa	Feb., 1878
23	Chattanooga, Tenn	May, 1878
24	Lake George, N. Y	Oct., 1878
25	Baltimore, Md	Feb., 1879
26	Pittsburgh, Pa	May, 1879
27	Montreal, Canada	Sept., 1879
28	New York, N. Y	Feb., 1880
29	Lake Superior, Mich	Aug., 1880
30	Philadelphia, Pa	Feb., 1881
31	Staunton, Va	May, 1881
32	Harrisburg, Pa	Oct., 1881
33	Washington, D. C	Feb., 1882
34	Denver, Colo	Aug., 1882
35	Boston, Mass	Feb., 1883
36	Roanoke, Va	June, 1883
37	Troy, N. Y	Oct., 1883
38	Cincinnati, Ohio	Feb., 1884
39	Chicago, Ill	May, 1884
40	Philadelphia Pa	Sept., 1884
41	New York, N. Y	Feb., 1885
42	Chattanooga, Tenn	May, 1885
43	Halifax, N. S	Sept., 1885
44	Pittsburgh, Pa	Feb., 1886
45	Bethlehem, Pa	May, 1886
46	St. Louis, Mo	Oct., 1886
47	Scranton, Pa	Feb., 1887
48	Utah and Montana	July, 1887
49	Duluth, Minn	July, 1887
50	Boston, Mass	Feb., 1888
51	Birmingham, Ala	May, 1888
52	Buffalo, N. Y	Oct., 1888
53	New York, N. Y	Feb., 1889
54	Colorado	June, 1889
55	Ottawa, Canada	Oct., 1889
56	Washington, D. C	Feb., 1890
57	New York, N. Y	Sept., 1890
58	New York, N. Y	Feb., 1891
59	Cleveland, Ohio	June, 1891
60	Glen Summit, Pa	Oct., 1891
61	Baltimore, Md	Feb., 1892
62	Plattsburg, N. Y	June, 1892
63	Reading, Pa	Oct., 1892
64	Montreal, Canada	Feb., 1893
65	Chicago, Ill	Aug., 1893
66	Virginia Beach, Va	Feb., 1894
67	Bridgeport, Conn	Oct., 1894
68	Florida†	Mar., 1895
69	Atlanta, Ga	Oct., 1895
70	Pittsburgh, Pa	Feb., 1896
71	Colorado	Sept., 1896
72	Chicago, Ill	Feb., 1897
73	Lake Superior	July, 1897
74	Atlantic City, N. J	Feb., 1898
75	Buffalo, N. Y	Oct., 1898
76	New York, N. Y	Feb., 1899
77	California	Sept., 1899
78	Washington, D. C	Feb., 1900
79	Canada	Aug., 1900
80	Richmond, Va	Feb., 1901
81	Mexico	Nov., 1901
82	Philadelphia, Pa.‡	May, 1902
83	New Haven, Conn	Oct., 1902
84	Albany, N. Y	Feb., 1903
85	New York, N. Y	Oct., 1903
86	Atlantic City, N. J	Feb., 1904
87	Lake Superior	Sept., 1904
88	Washington, D. C	May, 1905
89	British Columbia	July, 1905
90	Bethlehem, Pa	Feb., 1906

TABLE 6—(*Continued*)

No.	Place	Date
91	London, England	July, 1906
92	New York, N. Y	April, 1907
93	Toronto, Canada	July, 1907
94	New York, N. Y	Feb., 1908
95	Chattanooga, Tenn	Oct., 1908
96	New Haven, Conn	Feb., 1909
97	Spokane, Wash	Sept., 1909
98	Pittsburgh, Pa	Mar., 1910
99	Canal Zone	Nov., 1910
100	Wilkes-Barre, Pa	June, 1911
101	San Francisco, Calif	Oct., 1911
102	New York, N. Y	Feb., 1912
103	Cleveland, Ohio	Oct., 1912
104	New York, N. Y	Feb., 1913
105	Butte, Mont	Aug., 1913
106	New York, N. Y	Oct., 1913
107	New York, N. Y	Feb., 1914
108	Salt Lake City, Utah	Aug., 1914
109	Pittsburgh, Pa	Oct., 1914
110	New York, N. Y	Feb., 1915
111	San Francisco, Calif	Sept., 1915
112	New York, N. Y	Feb., 1916
113	Arizona	Sept., 1916
114	New York, N. Y	Feb., 1917
115	St. Louis, Mo	Oct., 1917
116	New York, N. Y	Feb., 1918
117	Colorado	Sept., 1918
118	Milwaukee, Wis	Oct., 1918
119	New York, N. Y	Feb., 1919
120	Chicago	Sept., 1919
121	New York, N. Y	Feb., 1920
122	Lake Superior Dist	Aug., 1920
123	New York, N. Y	Feb., 1921
124	Wilkes-Barre, Pa	Sept., 1921
125	New York, N. Y	Feb., 1922
126	San Francisco, Calif	Sept., 1922
127	New York, N. Y	Feb., 1923
128	Canada	Aug., 1923
129	New York, N. Y	Feb., 1924
130	Birmingham, Ala	Oct., 1924
131	New York, N. Y	Feb., 1925
132	Salt Lake City, Utah	Sept., 1925
133	New York, N. Y	Feb., 1926
134	Pittsburgh, Pa	Oct., 1926
135	New York, N. Y	Feb., 1927
§	Salt Lake City, Utah	Aug., 1927
136	New York, N. Y	Feb., 1928
§	Los Angeles, Calif	Sept., 1928
137	New York, N. Y	Feb., 1929
138	San Francisco, Calif	Oct., 1929
139	New York, N. Y	Feb., 1930
§	El Paso, Texas	Oct., 1930
140	New York, N. Y	Feb., 1931
§	Wilkes-Barre, Pa.**	May, 1931
141	New York, N. Y	Feb., 1932
§	Los Angeles, Calif	July, 1932
142	New York, N. Y	Feb., 1933
§	Chicago, Ill	June, 1933
143	New York, N. Y	Feb., 1934
§	Spokane, Wash	Sept., 1934
144	New York, N. Y	Feb., 1935
§	San Francisco, Calif	Oct., 1935
145	New York, N. Y	Feb., 1936
146	Mexico, D.F., Mexico	Nov., 1936
147	New York, N. Y	Feb., 1937
148	New York, N. Y	Feb., 1938
149	Tucson, Ariz	Nov., 1938
150	New York, N. Y	Feb., 1939
151	San Francisco, Calif	July, 1939
152	New York, N. Y	Feb., 1940
153	Salt Lake City, Utah	Sept., 1940
154	New York, N. Y	Feb., 1941
155	Duluth, Minn	Aug., 1941
156	New York, N. Y	Feb., 1942
157	St. Louis, Mo	Oct., 1942
158	New York, N. Y	Feb., 1943
159	Chicago, Ill	Oct., 1943
160	New York, N. Y	Feb., 1944
161	Houston, Texas	May, 1944
162	New York, N. Y	Feb., 1945
163	Chicago, Ill	Feb., 1946
164	New York, N. Y.***	Mar., 1947

* Begun in May at Easton, Pa., for the election of officers, and adjourned to Philadelphia.
† Begun in February at New York City, for the election of officers, and adjourned to Florida.
‡ Begun in February at New York City, for the election of officers, and adjourned to Philadelphia.
§ "General" meeting but not assigned a number.
** 60th A.I.M.E. Anniversary Celebration.
*** World Conference on Mineral Resources—75th Anniversary Celebration.

ENGINEERING SOCIETIES BUILDING

What might be called the "home office" of the Institute was the personal office of the incumbent Secretary until May 1, 1899. Martin Coryell, the first Secretary, resided at Wilkes-Barre, and there, no doubt, were kept such records as were needed. On November 30, 1872, Mr. Coryell exchanged posts with Dr. Thomas M. Drown, who was then a "Manager" of the Institute. On retiring as Secretary, Mr. Coryell was accorded a vote of thanks for his valuable services and "an appropriation of $100 was made to reimburse him for expenses incurred in the performance of his official duties." Doubtless this sum also included compensation for the use of such office space as the Institute's work had required.

Dr. Drown established headquarters in Pardee Hall at Lafayette College, Easton, Pa., where he was Professor of Chemistry. In June 1879, a fire destroyed Pardee Hall and much of the A.I.M.E. library, but Dr. Drown managed to rescue the Institute records, including the Minute Book and membership lists, and transferred his office to another building at Lafayette. Dr. Drown was paid a modest salary for his services, the amount being fixed at $2,000 per year in May 1878. However, at no time did he undertake to devote all of his time to the Institute.

At a meeting of the Council held in New York City on December 11, 1883, Dr. Drown, "compelled by reasons purely personal," resigned as Secretary; and Dr. Rossiter W. Raymond, elected to succeed him, took office on January 1, 1884. Headquarters were established temporarily at 18 Wall Street, New York City—rent free! From February 8, 1886 to May 1, 1899 they were at 13 Burling Slip, New York City. The minutes of the Council meeting of March 7, 1899 record:

> "That the Secretary be and hereby is authorized to rent offices for the business of the Institute in the new fire-proof building of Messrs. Phelps Dodge & Company, John Street, New York City, for five years at not exceeding $2,000 per annum, and to expend on fixing up the same, the necessary sum being not more than $1,000. The new office to be occupied May 1, 1899."

Dr. James Douglas, of the Phelps Dodge Co., had become President of the Institute in February 1899; and no doubt he had a hand in making this advantageous—to A.I.M.E.—arrangement. The John Street quarters were occupied until April 1907, when the Institute moved to its present quarters at 29 West 39th Street, New York City, in the building acquired by the Engineering Societies through the beneficence of Andrew Carnegie. The story of this project is extremely interesting and important.

Andrew Carnegie recognized the value of sound technology and competent engineering. He liked to associate with engineers. For example, he was a member of the A.I.M.E. and served as chairman of the Committee on Arrangements for the A.I.M.E. meeting in the fall of 1890, when members of the Iron and Steel Institute (Great Britain) were guests. Early in 1903 he became seriously interested in supplying funds to help the four leading national engineering societies—Civil, Mining, Mechanical, and Electrical—and the Engineers' Club in New York, acquire an appropriate building to serve as headquarters for all five. At the meeting of the A.I.M.E. on May 8, 1903, President Albert R. Ledoux reported, according to the minutes, that:

> "An informal meeting of members of the Councils of the four national engineering societies and the Engineers' Club was held on Thursday evening, May 7, at the House of the Society of Civil Engineers, to consider the subject of Mr. Andrew Carnegie's munificent proposal to erect a Union Engineering Building as set forth in the printed pamphlet issued on May 4, 1903, by Mr. Charles F. Scott and others, a copy of which had been sent to each member of the Council; that he had attended the said meeting together with several members of this Council; and that after full discussion, a resolution had been unanimously adopted requesting each Council to appoint a committee of three persons to confer with similar committees of other bodies named, and recommend to its own council a suitable plan of action."

Messrs. Ledoux, Charles Kirchhoff and Theodore Dwight were appointed to constitute the A.I.M.E. committee. Thereafter, events moved rapidly. An informal inquiry, signed by various individual Trustees, were directed to all members of the Institute, seeking advice as to their attitude regarding the plan. By March 10, 1904, the Trustees were able to assure Mr. Carnegie that the A.I.M.E. had the "desire and ability" to accept his offer in collaboration with the American Society of Mechanical Engineers and the American Institute of Electrical Engineers. A separate proposal had in the meantime been made to the Engineers' Club; and the American Society of Civil Engineers, which owned a building of its own, had declared its disinclination to participate. The other two societies gave assurances similar to those of the A.I.M.E.

On March 14, 1904, Mr. Carnegie wrote the following laconic but momentous letter:

> Gentlemen of The Mechanical Engineers, Institute of Mining Engineers, Institute of Electrical Engineers, Engineers' Club of New York:
>
> It will give me great pleasure to devote, say, one and a half million dollars for the erection of a suitable Union home for you all in New York City. With best wishes.
>
> Very truly yours,
> (Signed) ANDREW CARNEGIE

One necessary action was for the A.I.M.E. to amend its Rules so as to provide for the "creation under the statutes of the State of New York of a corporation to hold and administer, for the use and benefit of the Institute, such real or personal property as the Council may from time to time refer to it . . . " It was planned to make the corporation a creature of the Council. Although this proved to be impossible, the Council retained full and undivided control over the Institute's publications, meetings, and similar activities, but not its "business and financial affairs."

Incorporation under the Membership Corporation Law was duly effected at a meeting held at the John Street office on December 29, 1904; and the American Institute of Mining Engineers, Inc., became a legal entity. The incorporators were: James Gayley; Frank Lyman, James F. Kemp, Charles H. Snow, Frank Klepetko, Thomas A. Rickard, James Douglas, Albert R. Ledoux, and Rossiter W. Raymond—certainly a distinguished group.

Soon thereafter the three societies entered into an elaborate undertaking known as the "Founders Agreement" and a corporate organization known as the United Engineering Society (now the United Engineering Trustees) was created to proceed with the erection of a building. The site at 25 to 33 West 39th Street, New York City, had been acquired at a cost of $541,380.18 with funds loaned by Mr. Carnegie to the societies. For the erection of the building, Mr. Carnegie allotted, from his $1,500,000 gift, the sum of $1,050,000. The Engineers' Club was given $450,000; and its building project, though on an adjoining tract of land, was an entirely separate undertaking. Despite some widely held notions to the contrary, the Club, except for proximity, has no connection whatever with the Engineering Societies Building. It is a distinct enterprise operated like any other private club and supported by regular dues of its members—at present $125 per year, plus tax!

In accordance with his custom, Mr. Carnegie stipulated that the beneficiaries of his gift should, with their own resources, supply the site for the building and also equip it. Thus each of the three societies (Mining, Mechanical and Electrical Engineers) was obligated to contribute about $200,000. As noted, Mr. Carnegie had advanced the purchase price in order to avoid delay; but the money was all repaid. The A.I.M.E. share was raised by subscriptions from members and friends, some of them generous indeed. Payment to Mr. Carnegie by the U.E.S. extended over a period of about ten years.

The cornerstone for the new building was laid by Mrs. Carnegie on May 8, 1906; the finished structure was turned over to the U.E.S. on December 15 of that year. The dedication ceremonies for the building occupied the week of April 15 to 20, 1907; they included various formal and official functions; technical sessions; brilliant social events; and inspections of engineering plants and works. Mr. Carnegie was present in person to be guest of honor. The first meeting of the A.I.M.E. Council in the new building was held on April 23, 1907—40 years ago.

In 1916, the Am. Soc. C.E. became the fourth Founder Society by paying to the U.E.S. a lump sum of $262,500, which, with an additional contribution of $12,500 from each of the other societies, was used to build three additional stories atop the 13-story structure. Besides the offices of the Founder Societies, the building houses the Engineering Societies Library, occupying most of three floors, and contains an auditorium with 900 seats, and various smaller assembly rooms.

A number of engineering societies, called "associates," occupy office space in the building, for the use of which they contribute to the cost of maintenance and operation. However, the Founder Societies have grown to such an extent in recent years that the building is not large enough; and plans have been

FIG. 3—*Architect's drawing of the Engineering Societies Building*

under consideration for some time looking to the remodeling of the structure or otherwise expanding available space. One project is to provide a suitable entrance by means of an arcade on 40th Street, across from Bryant Park and the New York Public Library. This would be a big improvement over the present entrance on 39th Street, which is dominated by shoe stores and emporia of the cloak and suit trade.

Aside from the monies received from "associates," and the rental of meeting rooms to outside organizations (none but nonprofit-making groups can be accommodated), the income of the U.E.T. has come from assessments against the four Founder Societies. Until about fifteen years ago, the payments thus made were nominal. However, as the building became older, the cost of upkeep and maintenance increased and the routine cost of operation grew steadily. Moreover, the U.E.T. adopted the policy of allocating a moderate sum each year to a Depreciation and Renewal Fund. The fact that the Library paid no rent to U.E.T. also added to the cost of maintenance and operation. Assessments are apportioned among the four Societies mainly —though not entirely—on the basis of space occupied. The cost to the A.I.M.E. in 1946 was $16,051.

It is generally agreed that, despite some evident physical shortcomings, the Engineering Societies Building is the recognized focal point for the engineering profession of the United States. Without unbecoming conceit it may be said that no engineering center elsewhere in the world rivals it in importance.

COOPERATIVE ACTIVITIES WITH OTHER SOCIETIES

Cooperation among the four Founder Societies (Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers) never has been developed as far and as successfully as some have desired—and, indeed, as might have been expected. Necessarily, each organization faces problems that are common to all; and, entirely apart from specialized technologies, there would seem to be areas where joint action would be practical and advantageous to all concerned.

In 1917, an organization known as Engineering Council, having a paid secretary and an office force, was established with the following purpose: "to provide for convenient cooperation between the four Founder Societies for the proper consideration of questions of general interest to engineers and to the public and to provide the means for united action upon questions of common concern to engineers." Early in 1920, Engineering Council was succeeded by the Federated American Engineering Societies. Headquarters were established at Washington and Herbert Hoover was elected president. (He resigned on entering the Harding Cabinet as Secretary of Commerce.) The active direction of the Federation was delegated to a group designated as the American Engineering Council. At the end of 1923, the Directors of the A.I.M.E. concluded that not enough had been accomplished to justify continuation of affiliation with the Federated American Engineering Societies, one reason being the financial burden that it imposed on the sponsoring societies. Meantime the longer title had been displaced by the name American Engineering Council.

A heterogeneous group of regional, state and local organizations became affiliated with the Council; but the financial support came from (and, consequently, control resided in) the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, later joined by the American Society of Civil Engineers, which did not participate at the start. From 1920 to 1940, the three societies contributed about $750,000 to finance the Council; but finally the project was abandoned. Some believed the Council failed because it was not managed effectively; some ascribed the debacle to inability of the three financial angels to agree on matters of policy; and still others felt that inherent weaknesses of any organization of the federation type doomed A.E.C. from the start. In any event, the Council accomplished relatively little of value to the constituent societies or to the profession.

On the other hand, the four societies, occasionally with the collaboration of a few other organizations, have participated in a number of successful joint ventures, of which the more important will be described briefly.

United Engineering Trustees

Originally incorporated in 1904 as United Engineering Society to take title, on behalf of the Founder Societies (then three in number), to the property at 29 West 39th Street in New York, United Engineering Trustees, Inc. now owns and operates the Engineering Societies Building and the Engineering Societies Library. The land and buildings are valued at $1,993,793 and a depreciation fund of $585,721 has been accumulated. The business of the corporation is conducted by a board on which each of the four societies appoints three Trustees. Each society has an equal and undivided interest in the corporation.

The Engineering Foundation

Established in 1914 by a gift to the four Founder Societies of $200,000, made by Ambrose Swasey, The Engineering Foundation has for its purpose the furtherance of technologic research along broad lines. The income, however, is available for other activities that in the judgment of the Foundation Board will benefit engineering and the engineering profession. Additional contributions by Mr. Swasey and others have brought the principal of the endowment to approximately $940,000. In addition to income in the form of interest, funds contributed by corporations and individuals for the support of special research projects are expended under the direction of the Foundation. For example, since 1930 approximately $240,000, mostly from industry, has been raised to support the Alloys of Iron Research, a project sponsored by the A.I.M.E. Already 13 extremely valuable monographs on carbon steels, alloy steels, and cast iron have been published.

John Fritz Medal Board of Award

Established in 1902, the John Fritz Medal is awarded not oftener than once a year by a board of 16 members, four of whom represent the Founder Societies, one from each. It recognizes "notable, scientific or industrial achievement" and there is no restriction on account of nationality. Among the A.I.M.E. members who have received the award are the following: John Fritz, George Westinghouse, Thomas Alva Edison, Robert Woolston Hunt, John Edson Sweet, James Douglas, Henry Marion Howe, Sir Robert A. Hadfield, Ambrose Swasey, Herbert Clark Hoover, Daniel Cowan Jackling, Paul Dyer Merica, Clarence Floyd Hirshfeld, Everette Lee DeGolyer, Willis Rodney Whitney, and Zay Jeffries.

Hoover Medal Board of Award

"Distinguished public service" by an engineer is the criterion for the award of the Hoover Medal, established in 1929. The selection of the medallist is made by a joint board consisting of representatives of the four Founder Societies. The first award was made to Herbert Hoover in 1930; the second to Ambrose Swasey in 1936; the third to John Frank Stevens in 1938; the fourth to Gano Dunn in 1939; the fifth to D. R. Yarnell in 1941; the sixth to Gerard Swope in 1942; the seventh to Ralph E. Flanders in 1944; the eighth to William Henry Harrison in 1945; and the ninth to Vannevar Bush in 1946.

Washington Award Commission

The Washington Award Commission was founded in 1915 and is administered by the Western Society of Engineers. The Washington Award is presented annually "as an honor conferred on a brother engineer by his fellow engineers on account of accomplishments which preeminently promote the happiness, comfort and well-being of humanity." On the Committee of Award are representatives of the four Founder Societies and the Western Society of Engineers. Among the recipients who were or are members of the A.I.M.E. have been: Herbert Hoover, Robert W. Hunt, Frederick G. Cottrell, and Daniel C. Jackling.

Percy Nicholls Award

Established in 1942, by the A.I.M.E. Coal Division and the A.S.M.E. Fuels Division, the Percy Nicholls certificate recognizes "notable, scientific or industrial achievement in the field of solid fuels." A joint committee of the two Divisions selects the recipients. Among A.I.M.E. members who have received the award are: Ervin George Bailey, 1942; James Bain Morrow, 1945; and Arno C. Fieldner, 1946.

Alfred Noble Prize

Members of the four Founder Societies and the Western Society of Engineers are eligible for the Alfred Noble Prize. A substantial capital sum provides income from which a cash prize is awarded "for a technical paper of particular merit accepted by the Publication Committee of any of the foregoing societies for publication, in whole or in abstract, in any of their respective technical publications; provided the author, at the time the paper is accepted . . . is not over thirty years of age." The initial award of the prize was made in 1931 to C. T. Eddy, and in 1938 the award was made to Ralph J Schilthuis, both members of the A.I.M.E.

Engineers' Council for Professional Development

The Engineers' Council for Professional Development (E.C.P.D.) was organized in 1932 as a joint organization in which the participants, besides the four Founder Societies, are the American Institute of Chemical Engineers, the Society for Engineering Education, the National Council of State Boards of Engineering Examiners, and the Engineering Institute of Canada. The principal activities of the Council are indicated by the names of the four standing committees:

1. Committee on Student Selection and Guidance.
2. Committee on Engineering Schools, the principal function of which is the accrediting of curricula in engineering and technology.
3. Committee on Professional Training, the principal objective of which is to promote the personal and professional progress of young engineering graduates.
4. Committee on Professional Recognition.

The most tangible activity of the E.C.P.D. to date has been accrediting. Some 580 engineering curricula in 125 institutions have been certified as meeting minimum standards as to quality of content, adequacy of physical equipment, and proficiency of teaching personnel. A by-product of the Committee on Professional Recognition is the formulation of a creed for engineers, which appears on the following page.

Faith of the Engineer

I am an Engineer. In my profession I take deep pride, but without vainglory; to it I owe solemn obligations that I am eager to fulfill.

As an Engineer, I will participate in none but honest enterprise. To him that has engaged my services, as employer or client, I will give the utmost of performance and fidelity.

When needed, my skill and knowledge shall be given without reservation for the public good. From special capacity springs the obligation to use it well in the service of humanity; and I accept the challenge that this implies.

Jealous of the high repute of my calling, I will strive to protect the interests and the good name of any engineer that I know to be deserving; but I will not shrink, should duty dictate, from disclosing the truth regarding anyone that, by unscrupulous act, has shown himself unworthy of the profession.

Since the Age of Stone, human progress has been conditioned by the genius of my professional forebears. By them have been rendered usable to mankind Nature's vast resources of material and energy. By them have been vitalized and turned to practical account the principles of science and the revelations of technology. Except for this heritage of accumulated experience, my efforts would be feeble. I dedicate myself to the dissemination of engineering knowledge, and, especially, to the instruction of younger members of my profession in all its arts and traditions.

To my fellows I pledge, in the same full measure I ask of them, integrity and fair dealing, tolerance and respect, and devotion to the standards and the dignity of our profession; with the consciousness, always, that our special expertness carries with it the obligation to serve humanity with complete sincerity.

The FAITH OF THE ENGINEER of which the Secretary of the American Institute of Mining and Metallurgical Engineers is the author, was presented to the Eleventh Annual Meeting of Engineers' Council for Professional Development in October 1943, by the Committee on Principles of Engineering Ethics, and received unanimous approval.

Engineers Joint Council

For 15 years prior to 1941, an informal organization known as the Joint Conference Committee, consisting of the incumbent presidents and secretaries of the four Founder Societies, had met at irregular intervals to consider matters of mutual concern and to make recommendations for concurrent and concordant action by the societies. In 1944, a somewhat more formal program and procedure were adopted; and in 1944 the membership was enlarged by including the junior past president of each society and by inviting the American Institute of Chemical Engineers to become a participant. The name Engineers Joint Council was adopted in 1945.

Several meetings of this small hierarchy have been held each year and a number of projects have been undertaken, one being the development of a scheme for the "organization of the engineering profession as a whole" on a permanent basis and on a local and state as well as a national level. Another project is a comprehensive research on the "economic status of the engineer," an undertaking involving the expenditure of $26,000 to which the A.I.M.E. has contributed about $4,000—from sources outside its regular budget. A related subject of study through joint committees of the E.J.C. deals with problems arising from collective bargaining. Other joint committees have cooperated on several occasions with the U.S. War Department and the Department of State in matters where specialized engineering knowledge was important.

According to its charter, the E.J.C. is an advisory agency, its functions being to promote and recommend parallel and concurrent action by the constituent societies on matters of common interest. A proposal made in 1946 to turn it into an elaborate organization with a budget of $200,000 a year and a large paid staff was opposed by several of the constituents, including the A.I.M.E.

Engineering Societies Personnel Service, Inc.

From the minutes of the A.I.M.E. Council meeting held in Montreal, Canada, on September 16, 1879, is taken the following:

> "The Secretary [Dr. Drown] was authorized, on his own suggestion, to establish an employment agency for Members and Associates of the Institute, the object being simply to bring into communication persons desiring employment and those wishing professional services. Members and Associates may send their names to the Secretary giving the kind of position desired and also a brief account of previous experience. All persons (whether members of the Institute or not) may apply to the Secretary for information concerning suitable persons for mines and works, and the Secretary will then send the names on his list, exercising no further discretion in the matter than to give those names corresponding with the demand."

How much work of this kind was carried on in an informal way by the Secretary's office does not appear in the record. However, in the official Institute report for the year 1913 is the statement that "the Employment Department was started in March 1913 and already has shown its importance as one of the Institute's activities." The program provided for the publication each month, in the BULLETIN, of a list of vacant positions and "notes concerning the qualifications and desires of such members as are open for engagement." Further along in the report one reads, "No charge is made for this service, since the Institute considers it a privilege and a duty to help its members, whether they are employers or engineers, in search of positions."

Some years later—in 1918—the four Founder Societies joined in organizing the Engineering Societies Employment Service. Offices were established in Chicago and in San Francisco as well as at 29 West 39th Street, New York City. Walter V. Brown, who took charge in New York, devoted 22 years of conscientious effort to the Service before he retired in 1940. The societies through their publications gave free publicity to "Men Available" and "Positions Open" notices.

Although a charge is made to the member (or nonmember) who is placed by the Service, the financial record has been spotty; and, especially in periods of industrial and business depression, placements and income have shrunk and the societies have been obliged to contribute varying amounts each year to keep the Service alive. For years, assessments were based on the number of members of the particular society for whom positions had been found during the preceding year. However, the cost per A.I.M.E. member was never more than 20 cents per year, and that small subsidy seemed well warranted.

In 1940, it became expedient to form a corporation; and the present name —Engineering Societies Personnel Service, Inc.—was adopted, the incorporators being the Secretaries of the four Founder Societies, *ex officiis*.

The New York office was moved from 29 West 39th St. to 8 West 40th St., New York City. Since that time business has been excellent and a substantial reserve fund has been accumulated against a rainy day in the future. Two additional offices were established, one at Detroit and another at Boston, but the latter was discontinued as part of E.S.P.S. after about a year.

The Service has not been free of criticism. At times both employees and employers have found fault. No one, however, has proposed that it be abolished; and, despite some shortcomings, it has in 30 years found well-paid and satisfactory positions for many thousands of members of the four Founder Societies.

Engineering Societies Library

Periodical magazines and books in the field of technology, and bound volumes of the proceedings of professional societies, are indispensable tools of the engineer. A considerable collection of publications on geology, mining, and metallurgy had been accumulated by Dr. Drown as Secretary of the Institute and were housed in Pardee Hall, at Lafayette College, Easton, Pa., when the Hall was destroyed by fire in 1879. Dr. Drown persuaded members and friends to replace many of the volumes that were lost in the fire, and to donate others. The collection continued to grow during the time when the Office of the Secretary (Dr. Raymond) was successively at 13 Burling Slip and 99 John Street, New York City. It had become known as one of the best libraries of its kind when, in 1907, it was moved to the new "Carnegie" Building at 29 West 39th Street. At first, the three societies—A.I.M.E., A.I.E.E. and A.S.M.E.—maintained separate "departments"; but in 1913 the three were consolidated and in 1916 the library of the A.S.C.E. was added.

In 1917, Harrison W. Craver was made Director of the combined library, a post that he held with distinction for nearly 30 years. Steady and healthy growth continued; and, without question, the societies can claim for the Library the largest and finest collection of engineering books and bound periodicals in the world. Of the 160,000 volumes, many are extremely rare. A notable feature is the use made of the library by "nonvisitors"; i.e., by those who get information by mail or telephone, who write for searches, indexes, bibliographies, translations, photostatic or microfilm copies. Any or all of these will be prepared by competent specialists at moderate rates and orders for such service come from all parts of the world. Any member of a Founder Society in good standing, residing in continental United States or Canada, may borrow a maximum of three volumes at a time for a period of two weeks, at a charge of only 25 cents per volume per week. Frequently A.I.M.E. members living away from New York complain that the Library is of little value to them; but the fact is that about 35 per cent of those who avail themselves of the library service are not residents of New York.

The net cost of operating the Library is a charge against the Founder Societies. Each of the four pays $5,000 per year plus a flat amount for each dues-paying member. A part of the A.I.M.E. assessment is covered each year by the income from an endowment fund of something over $100,000 established in 1919 in honor of Dr. James Douglas. It is an A.I.M.E. fund; but the income was earmarked by the donors to be used *only* to help defray that part of the cost of the Library borne by the A.I.M.E.

ACTIVITIES IN TWO WARS

Addressing the Annual Meeting on February 19, 1918, Philip N. Moore, President of the Institute for 1917, made these pertinent remarks:

> "Coming to your leadership at a time of great national anxiety, your speaker was hardly installed ere this country joined in the world war. The question at once rose: What can the Institute do of national service? Following pilgrimages to Washington, certain conclusions forced themselves upon him. One was an impression of great confusion and duplication of work by officials and departments, as well as by patriotic volunteers, arising through lack of organization, and for which reason it would be unwise to attempt immediate independent service by the organization, as such. By elimination also, it was clear that nothing should be undertaken in duplication of work already in the hands of others, no matter if it might seem that such work could be more fitly assigned to our members; and, second, that whatever be undertaken, it should be through the official bureaus of the Government already dealing with matters wherein our profession is expert."

Pursuing the policy just outlined, the Institute participated during World War I in a number of worth-while projects; and its members contributed to them in an important way. Some of the more significant of these may be mentioned as follows:

1. In cooperation with the three other Founder Societies, a new agency called Engineering Council was organized in 1917. (It later became American Engineering Council.) The primary function of the Council was to assist the Federal Government by advising in matters where mature and competent engineering judgment and knowledge were needed.
2. A "branch" of Engineering Council was the War Committee of the Technical Societies, which assisted in mobilizing inventive and technologic ability. D. W. Brunton, Past President of A.I.M.E., was Chairman.
3. The A.I.M.E. aided the U. S. Bureau of Mines in preparation and distribution of a questionnaire that returned 7500 detailed records of the experience and qualifications of geologists, mining engineers, and metallurgists.
4. The War Minerals Committee, on which the Bureau of Mines and the Geological Survey cooperated with the A.I.M.E. rendered invaluable service in directing the development and exploitation of deposits of critical minerals. William Y. Westervelt, the Chairman, and all the committeemen were A.I.M.E. members.
5. More than 50 members of the Institute served on the Naval Consulting Board, of which W. L. Saunders was Chairman. One important func-

tion of the Board was to review "thousands of ideas weekly" and screen out those that had no practical value. The work of the Board won high commendation from the Secretary of the Navy.

By the time humanity plunged into World War II, the mineral industry had become even more vital than it was during the war period of 1914–1918. As the elaborate engines and matériel of modern mobile warfare are made, for the most part, of metals and other minerals, and are powered by mineral fuels, the industries represented by the A.I.M.E. were of primary and vital importance. Of some 29 critical materials officially listed by the War Production Board (a U.S. Government war agency), 24 were minerals. An alternate for one of the others, rated as a nonmineral, was made principally from petroleum. This alludes, of course, to rubber. The procurement of tremendous quantities of such raw materials and the effective processing, fabrication, and utilization of them depended on members of those branches of the engineering profession represented by the A.I.M.E. That an adequate supply was obtained was due to the finding and development of additional mineral deposits; the devising of improved methods for exploiting mineral deposits and processing the raw materials produced; the adaptation of sundry metals and other minerals as alternates for less plentiful materials; and the development of new techniques for utilization and manufacture involving minerals and metals. The Institute's attention was focused on problems of this kind during the war; but, more important perhaps, was the cumulative value of technology in the sphere of minerals that, over the years, had been fostered and sponsored by A.I.M.E.

As an organization the Institute did not strive to get its name identified with boards, committees or councils—of which there were scores—simply to get into the limelight. On the other hand, it appointed representatives to many joint agencies when it was felt that something useful could be accomplished. Among these were:

Engineering Consultive Committee to the War Manpower Commission.
Board of Technical Censorship, Office of War Information.
Advisory Committee, Roster of Scientific and Specialized Personnel.
Joint Committee on Postwar Planning (Founder Societies).
Committee on Inter-American Engineering Cooperation.
Engineers Defense Board.
National Technologic Civil Protection Committee.
Joint Committee on War Production Conferences.

The Secretary's office responded to innumerable requests for assistance from permanent Government establishments such as the War, Navy and State Departments; and from a multitude of special agencies that were established temporarily for the prosecution of the war. One particularly useful contribution was the nomination of men qualified for special assignments or to fill full-time positions in various agencies. Hundreds of men might be mentioned, but among those who held positions of importance over considerable periods of time are the following: Howard I. Young, R. C. Allen, C. K. Leith, Arthur H. Bunker, John A. Church, and George C. Heikes, of the War Production Board. It was the largest of the special agencies and had overall supervision of production, procurement and manufacture of materials and matériel. Among those who served in the Petroleum Administration for War were J. Terry Duce, W. B. Heroy and E. DeGolyer. In the Office of Scientific Research and Development was C. K. Leith; and one of the important branches of the Office was the War Metallurgy Committee, of which Clyde Williams was chairman and Zay Jeffries vice-chairman. G. Temple Bridgman, H. T. Hamilton and H. DeWitt Smith were active in the Metals Reserve Co., through which vital plant construction and metal production were financed. Fred Searls, Jr., spent a large part of his time in Washington on the staft of the Office of War Mobilization and Reconstruction. Alan M. Bateman was in charge of mineral resources of the Board of Economic Warfare, and scores of other A.I.M.E. members assisted him.

A significant side light is the fact that the membership of the Washington, D. C., Section, A.I.M.E., increased from 200 to nearly 600 during the war. In addition to those who moved their residence to Washington, hundreds of members spent a large part of their time, many of them commuted weekly, for civilian war work in Washington.

CONSTITUTION AND BYLAWS

Not until February 21, 1905, did the Institute boast the luxury of a Constitution and a set of Bylaws. Until that time the business of the Institute had been conducted under a set of Rules. As adopted on May 16, 1871, there were 22 such rules; but numerous amendments of relative minor import had compressed them into eight by 1904. In the original version, after setting forth the objectives and the qualifications for membership (Members, Honorary Members and Associates) the Rules specified:

> "The officers who shall constitute a Council for the direction of the affairs of the Institute, shall consist of a President, who shall be a Mining Engineer, six Vice-Presidents, at least four of whom shall be Mining Engineers (the words 'Mining Engineers' in these rules comprehend Engineers connected either with mining or metallurgy), nine Managers, at least six of whom shall be Mining Engineers, a Secretary, and Treasurer. All these officers shall be members or associates of the Institute, and shall be elected at the annual meeting."

One of the changes made later was the omission of the specifications as to eligibility. The method of conducting elections had undergone only minor change. It provided that any member could send to the Secretary in writing nominations for vacancies, at least 30 days before the Annual Meeting. Two weeks before the meeting the Secretary would mail to every Member and Associate a list of nominations, together with any additional nominations or recommendations that the Council might desire to add. A ballot prepared by the member could either be mailed to the Secretary or could be presented in person at the Annual Meeting. Immediately following the meeting, scrutineers would count the valid ballots and promptly, by mandate, destroy them!

The Bylaws provided for the holding of four general meetings each year (the number later reduced); outlined the procedure for acceptance and publication of technical papers and imposed an annual subscription by each Member and Associate of $10.

The occasion for incorporating in 1904 was to facilitate "giving assent and cooperation to the generous offer of Andrew Carnegie, a member of the Institute, to provide a building in the City of New York for the use of American engineering societies." At the meeting of the Council on April 6, 1904, a committee was authorized to proceed to take steps necessary to incorporate; and at a general meeting held on December 29, 1904, a resolution was adopted authorizing the Directors of the new corporation to "communicate and adopt a constitution and bylaws."

The original Certificate of Incorporation, under the Membership Corporations Law of the State of New York, was signed by Justice Samuel Greenbaum of the Supreme Court, on January 7, 1905. It provided for nine Directors, of whom three would be elected for a three-year term at each annual meeting of the Institute. The Directors *from among their number* were to elect each year a President, a Secretary, and a Treasurer. All "business and financial affairs of the Institute" were to be managed by the Board of Directors. An elaborate procedure for hearing charges of misconduct of a member and for suspension or expulsion was provided as a new feature.

Most significant among the provisions of the Constitution of February 21, 1905 was Section 1, Article VIII, which said:

> "The professional, technical, scientific, and social interest of the Institute shall be committed to the supervision of a Council composed of a president of the Council, six vice presidents of the Council, a secretary of the Council and nine Councilors who shall be elected . . . Members of the Council may or may not be members of the Board of Directors."

Except for the fact that the Secretary of the Institute and the Secretary of the Council were one and the same person, the dual scheme of organization might have been extremely awkward. In practice it became customary for the Directors and the Councilors to hold their meetings jointly, and in 1913 the obviously sensible step was taken of abolishing the Council and lodging complete control of the Institute's affairs in the Board of Directors as the single governing body.

Adoption of a completely revised Constitution and Bylaws was accomplished at the Annual Meeting on February 18, 1913. Among the changes introduced may be mentioned:

1. The Council was abolished and its functions assigned to the Board of Directors.
2. A "class" of membership known as Junior Member was established (afterward called Junior Associate).
3. A detailed procedure for nominating and for electing officers and directors by letter ballot was formulated.
4. The functions of a Committee on Papers and Publications were defined in detail. Provision was made for appeal by an author whose paper had been declined.
5. Provision was made for the establishment of Divisions of the Institute.
6. Provision was made for the establishment of Local Sections of the Institute. (A resolution authorizing Local Sections had been adopted by the Council in 1911 but the Bylaws had not been changed.)
7. Provision was made for the "recognition of Affiliated Student Societies," comprising students in engineering at an approved technical school. (The Council in 1910 by resolution had approved a plan to recognize "Auxiliary Student Societies;" the adjective had been changed to "Affiliated" and 11 student groups had been enrolled during that year.)

As early as 1876 the proposal had been made that the word "Metallurgical" be introduced into the name of the Institute. Thereafter at intervals the suggestion was a subject of warm debate; but 43 years elapsed before action was taken. Finally, at the meeting on February 18, 1919, the Constitution was amended to change the name to the American Institute of Mining and Metallurgical Engineers, with the specific proviso that the official abbreviation be A.I.M.E.—a proviso that is often breached by many members as well as by others.

At the meeting on February 21, 1928, the Constitution and Bylaws were again thoroughly revamped so as to shift a large part of the matter formerly in the Constitution into the Bylaws. The new constitution contains only four short articles, the longest describing the procedure for amending it! Many details formerly incorporated in the Bylaws were omitted from the new text. For the record, there is reproduced here Section 2, Article I, of the Constitution at last revised:

> "The objects of this Institute, as set forth in its certificate of incorporation, are: To promote the arts and sciences connected with the economic production of the useful minerals and metals, and the welfare of those employed in these industries by all lawful means; to hold meetings for social intercourse and the reading and discussion of professional papers, and to circulate by means of publications among its members the information thus obtained, and to establish and maintain a place for meeting of its members, and a hall for the reading of papers and delivery of addresses, and a library of books relating to subjects cognate to the sciences and arts of mining and metallurgy."

Amendments to the Bylaws have been made at frequent intervals since 1928; but no general revision has been undertaken. Many of the amendments are alluded to in other sections of this history; but mention will be made here of changes that have to do with the constitution of the Board of Directors and the method of nominating and electing Officers and Directors.

Election of Officers

Like most other professional societies, A.I.M.E. always has struggled with the problem of developing a satisfactory procedure for choosing its officers and directors. What is sought is a "democratic" system; and by this is meant a system in which the rank and file of the members have a voice in determining who their officers shall be. But a workable procedure to accomplish this purpose is not easy to devise. For one thing, experience has shown that the job must seek the man rather than the converse—a member does not come out and offer himself as a candidate. As a matter of fact, only in rare instances has a member permitted his friends to "run" him in competition with another. The reason is that there are no parties, no platforms, and no specific issues in a professional society election; and men of high calibre usually decline to enter a contest based purely on personalities.

The A.I.M.E. has found—and this conclusion accords with that reached by trial and error by most similar societies—that the naming by a nominating committee of an "official" ticket bearing the name of only one candidate for each office is the most satisfactory plan. As insurance against the possibility (however remote) that a nominating committee might select one or more candidates that were palpably unsuitable, provision must be made to permit any group of members to propose independent candidates. Having done this, the problem then becomes: (1) to choose a nominating committee that is thoroughly representative and that commands the confidence of the membership; and (2) to establish for the guidance of the committee conditions that will automatically assure equitable geographic distribution of directorships and appropriate representation on the Board of the various Divisions.

Contemporaneously with the abolition of the Council in the new Constitution of 1913, provision was made for the appointment by the Board of Directors "of a Committee on Nominations of which no member shall be at that time on the Board. This committee shall consist of the chairmen of three Local Sections, one ex-president and three other members of the Institute." The Board as constituted under the new Constitution had 24 members, of whom one was President, two Past Presidents, six Vice Presidents, and 15 Directors; and as election was for three years (the President to serve two years as Past President), the Nominating Committee each year named

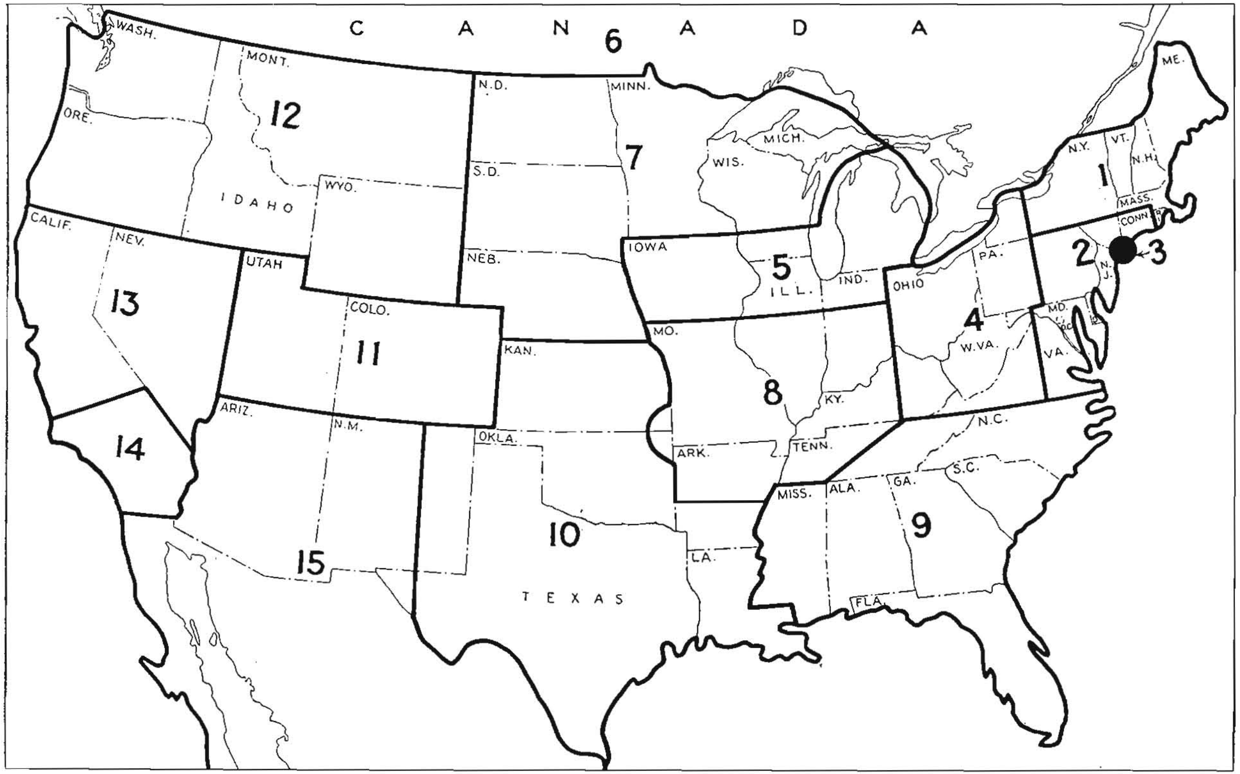

FIG. 4—*Geographical districts from which Directors are to be chosen.*

Districts 1, 5, 6, 11, 12, 13, 14, and 15 are assigned one Directorship each; District 2, three Directorships; District 3, eight Directorships; Districts 4 and 10, two Directorships; and Districts 7, 8, and 9, two Directorships between them. There are three Directorships at large.

eight candidates. In doing so they were instructed "so far as practical [to] distribute the representation of the Board geographically."

The Constitution also directed that the official ticket be published and that an interval be provided during which 25 members might submit a "complete or partial ticket in opposition to the official ticket." An elaborate procedure was formulated for conducting a secret letter ballot by printing and circulating to the membership the official ticket and any supplementary ticket, each printed separately. Spaces were provided on the official ticket so that any candidate could be "scratched" and the name of a substitute written in.

No essential change was made in this procedure until 1936. The delineation of the Districts had been dropped from the Bylaws and distribution of directorships, according to geography, had become rather haphazard. Moreover, the establishment and steady growth of the Divisions had introduced another element: the need for representation of the various technologic groups. Accordingly, on April 17, 1936, the Board of Directors approved a plan to establish 15 Districts for the assignment of directorships as shown on the map (Fig. 4) and adopted a resolution of which the following is part:

Instructions and Advice to the Members of the A.I.M.E. Nominating Committee

GEOGRAPHICAL DISTRIBUTION

The Bylaws provide that "the Nominating Committee shall, as far as practicable, distribute representation on the Board geographically." Pursuant to this provision, the United States, Canada and Mexico have been divided into fifteen districts, as shown on the official map. . . . It will be the duty of the Nominating Committee to make selections that will give effect to this allocation [see Fig. 4] of directorships. There is nothing to prevent a Director being named to succeed himself.

CONSULTATION WITH LOCAL SECTIONS

In order that the members residing in a District may be given an opportunity to express preference as to their representative or representatives, the Nominating Committee is instructed to invite the Local Sections in each District to suggest candidates for the consideration of the Committee. While the Committee may not always find it practical to nominate a person so proposed, such endorsement should be given primary consideration by the Nominating Committee.

DISTRIBUTION AS TO MAJOR INTEREST

In addition to geographical distribution of directorships it is highly desirable that the Board should include representatives of all the various phases of Institute activity. Each of the technical Divisions is entitled to representation by one or two Directors whose major interest is in its field . . .

In nominating the candidate for Director and President, particular consideration should be given to "major interest." It is desirable that the principle of rotation as to primary interest should be a factor in selecting the presidential candidate.

The foregoing provided for 27 Directors instead of 24; and an amendment to the Bylaws increasing the number was adopted at the meeting of the Board on June 18, 1936. Nine years later (November 1945), in order to bring the incumbent heads of the Divisions into closer contact with the current problems and deliberations of the Board of Directors, the Bylaws were amended by adding the following to Section 1, Article VI, of the Bylaws, which mentions the 27 Directors: "and in addition the Chairman of each duly constituted professional Division of the Institute, *ex officio*, shall serve as a Director with full voting power during his term as Chairman." This gives the Board of Directors a total membership of 33.

Agitation for a more democratic method for nominating and electing Directors resulted in the appointment in 1945 of a special committee headed by C. Harry Benedict to study the problem and recommend changes. Following the program formulated by this committee, two significant changes were made in 1946, as follows:

1. The seven-member nominating committee to be appointed by the Board of Directors was superseded by a committee of 18, of whom one shall be designated by each of the 15 geographical districts, and three, including the chairman, by the Board of Directors. The entire personnel of the Committee is published in the December issue of MINING AND METALLURGY, so as to give any Institute member ample opportunity to advance the interests of any potential candidate. The Committee convenes in one or more executive sessions at the time and place of the Annual February Meeting; and canvasses the situation thoroughly, fully and frankly, before preparing the official ticket. Heretofore, nominating committees have been handicapped by being obliged to do most of their deliberating by correspondence; but under the new scheme a full attendance in person is assured. The Committee operates under the instructions adopted in 1936, as heretofore recited; but there is no question that the members of the Institute feel that they have a more direct voice in naming the official ticket under the new plan.

2. Polling of the members by letter ballot has been abolished as a normal procedure; that is to say, no ballot is printed and distributed unless nominations are made other than those constituting the official ticket. In the absence of such nominations sponsored by at least 25 members and formally presented by September 1, the official nominees are declared elected at the meeting of the Directors in November. The casting of a ballot as a matter of form when the result was a foregone conclusion has sorely irritated many members. Moreover, the meaningless procedure cost about $1,000 annually.

Mr. Benedict's committee, the members of which were drawn from widely scattered sections, were in general agreement that the candidates chosen by the Nominating Committees over the past 15 years had been men of the highest calibre. Such discontent as had been found was based *not* on the results attained by the system but on the system itself.

THE INSTITUTE AS A FORUM

One of the most frequently made errors of A.I.M.E. members regarding basic Institute policies has stemmed from the stern interdiction against "official participation or action" in controversial matters. Many deemed this to prohibit frank discussion of such matters at Institute meetings or in the columns of its publications. This emphatically is a misapprehension. The Institute, in the most liberal sense, provides an open forum to which members, or, in fact, anyone else, are welcome. For reasons that are apparent, the subject matter of debate should have more than a remote relation to the mineral industry; but granted this relation, whether the topic of controversy is scientific, technologic, economic, or even broadly political, the Institute offers an open forum for intelligent discussion. For example, the Institute has refused to take a position *as an organization* on the questions listed below, but it has permitted and encouraged debate, written and oral, of each:

1. The relative merits of aluminum vs. stainless steel for railway cars.
2. High tariffs on metals vs. low—or none at all.
3. Public ownership vs. private ownership of hydroelectric systems.
4. The "hot-water" vs. the "cold-water" theory of ore deposition.
5. Participation vs. nonparticipation of professional engineers in collective bargaining through unions.
6. The virtues vs. the vices of "simplified" spelling.

A highly significant episode occurred in 1923. Henry L. Doherty was the instigator and ardent advocate of a plan to restrict by law the production of petroleum as a measure for conservation. At the time this notion was so "radical," so "full of dynamite," that the American Petroleum Institute declined to let Mr. Doherty deliver a paper on the subject at its meeting, although he was a director of the organization. The A.I.M.E. promptly agreed to presentation of the paper as a feature of its annual meeting. The principles advocated by Mr. Doherty later became the basis for a conservation program adopted by the petroleum industry; but that is not the point—the point is that the A.I.M.E. welcomed presentation of a subject that was controversial almost to the extent of hysteria!

Rule 17 of the 22 Rules adopted on May 16, 1871 reads:

> "The Institute is not, as a body, responsible for the facts and opinions advanced in the papers which may be read, nor in the abstracts of the conversations which may take place at the meetings of the Institute."

At the New York meeting in 1877, a resolution was introduced urging the adoption of the metric system of weights and measures. It was ruled that the

Institute "could not declare opinions or take or recommend action on any subject outside of the conduct of its own proceedings and publications . . . because the first object—information—requires that questions shall not be settled, but kept open; while the second object—social enjoyment—requires that contests of the parties shall be avoided."

Adopted in 1896 was a rule that provided "nor shall the Council or Institute approve or disapprove any technical or scientific opinion or any proposed enterprise"; and furthermore, "no action shall be taken binding the Institute for or against the conclusions of any such report [one made by a special committee]."

In substance, the foregoing declarations form the basis for the policy of today. An editorial from MINING AND METALLURGY for March 1946, entitled "Controversial Matters and the Institute," among other things says:

> "Frequently it is urged that the Institute should abandon its expressed policy to refrain from 'official participation or action' in controversial matters—whether they are 'political,' 'semipolitical,' or 'nontechnical economic,' to quote from the resolutions of the Board of Directors. One valued member argues that as a result of adherence to this policy 'we engineers find ourselves playing second fiddle to economists, lawyers, and members of other professions in making policy and framing legislation that greatly affects the welfare of the nation, our industry, and the members of our profession.' Many feel that the prestige of the Institute and of the profession would be enhanced if this basic policy were changed. . . .
>
> "Fundamentally, the basis for the present policy is the fact that all members of the Institute seldom see eye to eye on controversial matters, even those involving broad economic policy. . . .
>
> "On numerous occasions the Directors of the Institute have adopted resolutions addressed to Washington officials supporting various policies and even endorsing specific legislation. Questions involving Selective Service and the establishment of a National Science Foundation (Kilgore Bill) are examples. However, such action has been taken only when the Board was morally certain that the position taken would have the support of at least 99 per cent of the Institute's membership. In other words, the matters were outside of the realm of controversy—so far as the Institute was concerned.
>
> "One significant aspect of this subject that members sometimes overlook is that the interdiction applies only to committing the whole Institute publicly and officially to a given position or policy. It is important to stress that the Institute at its meeting and in its publications—primarily Mining and Metallurgy—welcomes discussion and debate on controversial questions. So long as the matter is one of broad significance to the mineral industry, to one of its branches, or to the profession, and so long as it is conducted with reasonable decorum no verbal battle can be too impassioned for the forum provided by the Institute. . . . "

The A.I.M.E. is never afraid of facts, of the opinions of its members, or of intelligent argument or debate. It can endorse wholeheartedly the philosopher who wrote:

"Whoever knew truth put to the worse in free and open encounter."

The greatest enemy to progress is secrecy—the suppression of the facts—censorship. From the start, the A.I.M.E. has been an ardent advocate and promoter of free and open discussion. Only in such a climate can technology thrive and progress. The present healthy condition of most of the mineral industries is in no small measure the result of the Institute's policy in this respect.

THE WOMAN'S AUXILIARY

Born just a few months before the United States entered World War I, and after almost three years of devastating struggle in Europe, it was natural that the Woman's Auxiliary to the A.I.M.E. should have set for itself a goal of high endeavor "for our country, for our community, or for any section of humanity," to quote the remarks of Mrs. Sidney J. Jennings, on the morning of February 20, 1917.

The published report of the Annual February Meeting in New York contains this statement:

> "On Tuesday morning at 10:30 a.m., under the chairmanship of Mrs. Sidney J. Jennings an open forum on current events of the day was held Mrs [W. L.] Honnold and Mrs [Vernon] Kellogg of the Commission for the Relief of Belgium, made addresses on the work of this Commission and the ladies present thereupon organized a Woman's Auxiliary of [to] the American Institute of Mining [and Metallurgical] Engineers."

Later, the following officers were elected:

Mrs. Sidney J. Jennings, *President*
Mrs. Arthur S. Dwight, *First Vice President*
Mrs. Henry S. Munroe, *Second Vice President*
Mrs. H. W. Hardinge, *Third Vice President*
Mrs. George D. Barron, *Treasurer*
Mrs. Axel O. Ihlseng, *Corresponding Secretary*
Mrs. Bradley Stoughton, *Recording Secretary*

In her address, Mrs. Jennings outlined two principal purposes for the Auxiliary. She recalled the "royal hospitality" that had been extended by the wives and daughters of the members in Arizona, Utah, California, Montana, and elsewhere to visiting ladies on the occasion of recent western meetings. This had suggested that one object of the Auxiliary might be to develop "a closer bond of union such as is now enjoyed by the men" among the women of the families of Institute members. The desirability of this social side of the new enterprise was accentuated no doubt by the habit of engineers in mining and allied fields to move about the country more than "normal" people and to take their families with them.

The establishment of Local Sections of the Auxiliary, of which 26 are now active (Table 7), was a means of implementing the "good fellowship" activities. The Sections are by no means confined to metropolitan centers; and in both large and small communities the Auxiliary is often a focal point for pleasant social intercourse among the families of members of the Institute. As already suggested, one important function of Local Sections of the Auxiliary has been to act as host to visiting ladies on the occasion of Regional, and, in many instances, of Divisional meetings.

The ladies in New York always have been active as hostesses sponsoring the social events in connection with the Annual February Meeting. Some doubt seems to exist as to whether they function as members of the New York Section or as members of the "national" organization; but the question certainly is academic. They do the work, and do it well.

Rather than suggest that social activities are subordinated to the "serious" work of the Auxiliary, or vice versa, it might be said that the two make an excellent team and complement each other. Moreover, the Local Sections participate effectively in many of the activities that are directed by the national organization. The principal committees in charge of this work are:

1. Educational Fund Committee.
2. Library Committee.
3. Chest Committee.

The purpose of the Educational Fund is to give financial assistance to deserving young men studying mining, metallurgical, and petroleum engineering or other courses in mineral technology. Local Sections recommend and vouch for candidates; and great care is exercised in making selections. Loans have ranged from $100 to as much as $750 a year and a repayment after graduation of 50 per cent of the loan is expected. Since 1920, when the Fund was first established, loans have been made to 155 young men in amounts totaling $92,833; and $33,709 has been repaid. The Fund has endowments totaling more than $100,000 from which the income is available for loans; and in addition most of the Local Sections make annual contributions that in the aggregate are substantial.

The Library Committee was organized in 1922. Since that time the Auxiliary has established 29 libraries in 14 states and Alaska, serving mining communities that otherwise would not enjoy adequate library facilities. About 75,000 volumes have been contributed to stock these libraries; and naturally the greater part of this work falls on the Local Section groups.

During World War II the Auxiliary found expanded opportunity for library work in connection with training camps, hospitals, naval vessels, and U.S.O. (United Service Organizations) centers. The record of accomplishment is one in which the library committees, national and local, can be more than proud.

A third "service" activity is under the direction of the Chest Committee, first known as the Welfare Committee (1918), and later as the Emergency

Chest Committee (1922). Hundreds of undertakings of a wide variety of types, involving the collection and expenditure of tens of thousands of dollars, can be credited to this group. Again the work can be divided into two categories: (1) projects of the National Committee; and (2) projects of the Local Sections.

Soon after the Auxiliary was organized, $12,000 was raised by a subcommittee on Belgian Relief for the purpose of feeding Belgian children. A subcommittee on Americanization was organized to work in the United States among children of foreign-born parents. A fund of $6,000 was raised to endow a memorial bed at the American Hospital for Women and Children at Rheims (France). In 1926, financial aid was given to the Tubercular Hospital for Children at Tucson, Ariz.; and in 1928, the Chest Committee assisted the U. S. Bureau of Mines in relief work among the families of stricken coal miners. During the years of the depression (1931 to 1933), the Auxiliary aided the work of the Engineers Emergency Unemployment Committee.

TABLE 7—*Local Sections of the Woman's Auxiliary to the A.I.M.E.* (*Active in 1947*)

Section	Established	Section	Established
Alabama, Birmingham	1940	Montana, Butte	1919
Alaska, Fairbanks	1942	Nevada, Reno	1919
Arizona, Tucson	1919	New Mexico, Socorro	1924
California, Northern	1919	New Mexico, Carlsbad	1941
California, Southern	1919	New York	1917
Colorado, Denver	1919	Ohio, Cleveland	1934
Colorado, Climax	1941	Ohio, Columbus	1919
Connecticut	1919	Pennsylvania, Western	1920
District of Columbia	1918	Pennsylvania, "Anthracite"	1919
Illinois, Chicago	1919	South Dakota, Black Hills	1921
Massachusetts, Boston	1919	Texas, El Paso	1920
Missouri, St. Louis and Rolla	1919	Utah, Salt Lake City	1920
Montana, Anaconda	1919	Washington, Puget Sound	1919

Projects of the National Committee during World War II included: The purchase of two mobile canteens for Great Britain at a cost of $3,500; an ambulance for the U. S. Army that cost $1,350; recreation facilities for the U.S.S. *Boise*, $800; and similar facilities at one of the Pacific outposts, $2,000. But apart from such major activities, most of the 2200 members were working in their Local Sections on a wide variety of useful projects that well met the specifications laid down by Mrs. Jennings in 1917 "for our country, for our community, or for any section of humanity."

One of the reasons for the success of the Auxiliary is the establishment in 1926 of a printed monthly *News Letter*, of about 3500 words, that goes to all members, reporting meetings and activities of the Local Sections and of the national organization. Since 1935, Mrs. George D. Barron has been editor; and according to reports from the Local Sections (so the writer of these notes is assured), the *News Letter* is regarded as indispensable current literature among the members of the Auxiliary.

One index of the value of the Auxiliary to the Institute is the statement frequently made and easily authenticated that Mr. Blank became a member of the Institute because Mrs. Blank insisted that she wanted to participate with her friends as a member of the Local Section of the Auxiliary. At any rate, it is a recognized fact that many of the most successful Local Sections regard themselves as fortunate in having the help of an active and vigorous Section of the Woman's Auxiliary.

TABLE 8—*Presidents of the Woman's Auxiliary to the A.I.M.E.*

Mrs. Sidney J. Jennings	1917
Mrs. Robert C. Gemmell	1918
Mrs. James F. Kemp	1919
Mrs. Arthur S. Dwight	1920–21
Mrs. H. W. Hardinge	1922–23
Mrs. W. Y. Westervelt	1924–25
Mrs. George D. Barron	1926–27
Mrs. Herbert Hoover	1928
Mrs. Donald M. Liddell	1929–30
Mrs. William H. Bassett	1931–32
Mrs. Frederick Laist	1933–34
Mrs. Karl Eilers	1935–36
Mrs. Harrison Souder	1937–38
Mrs. Reed W. Hyde	1939–40
Mrs. Robert Hursh	1941–42
Mrs. Thomas T. Read	1943–44
Mrs. W. Sprott Boyd	1945
Mrs. John P. Dyer	1946–47

CONCLUSION

At the beginning of this recital it was remarked that 75 years had seen no change in the purpose and objectives of the Institute. It has, however, been made evident that the means and methods for achieving these objectives have been changed to meet new conditions as they developed. There has been a process of evolution. No organization can remain static; it will move backward if it does not move forward. The record of the past speaks for itself. Looking ahead, the opportunity for healthy growth and useful achievement is boundless; and no one can reasonably doubt that the A.I.M.E. will attune itself to the progress of the times and meet the challenge of the future.

Seventy-five Years of Progress in Metal Mining

By Lucien Eaton

LUCIEN EATON

Few mining engineers have as broad a background in the technique of removing ores from the earth as is enjoyed by Mr. Eaton. Starting with the Cleveland-Cliffs Iron Company in 1902, he has practiced his profession in many countries of the world, mostly as a consultant on operating problems. He is an inventor and author of several books and many technical articles dealing with the production of ores of copper, gold, lead, zinc, and iron.

THE changes that have occurred in metal mining in the past 75 years include almost everything that we know about modern mining. It is true that in odd corners of the world mining is still carried on as it was before that period, but in the United States such instances are rare. Everything has changed to some extent. Even picks and shovels have changed in design and materials. At the beginning of this period steam power had been used for pumping and hoisting for nearly 75 years, but almost every other operation underground was performed by manpower.

Although mining was carried on in a small way east of the Appalachian Mountains before the Revolution, and continued thereafter on an increasing scale for more than 100 years, it was not until the discovery of the iron and copper deposits in Michigan and Minnesota and the opening of the mineral areas of the West after the building of the transcontinental railroads that the real development of modern metal mining began. In the same period many problems of deep mining in South Africa were solved by new techniques in shaft sinking and hoisting.

Before this time knowledge of mining and skill in its performance were handed down from father to son by the apprentice system, and the son learned to do things in the way his father and grandfather had done them. The rapid expansion of mining in the United States after the Civil War required more men than the apprentice system could supply, and the ever-increasing use of power necessitated new methods and new equipment.

The founding of the Institute, through its meetings and publications, gave to the mining men of the country an opportunity to exchange experiences and ideas, and paved the way for many advances in technique and equipment.

Not least of the changes that have been brought about is the increase in the productivity of labor. Men work much shorter hours than they used to, and do not work as hard physically, yet production per man has increased many fold. The reasons for this increase are better planning, better methods, more and better tools, better explosives and more preliminary development—all requiring greater capital investment. In the old days an investment of $100 to $200 per man was all that was necessary before starting work, whereas now average requirements are $7,000 to $10,000 per man. This change has come about naturally and slowly as the cost of capital has come down and the cost of labor has gone up.

The increase in productive capacity underground has been made possible largely through the development of methods of transmitting power. Steam can be used only on surface and near the shaft underground, and losses in transmission are large. Compressed air can be taken close to the face, and its convenience, in spite of large losses in compression and transmission, has for many applications outweighed its cost. Now electricity has taken the place of compressed air for nearly all operations except drilling, and has even made some inroads there.

Coincident with the increase in production per man has come a greater interest in the safety and well-being of the miner and a reduction in accidents.

In order to evaluate the changes in metal-mining practice and equipment that have occurred in the past 75 years, it seems best first to outline the status of the industry in 1871, describing briefly the practice of that period, and then to follow the changes in different branches of the work since that time.

Metal Mining in 1871

Iron and copper ores were mined in New England, New York, New Jersey, Virginia and North Carolina both underground and in open pits. Before the Civil War gold mining had been active in Georgia and the Carolinas, but had been much curtailed by the efflux of miners to California.

In the Mississippi and Ohio Valleys there was some iron mining in Ohio, Missouri and Alabama, and the Marquette and Menominee iron ranges in Michigan were in full blast. Copper mining in northern Michigan was booming, and work on the conglomerate ores was just starting. Lead and zinc were mined in the Missouri and Wisconsin fields, and the Joplin district had just been opened.

In the West placer mining was widespread, and gold and silver mining were active in Colorado. In California, Idaho and Montana placer mining was active, and Butte was still a placer camp not yet served by a railway. The Black Hills deposits had not been discovered. The greatest activity in underground mining had been on the Comstock Lode in Nevada and on the Mother Lode in California.

In Europe tin, copper, lead and iron were widely mined in England, and early mining practice in California and the Michigan copper country came directly from Cornwall. Mining of many kinds of ores was widespread on the Continent, and the School of Mines at Freiberg was influential in introducing German methods into many other parts of the world. Spanish mining methods had been introduced into Mexico and South America, but in Latin America gold and silver were the principal metals sought, and work was confined to placer mining and mining oxidized ores.

In Africa diamond mining had started at Kimberley, in Cape Colony, but the Rand had not been discovered.

In Australia gold was discovered in 1851, and gold mining was in full blast, using methods imported from California.

MINING METHODS AND EQUIPMENT

In the copper veins of the Keweenaw Peninsula of Michigan and in the California quartz veins, Cornish mining practice had been transplanted almost unchanged, but on the Comstock Lode new practices had been developed to mine the wide veins of shattered quartz, the most important being the use of square sets. In the East and South ore was mined underground by simple open stopes, using much the same practice as had been followed in mining the outcrops of the veins, except that pillars were left to support the back and walls.

In 1871 drilling was done almost entirely by hand, although the first piston drills to be run by compressed air, invented by Sommeiller, had been used in the Mont Cenis tunnel in 1861, and the Burleigh drill had been developed at the Hoosac tunnel in Massachusetts not long after. The drill used at Mont Cenis was not suitable for mining, but the Burleigh drill was widely used in tunneling and drifting in western mines. E. G. Spilsbury reported a test of rock drills in mining at Moresnet, in Belgium, as early as 1865.

Tramming was done in wooden cars, pushed by men or hauled by mules or horses. On short hauls the ore was often moved in wheelbarrows, and was dumped on a platform at the shaft, from which it was shoveled into a skip or bucket. Tracks were poor, and in some instances were laid with strap iron on wooden stringers instead of rails, or with angle irons, the flange being on the track instead of on the wheels. In general the equipment was small, being based on hand drilling and small unit production.

Hoisting was done largely in buckets; at the larger vertical shafts, on cages. Skips were in use on inclines, but the Kimberley skip for vertical shafts had not been invented. Hoisting engines were steam-driven, usually geared to one to four cylindrical drums. If hoisting in balance was practiced, it was only just beginning to be used. Some large steam hoists were in use on the Comstock Lode.

In shallow mines steam pumps were used for removing the water, but most of the deep mines had Cornish pumps driven by steam engines on surface, and in some both hoist and pump were driven by the same engine.

Changes in Practice

Changes in practice have been generally based on greater use of power, better engineering and equipment, better planning and greater preliminary development. The result has been an increase in unit production both in units of area and units of manpower. The improvements have been brought about partly by necessity, because of the exhaustion of rich ores near the surface of the ground, which could be easily won by simple methods, and partly by the greater amount of capital available. Higher wages also have influenced the trend, although the rise in wages has to a large extent been the result of increased productivity. Examples of the changes in practice are the Michigan copper mines, whose large production was based on a large number of small units of production, and the Arizona "porphyry" copper mines, where a large tonnage is obtained from a small number of units.

An interesting point in connection with these changes is that the greatest advances have been made in periods of depression and low prices, at times when a reduction in cost had to be made, if the enterprise was to survive.

EXPLORATION

In 1871 most mineral exploration was carried on first by panning and following float ore and then by trenching and test-pitting, or by shafts and tunnels, methods that sometimes are not used in modern times as much as they ought to be.

Divining rods and "diviners" or "dowsers" were used to some extent, especially in Europe, and still have their following, but seldom among real mining men. Probably the first geophysical instruments successfully used were the dial compass and dip needle, the technique of which was perfected in the early nineties. These were followed shortly by the Tiberg-Thalen magnetometer, which has lately been improved by Lee, and has been adapted to aerial surveying—how successfully has yet to be shown. In the last 25 years much interesting work has been done with torsion balances, with instruments for measuring the differences in electrical resistivity of geological formations, and with seismographs, but less has been accomplished in the discovery of metallic ores than in mapping geological formations in the search for oil and nonmetallics. The subject is too large to be discussed in a paper on metal mining.

In metal mining, drills have been used in exploration for many years. The churn drill far antedates the period under discussion, the cable-type drill having been invented by the Chinese to drill for salt possibly a thousand years ago, but most of the improvements and refinements in its design have come about in the last 30 years. Diamond drills were first described in the TRANSACTIONS of the Institute in 1873, but their prototype was Fauvelle's hollow boring rod with steel crown, described in England in 1846. In recent years they have been radically changed in design. The new drills are lighter and more convenient, and those used underground are driven by electric motors or rotary compressed-air motors. Surface drills are mostly driven by gasoline engines. There have been other improvements, but the most radical change has been the use of bortz chips instead of "black diamonds" in the bits. The chips are impregnated in cast alloy rings, instead of being set individually in the steel of the bit.

Calyx drills were invented a long time after diamond drills. They use loose, chilled shot as a cutting agent, and take out large cores, but are limited to vertical holes and unbroken formations. Among their recent applications perhaps the most interesting is the Newsom method of sinking shafts, which will be discussed under shaft sinking.

SURVEYING AND MAPPING

Although Scott's mine transit was invented in 1831, even 40 years later most mine surveying was done by compass, and accurate maps were the exception rather than the rule.

The accurate surveying and mapping of mine workings since developed have made possible the keeping of invaluable records, and also have become prime necessities in preliminary development work for our most successful mining systems. Without accurate maps and sections the achievements of our geologists would have been impossible, and such engineering feats as sinking and raising shafts from several levels at once could not have been performed.

One of the most noteworthy advances in mine mapping took place on the Witwatersrand, South Africa, where the mining companies adopted uniform scales for their maps, and made those scales proportional—i.e., 1 to

500, 1 to 1000, and so forth—so that they can be used for feet or meters equally well, instead of the awkward scales used by most English-speaking engineers, such as 40 feet to the inch, which is a proportion of 1 to 480.

EXPLOSIVES

Modern methods of mining—in fact, our whole modern civilization—would be impossible without the use of high explosives, and changes and improvements in mining practice have gone hand in hand with improvements in explosives. In 1871 dynamite was only a few years old, and the changes in mining practice that followed were to a large extent due to the introduction of dynamite.

In the following discussion of the origin and development of explosives for mining, I am indebted in large part to "The History of the Explosives Industry in America," by A. P. Van Gelder and Hugo Schlatter, published in 1927.

Coarse black powder was used entirely for blasting until 1865, and for 50 years thereafter it was largely used for many purposes. It is still used in coal mining in many parts of the world, but it has ceased to be a factor in metal mining.

Nitroglycerin was discovered by Ascanio Sobrero, of Turin, Italy, in 1846, but commercial nitroglycerin, or "blasting oil," was first put on the market by Alfred Nobel and his father in 1862, and was first used in the United States in New York in 1865 and in the Pennsylvania oil wells in 1866. It was used in the hard-ore pits on the Marquette Range in Michigan as late as 1892, but disappeared from mining soon after that date.

Nitroglycerin dynamite was invented in 1867 by Alfred Nobel. It had been used to strengthen black blasting powder before that date, but the first real dynamite was a mixture of diatomaceous earth and nitroglycerin, discovered by accident. Other absorbents, such as sawdust and cellulose, were also used.

Ammonia dynamite, containing 80 per cent ammonium nitrate, 6 per cent charcoal, and 14 per cent nitroglycerin, was invented by two Swedish chemists in 1867, and the patents were bought by Nobel. As first made, the explosive deteriorated rapidly in moist air, because the ammonium nitrate exuded from the cartridges. A salt was added to prevent this exudation, and such dynamites were labeled "Extra." Ammonia dynamite was not popular in metal mining until after 1900, because of its rapid deterioration when exposed to moisture.

The first nitroglycerin and ammonia dynamites froze at temperatures below 40°F. and had to be thawed before detonation. Thawing dynamite was one of the most hazardous operations in mining, and it was a great advance when E. I. DuPont de Nemours and Co. in 1907 made a low-freezing dynamite by introducing liquid isomers of TNT. As this gave off bad fumes, it was soon replaced by glycerin and sugar, and finally by nitroglycol.

Dynamite was made in San Francisco in 1868, and sold for $1.75 a pound.

Various improvements in handling dynamite have been made in the last few years, such as cartridges that can be expanded without splitting the paper wrapping, and tubes that can be fully loaded beforehand and then slipped into the holes as a unit.

Within the last 10 years a new ammonia dynamite has been put on the market by the DuPont company for use in quarries. It contains no nitroglycerin and is put up in sealed tin cans in sizes to fit churn-drill holes. The cans are impervious to moisture and safe to handle, but can be set off by detonating fuse like Cordeau or Primacord.

Blasting gelatin and gelatin dynamite, which are mixtures of nitroglycerin and 7 to 10 per cent collodion nitrocotton, were patented by Nobel in 1875. Later, part of the nitroglycerin was replaced by ammonium nitrate to form ammonia gelatin, and nitroglycol was added to prevent freezing.

About 1927 a new type of granular ammonia powder, containing little or no nitroglycerin, was put on the market, and has almost entirely replaced black powder in blasting banks of earth and soft rock in stripping. Packed in cartridges, it was introduced underground, and proved to be more economical than standard and ammonia dynamites and gelatins for most work.

Liquid Oxygen Explosive, or LOX, was invented about 1915. It consists of powdered carbon soaked in liquid oxygen, and is about equal in strength to 50 per cent dynamite. When put up in small cartridges, suitable for underground use, it loses its oxygen and its strength quickly, and is dangerous, because the deficiency in oxygen produces carbon monoxide on detonation. In the Lorraine iron mines, in Europe, it was still used a few years ago, but was mixed with aluminum powder, which overcame to a large extent the danger of carbon monoxide. In large cartridges, 5 inches or more in diameter, LOX retains its strength for two hours, and is successfully used in quarry blasting.

Detonators and Fuses

Alfred Nobel invented a fulminating blasting cap in 1864 and patented it in 1867, and this cap with only slight changes has been the standard type until recently. In the past 10 years a cap that contains no fulminate of mercury has displaced the fulminating type.

Electric detonators, or exploders, came into use about 50 years ago but were not widely used until they were made go off in rotation, the so-called "delays." They are standard for shaft sinking and tunnels.

William Bickford's original "miner's safety fuse" has been standard since 1831. It was introduced into the United States in 1836. It has been superseded to a large extent in quarry work by detonating fuse. The first detonating fuse was Cordeau, which consists of TNT in a small lead tube. Cordeau was invented by Louis l'Heure in France in 1907, and was introduced into the United States as Cordeau-Bickford in 1913. It soon became the standard detonating agent in large quarry blasts. The TNT is set off by a blasting cap, and the rate of detonation is so rapid, 17,000 feet per second, that large numbers of holes can be fired simultaneously. About 10 years ago a new detonating fuse, called Primacord, which has largely replaced Cordeau, was put on the market by the same manufacturers. It consists of PETN (pentaerythritetetranitrate) in a waterproof textile covering. It is much lighter and cheaper than Cordeau, and even more effective, its rate of detonation being 20 per cent faster.

Open-pit Mining

STRIPPING

Stripping was at first done by hand or with horse-drawn slip scrapers. The steam shovel was first used in stripping anthracite in 1877, and was almost immediately adopted. The first shovels were steam-driven, of railroad type, and were mounted on trucks for standard-gauge railroad tracks. The earth was moved in small, narrow-gauge "contractor's cars," hauled by donkey locomotives, and this was standard practice until about 1902. Larger shovels and standard-gauge cars and locomotives then came into general use. Soon thereafter large steam shovels of the full-revolving type, which could load cars on top of a 40-foot bank, came into use. They had dippers holding 6 or 7 yards and ran on two standard-gauge tracks. Later they were mounted on caterpillar treads and were driven by electricity, and the size was increased to several times the original. Large shovels with dippers that hold as much as 40 cubic yards are used for overcasting in coal mining, but have not been tried in metal mining.

On work that is not big enough for the giant shovels, and for cleaning up, smaller revolving shovels, with dippers holding 1½ to 2½ yards, driven by electricity or diesel power are used. Bulldozers are now used for the final cleaning up, doing work that formerly was done largely by hand, and increasing the efficiency of the shovels.

The cars used for hauling stripping to the dump were made larger and changed to standard gauge, but were dumped by hand. They were soon followed by power-dumped cars, and the size was increased again. Cars of the drop-door type, dumped by air, and holding 30 to 40 cubic yards, were standard for several years but have been gradually replaced by large trucks except for long hauls.

With bulldozers to clean up after the shovels and no tracks to lay or move, the number of men required has been reduced, and the cost of stripping has been reduced, so that a greater ratio of stripping to ore is now profitable.

Draglines have been used in easy digging, but they cannot dig frozen ground and are at a disadvantage in northern climates for this reason. In winter the big revolving shovels rip off 3 or 4 feet of frozen ground from the face, and can then dig as easily as in summer.

Hydraulicking has also been used successfully in sand and fine gravel, but for these conditions has been superseded by diesel-driven carry-all scrapers, which hold as much as 17 cubic yards and move dirt more cheaply than any other equipment yet devised. Belt conveyors are also used occasionally for disposal of stripping, in order to reduce the haul to the rim of the pit, but have a limited application.

In stiff ground, blasting to loosen the dirt has been found to increase the efficiency of the shovels materially. Formerly this was done with "gopher holes" and churn-drill holes, but electrically driven rotary drills, drilling horizontal holes into the bank a few feet above the ledge, are growing in favor. They use twisted auger steel, and have hard alloy welded to the cutting edges of the bit. The blasting powder formerly used for this work has been superseded by granular, bulk powder with ammonium nitrate base, fired by electricity or detonating fuse.

With decreased cost of stripping and higher wages for underground mining, the "stripping ratio" has increased tremendously. Whereas in the early days the limit for open-pit mining was less than one ton of stripping to a ton of ore, it is now nearer three to one.

MINING

After the finish of the Hoosac tunnel, in the driving of which the Burleigh drills were developed, piston drills driven by steam were used in most quarries and open pits. After about 30 years steam was replaced by compressed air, and the piston drills carried on for another 30 years. Even now a few pits and quarries use them.

Hand-held jackhammer drills are almost universally used in pits and quarries for blockholing. They are used to some extent in primary drilling, especially in the smaller pits, but have been replaced by wagon drills and churn drills in most operations. The wagon drills will put down holes 25 feet deep rapidly and cheaply, but are limited to benches approximately 20 feet high, which is not enough for large production.

Churn drills are standard equipment in most large pits. For open-pit and quarry work the drills must be moved easily, therefore the early drills were mounted on wheels or skids. They were driven by steam but could not move themselves. Later they became automotive and had collapsible derricks. Development of the churn drill for mining followed that of churn drills for prospecting alluvial deposits and for drilling wells for water. With the introduction of the automobile, the types gradually drew apart. The well drill is now usually mounted on a truck with rubber tires and can travel at high speed. The quarry drill is mounted on caterpillar treads and travels slowly, but will move itself over rough ground. It is more likely to be driven by an electric motor than by a gasoline or diesel engine.

The first quarry drills made holes about 4 inches in diameter, but this was soon increased to 5 and 6 inches, and later to 9 inches. These larger holes permit a burden of 30 feet on the holes, and a spacing of 25 feet. They are drilled 3 to 7 feet below the floor of the bench.

Blasting

Churn-drill holes are fired simultaneously in rows, using detonating fuse, Cordeau-Bickford or Primacord. Sometimes electric detonators are used, but the detonating fuse detonates all parts of the charge almost simultaneously and permits "deck loading." The bulk of the explosive is placed in the bottom of the hole, then part of the hole is filled with stemming, and more powder is then loaded, followed by more stemming. Sometimes there may be two or more deck loads. These deck loads break free the upper part of the face and help to prevent "back break" beyond the line of holes. In horizontally bedded deposits the face is often held right on the line of holes.

If two rows of holes are fired together, the second row is staggered; i.e., the holes are drilled halfway between those in the front row, and the burden usually equals the distance between holes in the row. If more than two rows of holes are fired simultaneously, it is called "field blasting." Field blasting enjoyed a short-lived popularity, and blasts as large as a million tons at one shot were made, but these large blasts were discarded in favor of double-row blasting, because of the humps that were left in the floor between holes.

Fifty feet is almost standard for the height of the bench in hard ground, but 30-foot and 40-foot benches are common. The height depends on the reach of the shovel and the character of the ore. If the ore stands well, and the face is nearly vertical, a higher bench can be carried than if the "back break" is considerable. If the back break exceeds the burden on the holes, the burden on the next row will be too great, and "toe drilling" must be resorted to. Occasionally higher benches are used. Utah Copper Co. uses some 75-foot benches, but it does not use churn drills. The ore is very much shattered, and does not stand well in the face. Blasting is done therefore with toe holes, drilled along the base of the bank with heavy piston drills, and then chambered. When the toe is shot out, the bank above breaks by gravity to its angle of rest.

The kind of explosive used depends on the kind of ground to be blasted. In hard ground it is customary to use strong gelatin in the bottom of the hole and a weaker gelatin or bulk powder in the rest of the hole. The sticks of powder are made a little smaller in diameter than the hole, and may be as large as one stick to a box.

Under some conditions in open-pit work tunnel-blasting is used; i.e., the charges of explosive are placed in tunnels, or "coyote holes," driven in the base of the face. By this means large blasts can be made at relatively low cost, but the back break cannot be controlled at all, and comminution is not as good as when churn drills are used.

Loading

Loading was done by hand 75 years ago, and under circumstances where selective loading is advantageous, especially where the wage rate and the I.Q. of the workers is low, it is still practiced. In small pits various kinds of small loaders, such as scrapers or tractor loaders, are sometimes used, but in most places the loading is done with a power shovel, the size of the shovel depending on the comminution of the ore and the production wanted. All shovels, even the largest, are mounted on caterpillar treads and swing in a full circle. The size of the dipper varies from 1½ to 5 cubic yards, and the swing cycle is 20 to 25 seconds. There are a few exceptions, some large shovels with dippers holding 14 to 16 cubic yards being used in very large quarries, but the swing cycle is about one minute. For large production the smaller, faster shovel with 4 or 5-yard dipper is preferred.

Draglines are seldom used for loading ore, except in placer mining or in cleaning up irregular bottom.

Scrapers and scraper hoists have also taken a place in open-pit mining. The hoists are powered by motors as large as 125 horsepower and the scrapers have capacities up to 3 cubic yards. Although used extensively underground and in gravel pits for years, scrapers, with a few exceptions, have only recently been used for handling ore on a large scale. In the larger size they are very effective in removing banks of ore that would be difficult to reach with other kinds of equipment. They are primarily clean-up equipment in the difficult parts of the pit, and have the advantage that they will work below grade and even under water.

Tractors equipped with bulldozers are used for pushing ore over banks so that it can be reached by the shovel, but their most effective use is in cleaning up after the shovel, pushing loose ore back against the toe of the pile, where it can be readily picked up on the next cut.

Transportation

Transportation in open pits followed much the same cycle as in stripping, but adopted standard-gauge cars sooner. In the iron-ore pits, ore cars were brought directly to the shovel, and this was standard practice for many years. In very large pits it still is standard practice, but new installations are using trucks instead. The trucks are large and sturdy, some carrying as much as 40 tons, but the advantage of these large trucks over those that carry 15 to 20 tons has not been definitely proved. Trucks eliminate all tracks in the pit, and reduce the number of men required. Being able to negotiate sharper curves and steeper grades, they shorten the haul and lessen the amount of ore tied up under roads and tracks. Curves of 50-feet radius and grades of 8 to 10 per cent against the load are common practice, and return grades for empty trucks may be as steep as 20 per cent. All trucks are self-dumping, and most of them dump to the rear. The rear door has been eliminated in some of them.

There have been a number of installations of conveyor belts for transporting ore from open pits, and one of the improvements has been the use of belts that have been strengthened by wire strands, running lengthwise, that make possible much higher lifts. The ore is delivered to the belts by feeders from pockets, into which it has been dumped by trucks or scrapers. The conveyor is most helpful in the final cleanup of the pit, and, although it is limited to ore that is reasonably fine and dry, it has taken a definite place in open-pit mining.

Early in the period under discussion the ore mined in deep pits, such as the Tilley Foster in New York, was hoisted in skips by cableways, a practice that was in vogue for many years all over the world, where pits were deep. Later this practice was superseded by inclines built down the side of the pit or by shafts outside the pit. In the United States the ore usually was hoisted in skips but in Europe small cars were hoisted on cages. Some of these cages ran on inclined tracks down the sides of the pits, and were known as "bramsbergs."

In Africa, in the Premier diamond mine at Pretoria, the ore to a depth of 600 feet was hauled in small cars by endless rope up a long spiral incline, and this practice on a smaller scale was followed at other places. It is not as satisfactory, however, as hoisting with skips through a shaft.

Special Methods

In places where the bottom of the ore is irregular in depth or outline, or where the ore is too narrow or the topography too steep to permit open-pit mining by the usual methods, a technique was developed early, in which the ore was broken directly into raises or mill holes, from which it was drawn off through chutes into cars in a tunnel or drift below.

Later practice has been to put the mill holes farther apart and to drag the ore to them with scrapers, or to load it with power shovels, dumping it directly into the mill hole or tramming it in cars. By this method selective mining, which would have been extremely difficult otherwise, has been carried out successfully.

Drainage

Drainage of pits that have been sunk below water level has changed considerably. Modern systems of loading and transport require that the pit be kept as dry as possible, and usually this is accomplished by sinking a shaft at one side and driving drifts under the ore, if the deposit is a large one, or by putting down large drill holes and installing vertical, centrifugal deepwell pumps in them. At the same time large drainage ditches are dug around the pit to prevent inflow of surface water.

Underground Mining

SHAFTS AND SHAFT SINKING

In 1871 shafts usually were small and closely spaced. It was customary to sink them on the vein, and frequently they were crooked. That was because they performed two functions; exploration as well as exploitation. Drifting was slow, and so shafts were sunk close to the ore. Shafts in the hanging wall and inclines sunk in the vein were more common than shafts sunk in the footwall. The maximum economical distance between shafts was considered to be 600 feet, and the reason given was that it did not pay to tram ore by hand more than 300 feet. That being incorrect, the real reason was probably the slowness with which drifting was done, and the necessity of getting a number of working places into production as soon as possible. Be that as it may, as the speed of drifting increased the distance between shafts also increased, until now it is economical to sink deep hoisting shafts 2 miles apart, and they can be connected by drifts in little more time than could be done with shafts 600 feet apart 75 years ago. For the same reason, shafts now are seldom sunk in the hanging wall and vertical shafts are preferred to inclines.

In the same way level intervals have increased; but here other factors have come into the picture, and have set economic limits, which have not yet been overcome, except in rare instances. Levels at first were 40 feet apart; then 50 feet, and then moved up to 100 feet. Greater intervals were tried, 150 feet, 200 feet, and even 300 feet, but it was found that the difficulty of transferring ore through long chutes, the cost of getting men and supplies to the working places, and the increase in the cost of timbering and repairs all more than offset the reduction in cost of development, and the level interval was reduced again to between 100 and 125 feet. There was one exception—in mines using undercut caving, lifts were made as near 300 feet as possible.

As shafts were sunk farther apart, their size and capacity were increased, so that they could serve the larger area assigned to them, and the size of the compartments was increased as well as their number. The lining was changed also, and steel and concrete largely superseded timber for ground support.

Circular shafts, lined with brick, stone or concrete, were in use in Europe and even in Africa before they became common in the United States. On the Rand there are still two rival schools of thought in regard to shaft design—one prefers long, narrow shafts, lined with heavy timber, following the practice of California gold mines, and the other prefers vertical circular shafts lined with concrete. The second school of thought is about equally divided between monolithic concrete lining, cast in place, and a lining made of precast concrete blocks. In the United States, what are known as "square shafts," which have two skip compartments and one or two large cage compartments, are now the most popular, because they allow the use of large cages, on which mine timber can be taken into the mine on trucks without rehandling. These shafts have the additional advantage of getting the crew into the mine and out again in a relatively short time.

"Square shafts" usually are lined with steel sets, made of heavy 6-inch H-beams, which sometimes are made of copper-bearing steel, which resists erosion. They are often lagged with concrete, which is poured into the open space outside the sets.

Processes of Shaft Sinking

Shaft sinking has been one of the most difficult phases of mining to mechanize. When the Cornish miners came to the United States, beginning in 1850, they brought with them a very effective technique of shaft sinking, but it was based on hand drilling and was slow. When piston drills came into use in the seventies, they were used in shaft sinking, and in large shafts were more effective than hand drilling, but did not add much to the speed. It was not until the hand-held hammer drill, later called a jackhammer, was introduced, that shaft-sinking speeds were much increased. By hand drilling shafts were sunk about 30 feet a month in reasonably hard ground, and by the use of hammer drills this speed was increased until records of more than 400 feet in a month were made. Various other devices contributed to this increase in speed. A man named Galloway invented a stage on which men could stand and put in timber, while others drilled underneath. Drills were connected to a manifold, which in turn was connected to the main air line.

Improvements in pumps and in fans and tubing reduced lost time after blasting, but shoveling by hand continued until very recently to be the only successful method of removing broken rock. A partial solution of this difficulty was reached in South Africa by using large, relatively low buckets, about which many men could work. Then "trays" or "pans," sometimes called "loading boxes," were used. The broken rock was shoveled on these, while the bucket, skip or cage, was being hoisted and dumped, and they were hoisted by small auxiliary air hoists, when the bucket came down, and were dumped into it. This and the use of self-dumping buckets, cages with extension guides or double crossheads, which allow the skip or bucket to be lowered below the bottom of the guides, and skips with extension guides, all increased the speed of mucking.

At the Champion mine, at Painesdale, Michigan, which had long narrow shafts, the bucket was loaded with a scraper; but the greatest labor saver is a small clamshell bucket, hoisted and moved by small air hoists, which fills the skip or bucket without hand shoveling. This was invented by J. M. Riddell, now head of the mining department at the Michigan College of Mining and Technology. A clamshell bucket had been used many years before by J. R. Thompson, at the Boston-American mine on the Marquette Range, Michigan, but it was discarded because of accidents.

The Cornishmen were adepts at sinking drop shafts through quicksand before they came to the United States, and most of the shafts sunk through quicksand in this country up to 1904 were sunk by their methods. Soon after the turn of the century the Foundation Company began to sink drop shafts through quicksand, using concrete shafts with air locks inside, and many shafts have been sunk by this method.

The freezing method of sinking shafts through water-bearing strata, invented by F. H. Poetsch in 1883, was used mostly in coal mines, and has been used more often in Europe than in the United States.

The cementation process, by which grout is pumped into fissured rock, was first used at Lans, France, in 1882. It was improved by François, who injected aluminum hydrate as well as cement into the pores of the rock under great pressure, and allowed it to set before the rock was excavated. This process, although intended primarily for sinking coal shafts, has been much used in metal mining, especially for sealing off water-bearing strata.

The Kind-Chaudron shaft-sinking process was invented prior to 1871, and was used only in coal mining.

A new process or method of sinking small circular shafts was invented by J. B. Newsom in 1935, using a special type of shot drill in which the driving motor is close to the cutting bit. The operator goes down into the hole to run the machine. The first shaft to be sunk by this method was at the Idaho-Maryland mine, Grass Valley, California, where a 5-foot bore was drilled, and the second was at the Zenith mine, Ely, Minnesota, where the bore was 5½ feet. This shaft was 1208 feet deep, and was sunk in 8 months at a cost of $20 per foot. A third shaft was sunk at the Cary mine, Hurley, Wisconsin.

TUNNELS AND LEVEL DEVELOPMENT

The old tunnels, where drilling was done by hand, were usually small and often crooked. When piston drills were developed they were largely used in drifting and tunnel work, and the cross section of tunnels and drifts was increased in order to pull longer rounds. Speed was increased until advances of 200 to 300 feet in a month were made. Fast driving, as we know it today, dates from the development of J. George Leyner's hammer drill and the driving of the Roosevelt tunnel at Cripple Creek, Colorado, in 1909. Although mucking was done by hand in this tunnel, advances as great as 435 feet in a month were made. With the introduction of mechanical mucking, speeds increased rapidly, until more than 1500 feet have been driven in a month in one heading.

The fastest driving was done by tunnel contractors with highly trained crews, but excellent records were made in drifting underground, an advance of more than 900 feet being made in a month. When speed is of first importance, drifts can be driven 600 feet a month with regularity in reasonably hard ground, provided that timber does not have to be placed; but it has been found to be more economical to drive 400 to 500 feet a month with a smaller crew. This means that a main drift can be driven more than a mile in a year, and a large territory can be brought into production quickly.

In the early days, it cost almost as much to put up a raise as to sink a winze; but this was changed with the development of the Waugh stoper with air-feed leg about 1904. Stoper drills revolutionized raising, and their advantage was retained even after the jackhammer drill improved winzing.

The greatest improvement in development has been in large ore bodies in preparation for sublevel stoping and undercut caving. In these systems of mining the cost of development may be greater than that of stoping, but the overall cost is lower than in the older and simpler systems, and production per unit of area and per man employed is greater. Such systems would not be possible if we had to depend on old methods of drifting and raising.

UNDERGROUND MINING SYSTEMS

Most systems of mining in use 75 years ago would be classed as advancing work, and required little development. As soon as the ore was reached a room was opened out and stoping commenced. The system most often used was some form of open stope, usually breast stoping, back stoping or underhand stoping. In all three variations the ore was loaded out by hand as soon as possible after it was broken, pillars were left to support the back, and little timber was used. Even today more than half the metallic ore produced from underground is mined by open stopes with rooms and pillars, but the technique of mining has been vastly improved.

Cut-and-fill stoping was used in mining wide ore bodies in central Europe before 1871, and is still in vogue there.

Square sets were invented to support the back in the Comstock Lode, Nevada, in 1865, and were so successful that they were soon adopted all over the world, even where their use was unsuited to conditions. It was many years before they were recognized as a temporary ground support and working platform, rather than a mining system.

Some time before 1871 top slicing was devised for mining soft iron ore in England, and sublevel caving, as it is now called, was a variation of it. Top slicing was brought to the Lake Angeline mine on the Marquette Range, Michigan, by Captain Thomas Walters in 1884, to overcome the difficulties encountered in room-and-pillar square-set mining.

Breast Stoping

In breast stoping, when drilling was done by hand, the holes were short with light burden, and were placed almost anywhere in the face, wherever they would break to the best advantage. With the introduction of rock drills the method was changed. Usually a cut about 7 feet high was carried in advance across the top of the face, leaving a bench 10 to 15 feet high, or higher, and this bench was mined by either horizontal or vertical holes drilled rather deep—8 to 10 feet—and having a burden of 3 to 5 feet.

The introduction of mechanical loading caused great changes in breast stoping. Many open stopes are large enough to accommodate small revolving shovels, and they were used for some years after 1918, but have been mostly replaced by shovels specially designed for underground work, such as the St. Joe shovel and the Conway loader, or by scrapers and hoists. In order to get the full benefit from these loaders a larger supply of broken ore was needed, and this was obtained by working stopes in rotation, drilling being done in two to four stopes while one was loading, or by increasing the number of drills in the breast.

Another variation has been to drive large drifts or flat raises on the center lines of the stopes, and then to drill radial holes from these drifts, as in sublevel stoping, the principal advantage being that the ring drilling can be done continuously and be completed for the whole room before any of the holes are blasted. Both these systems permit a large production per unit area, and the latter system is especially well suited to scraper loading, because the men then do not have to work out in the room, where they are exposed to falling ground.

Another change that has come about is the use of unbroken, long, narrow pillars instead of intermittent round or square pillars. If stoping is done on the retreat, the pillars can be allowed to collapse after the rooms have been worked out.

Straight overhand stoping, in which the broken ore is not allowed to accumulate, has been superseded by shrinkage stoping or some other method in which the miners do not have to work under a high back. For a time, until about 1910, underhand stoping, in which the ore was milled down into a central raise or a series of raises along the center line of the stope, was in vogue at some mines where the ore and the hanging wall were both strong, but the system is now obsolete.

Cut-and-fill Stoping

Although cut-and-fill stoping is one of the oldest methods of mining wide veins and masses of ore, new ideas and equipment have changed techniques. In its simplest form the system consists of blasting down a horizontal cut across the vein for a length of 50 feet or more, removing the broken ore and filling the opening thus made high enough to attack the back again. The broken ore is thrown down chutes and cribbed up through the fill; the waste is run down from above through raises and is distributed in the stope with cars or wheelbarrows. Changes have been made in the removal of the broken ore and in placing the fill. If the slices are inclined roughly 35°, both fill and broken ore are moved almost entirely by gravity, at great saving of labor, but other operations in the stope become more laborious and complete extraction is more difficult. Removal of broken ore by mechanical loaders or scrapers, and spreading fill with scrapers, have accomplished the same ends without the disadvantage of working on an incline. Placing sand filling by blowing it through pipes with compressed air has also been successful, dropping the sand from surface through boreholes or pipes.

In mining thin, flat beds or veins, the system has been used for a long time as a sort of panel longwall, and much the same procedure has been followed in removing pillars in mining the reefs on the East Rand in South Africa. Removing pillars between open stopes in thick ore by first erecting artificial pillars of concrete filled with sand or rock is another application along the same lines.

The advantages of cut-and-fill mining are complete extraction, little dilution, and small consumption of timber. If the back needs support, stulls and headboards are used, and cribs are built. Some of these can be recovered and used again, but as the weight of the back increases the percentage of timber recovered decreases. When the consumption of timber exceeds one cubic foot per ton of ore, it is better and safer to use square sets, and a combination of the two methods of supporting the back is sometimes used, taking out the lower part of the back by ordinary horizontal cut-and-fill and changing to square sets for support, when the ground gets weaker.

It was thought that shrinkage stoping would replace cut-and-fill almost entirely, but in many places—for instance, the Canadian gold mines—the broken ore in shrinkage stopes was so diluted by rock from the hanging wall that a change was made to cut-and-fill. Improvements in handling ore and fill are bringing the system back into favor.

One of the interesting applications of cut-and-fill mining was devised by Albert Mendelsohn in 1929 at the Champion mine of the Copper Range Co., Painesdale, Michigan. It has been called sublevel inclined cut-and-fill, and is strictly a retreating system. It is applicable to steep veins of moderate width, in which the ore will stand with little support long enough for the cycle of operations to be carried out. It presupposes a large amount of freely running fill in the workings above the ore that is being mined, and its successful application is assisted if a considerable amount of the waste necessary to fill the workings is sorted from the ore. Sublevels 30 to 40 feet apart vertically are driven from raises put up from the main level at horizontal intervals of 200 to 400 feet. The ore is mined on the retreat on successive sublevels, beginning with the top sublevel. Slices are driven upward at 35° to the old workings, and waste drawn from these workings is then allowed to fill the opening.

In mining soft ore, where subsidence of the surface must be avoided, two systems have been developed. The first is bottom slicing with fill. A block of ore is mined one set high, using drift sets, the size of the slice being determined by the strength of the ore. This slice is then tightly filled with sand blown in. Then another slice immediately above is mined and filled, and the process is repeated until the top of the ore is reached. Then another section of ore alongside is worked out in the same way. If the ore is weak and likely to run, it is mined from the top down, the floor of each slice being tightly lagged before it is filled.

Ordinary fill is subject to 10 to 15 per cent compression, therefore, when used on a large scale, it does not prevent subsidence, although it limits its extent; but sand and gravel washed or blown into place by compressed air can be packed so tightly that the subsidence is almost negligible.

Square Sets

It is surprising how little change has been made in square sets since they were introduced on the Comstock Lode in 1865. The length of the members has been increased and there are different styles of framing, but the main concept is unchanged.

Perhaps the greatest advance is the recognition in later years that square sets alone will not support large blocks of ground, and that their function is to serve as a working platform for the miners and as a protection from falling ground. Consequently they have become recognized as a system of timbering rather than a system of mining. In good practice, not more than two sets high are allowed to stand open. On the top floor the ore is drilled and blasted, and is allowed to fall to the floor below, where it is shoveled into the chutes.

At Broken Hill, New South Wales, the ore is mined by horizontal cut-and-fill, but frequently in the wide ore bodies, when the ore has been mined halfway or more to the level above, the ore starts to cave, and little can be done to stop it, until a large area has collapsed. The miners have become expert in recovering these caved areas by catching up the back on square sets, which are supported by booms extended from sets already in place. The broken ore underneath is then mined by underhand square sets.

An ingenious variation of square sets, which saves both labor and timber, is the Mitchell slice. It was developed at the Calumet and Arizona mine, Bisbee, Arizona, about 1905. It is used to mine pillars between filled rooms in narrow vertical slices. A pillar of ore two or three sets wide and four or five sets long is mined underhand into a chute, starting at the top. The back is supported by long timbers, supported by knuckle braces, and the walls or sides are held apart by long stulls. When the stope is four or five sets deep, long timbers are laid across the bottom and lagged over. Then fill is run in from above, till the room is completely filled. Mining is then started below, as before.

Shrinkage Stoping

Shrinkage stoping is not new, although the modern type is only 40 years old. When miners began to drive stopes up the footwall, they either left broken ore to stand on or put in stulls and built scaffolds. The system tied up a great deal of broken ore, and was not much used until the invention of the raising drill, a hammer drill with air-feed leg, which was perfected about 1904.

Although shrinkage stoping was made popular by a drill designed for drilling vertical holes, it was soon found that long, horizontal holes gave better production, and left a safer back. The drilling was changed, but the popularity of the stoping method continued, and it is still probably the best method of mining reasonably hard ore in narrow, steep veins with strong walls. In wide veins it has been very largely superseded by sublevel stoping, and in narrow veins with weak walls by cut-and-fill stoping.

There have been a number of improvements in the layout for shrinkage stoping. The first stopes had simple chutes at 15 to 25-foot intervals along a timbered drift. The next step was to leave pillars above the drift, with short raises through them. Then a grizzly level was driven about 30 feet above the main level and chutes were 50 feet apart. On the grizzly level one grizzly drew ore from two or more pull holes and large chunks of ore were blasted on the grizzlies. In large stopes this worked very well, but in narrow ore there was too much development and too much ore tied up in pillars. A more recent arrangement eliminates both chutes and grizzlies, pull holes being put up along one side of the drift, and from these the ore is loaded into cars by a small mechanical loader. If large chunks are encountered, they are blasted on the level at the base of the pull hole.

Sublevel Stoping

Sublevel stoping was first used on the Menominee Range, Michigan, in 1902. It is a very flexible system and has many variations, all of which it will be impossible to describe. Some of these have enjoyed a short-lived popularity and have been superseded by better methods. It is seldom used in ore less than 15 feet wide.

In its standard form a sublevel stope is laid out as follows: A drift is driven on the main level under the center line of the stope, and above it there is a grizzly level with pull holes arranged as has been described under shrinkage stoping. The holes are belled out on top to approximately the width of the stope; a service raise is put up in the pillar at one end of the stope and a stoping raise at the other end over the last pull hole. Sublevels are driven from the service raise to the stoping raise at 25-feet vertical intervals. Stoping begins at the stoping raise, which is enlarged to the full width of stope, and a bench, or "trail," open on the side toward the stoping raise, is cut across the stope on each sublevel. From each sublevel vertical holes are drilled up and down in rows, so that when they are blasted the whole face of ore is broken off, and falls into the hopper below. New trails are then cut, and the operation is repeated. Although the cost for development is large, the drilling and blasting in the stope are cheap and effective, the total cost per ton is low, and the production per man and per unit of area is large. In wide ore, where rooms and pillars are laid out across the vein, the pillars can be largely recovered (unless the surface must not be caved), either by first filling the finished rooms and then opening sublevel stopes in the pillars, or by completely drilling the pillars and shooting them down at one blast and drawing the broken ore off through the chutes.

Standard sublevel stopes can be driven parallel with the footwall, if the ore is not too wide, provided that the footwall dips 45° or more, and with slight variations in the procedure and layout ore can be mined with a dip as low as 35°, which is the flattest angle at which ore will slide on the footwall. Special arrangements of various kinds are used for mining ore that dips less than 35°, the ore being dragged down the stope by scrapers. This type of mining was first planned for the Roan Antelope mine, Northern Rhodesia, in 1929, and successful variations of the original scheme have been used there and elsewhere since then.

Two methods of mining, which are in fact varieties of sublevel stoping, were developed at Granby, B. C. In spiral-raise stoping a spiral raise, starting from the top of a chute, is driven up on a grade flat enough to permit walking, the interior core being mined at the same time. Connections with a manway raise are made at the outer edge of the spiral. The raise is continued to the top of the ore, the diameter increasing with the height, and stoping is continued by widening the spiral and mining the rib between coils.

Long-stope mining, as it was called, is really only inclined sublevel stoping, the sublevels being inclined at 38° so that ore broken in development slides by gravity into the stoping raise. The whole sublevel is stoped out 8 to 10 feet high for the full width and length of the block being mined, and holes are then drilled up and down along the edge of the stoping raise, as in sublevel stoping. The method is applicable only in very strong ore, and the loss of efficiency of labor on account of the slope has caused its discard in favor of standard sublevel stoping.

The Beatson, or La Touche, method of stoping is sublevel stoping turned on end, raises being used instead of sublevels. The use of trails being impossible, blasting chambers are cut around the raises at intervals and radial holes are drilled from them to break down the whole face. Its principal advantage was that raises cost less than drifts, but mechanical mucking has robbed it of this advantage.

Top Slicing

Top slicing was brought to the United States in 1884. In its original form it is still used in England, but there have been many changes in the United States principally since the introduction of scrapers.

Under the original system raises about 60 feet apart were put up from a main drift to the top of the ore, and were connected by drifts on the top sublevel. Then a crosscut was driven from each raise to the limit of the ore and the ore was mined in successive slices, starting at the end of the crosscut and working back toward the raise. The floor of each slice was covered with old timber and lagging. When two or three slices had been mined, and the timbers started "taking weight," the legs were blasted out, and the back was allowed to cave. The process was repeated until the raise was reached, and then another sublevel was started 10 to 12 feet lower down. Drilling was done by hand, and the broken ore was shoveled into small cars and trammed to the chute.

One of the first changes was to take the ore out in slices two sets high, but this caused too many runs of rock. Later the timbers were lengthened from 7 to 8 feet, and finally to 9 feet, and the height of each slice was made correspondingly higher. More care was used in covering down, cross-lagging being laid on poles, and in some places heavy wire netting was nailed to the lagging.

The first step in mechanization was the introduction of jackhammer auger drills in 1913. Then scrapers and scraper hoists replaced cars and tracks, the first experimental work being done in 1918. As a result of the use of scrapers, production per man stoping doubled, increasing to 25 tons or more per day, and the area served by each raise increased two to four times. The greater rapidity of extraction caused a marked reduction in repair work.

Sublevel caving, or "caving with a back" as it used to be called, started with the idea of saving timbering. The sublevel interval was increased to 15 to 20 feet, and stoping drifts on the sublevel were driven about 25 feet apart. When the end of a block was reached, the last set was shot down, and the ore in the back and on both sides was drilled and blasted, and as much of it as could be reached was shoveled out. Then the process was repeated with the next set. The system saved timber, but at the expense of considerable dilution and loss of ore. In some places, as on the Gogebic Range, in Michigan and Wisconsin, where the ore is "rubbly" and runs well between timbers, and the capping is the reverse, sublevel caving is used successfully, but elsewhere it has been largely given up. At the Montreal mine, Wisconsin, a variation of the system is used, the sublevel interval being increased to 30 feet, and small spiral-raise stopes being opened above the drift. At the diamond mines at Kimberley, Cape Province, South Africa, a somewhat similar system is followed, using very little timber, the sublevels being 40 feet apart.

In some Arizona copper mines where top slicing was used, the floor covering of each slice was picked up by the timbers below, to save lagging. In these mines also a system of inclined top slicing was developed, by which the broken ore ran into the chutes by gravity, but the difficulty of working on an incline robbed the method of much of its advantage, and when scrapers were introduced for moving the ore inclined slicing was discarded.

Undercut Block Caving

The first undercut block caving was used at the Pewabic mine, Iron Mountain, Michigan, in 1895, to mine low-grade siliceous iron ore. A block of ore 250 feet square and 100 feet high was undercut by a gridwork of drifts and crosscuts on 30-foot centers. The small pillars thus blocked out were reduced in size until they crushed, and the whole mass was allowed to settle and crush. Timbered drifts were then driven through the block of crushed ore, and the timber in these drifts was blasted down one set at a time on the retreat, allowing broken ore to run into the end of the drift. This ore was then shoveled into cars. When waste appeared, another set was blasted in, and the process was repeated.

In 1906, Felix Macdonald laid out an undercut caving system at the Ohio copper mine, Bingham, Utah, drawing the caved ore through chutes and branch raises, and five years later a similar system was started at Inspiration. At the same time a combination system of shrinkage stopes and undercut caved pillars was started at Ray Consolidated Copper Co., and Nevada Consolidated Copper Co. started caving at Ely, Nevada, in 1915. From then until 1930 various large mining companies started caving systems of mining ore, each profiting by the mistakes of its predecessors, until a fairly well standardized system was developed. At the same time induced caving was introduced at Alaska-Juneau, large blasts being used to start the movement of the ore, and caving was started at Climax, Colorado, blasting being necessary at first. Each mine presented a slightly different problem, but the various systems were eventually closely coordinated. It was demonstrated that 300 feet is an economical height of ore for caving, and that the ore should be mined in panels in a retreating system. In each panel the ore is undercut on a sublevel, the width of the unsupported section depending on the strength of the ore.

In thick ore an elaborate system of branch raises carries the broken ore to the main level, caving being regulated by the amount of ore drawn off through the finger raises immediately under the undercutting level.

In thinner ore, and in places where such an elaborate system of branch raises was not justified, various expedients have been used instead of the branch raises. Scrapers in transfer drifts, pulling the ore from finger raises to main chutes, are one successful expedient, and shaking conveyors for the same purpose are another.

Undercut caving has been applied to asbestos mining at Thetford, Quebec, using the system developed in Arizona, and an interesting technique has been developed to prevent or reduce the draw of ore beyond property lines. Tailings from the mill are dumped on top of the subsiding ground, and these help to support the ground standing at the property line. One of the interesting problems in asbestos mining is that no timber can be used in mining, because it forms fibers.

Undercut caving has been one of the most successful and revolutionary of the new mining systems, and by its reduction in cost has changed tremendous quantities of what would otherwise be waste rock into profitable ore, thereby increasing the world's mineral resources.

ROCK DRILLS AND ACCESSORIES

At the beginning of the period nearly all drilling was done by hand with hammer and drill, jumper or auger, and in stoping this continued to be true for many years.

Piston drills driven by compressed air came into use soon after 1871, and were in vogue for approximately 40 years. At first they were used mostly in tunneling and drifting. The first drills were heavy and cumbersome, and the materials of which they were made were inferior. There were a large number of designs and makes, and progress was slow. Gradually the good points of different makes were combined, and a practical drill was the result. This took about 15 years. Ten years later there came a rapid improvement in design and material, a decrease in weight and an increase in drilling speed.

The first hammer drills appeared about the turn of the century. They were small, hand-held drills, closely following the design of riveters, and were used for blockholing. Then followed hand-held, self-rotating drills, using hollow steel, whose early development was more rapid in Europe than in the United States. In their heavier models these machines were used for sinking shafts. A light model, using twisted auger steel, was introduced in the Lake Superior iron mines in 1913, and put an end to hand drilling even in the soft ore.

About 1904 a hand-rotated hammer drill, mounted on an air-feed leg, using solid steel, was built especially for drilling uppers. It was so successful in shrinkage stoping that it was given the name of "stoper." Wet stopers were not successful at first, because the water dripped on the operator and washed grit into the mechanism, but this difficulty was largely overcome later. By reversing the design of the feed leg, a "reverse-feed" stoper was turned out, which could be mounted on a bar or column, and that is used successfully in drilling horizontal holes in drifting and stoping where the ground is uniform.

At about the time that stoping drills were starting, J. George Leyner, in Denver, began to make mounted hammer drills for drifting, but his drills were not a success until 1909. At that time improvements in design overcame the heavy breakage of parts that had prevented their previous success, and the good records made in driving the Roosevelt tunnel at Cripple Creek drew favorable attention to them. They were introduced into the Lake Superior iron and copper mines in July of that year, and not long afterward the patents were taken over by the Ingersoll-Rand Co. Further improvements were made, and mounted hammer drills of the Leyner type replaced piston drills almost everywhere. The original Leyner patents soon expired and all the drill manufacturers began to make drills of this type. Keen competition brought about many improvements, among the most important of which was the automatic feed for drifter drills.

One of the disadvantages of the early Leyner drills was the large amount of drill steel broken. The steel was round and hollow, and was rotated by means of lugs forged on the shank, near which most of the breakage occurred. In order to reduce this breakage, I designed and built in 1912 anvil-block chucks, using hexagon hollow steel, which eliminated most of the breakage. They were widely adopted, especially in the Michigan copper country and in Canada.

Concomitant with the development of the rock drill was the development of machinery for sharpening steel. Up to 1900 nearly all drill steel was sharpened by hand, and every blacksmith had his own ideas about the proper shape for bits. About 1903 Word Brothers brought out a good machine for sharpening piston drill steel, and a little later J. George Leyner invented a sharpener for hollow steel, which contained the basic ideas of most modern sharpeners. Improvements were made in steel and its treatment, in the cutting angle and shape of bits, reducing gauge wear and increasing cutting speed tremendously. Oil-burning furnaces under pyrometer control replaced blacksmith forges and coke furnaces, controlled by guesswork, and on the Rand a salt bath of potassium and barium chlorides, heated by electricity, was used for heating bits for tempering. On the Rand, also, tapered drill steel came into use, the taper of the steel being parallel to the taper of the hole. This permits the use of smaller bits. About this time George Gilman brought out an automatic tempering machine, which used either oil or electricity for heating, and was very successful at large mines. Finally hot millers were used for finishing bits.

About 15 years ago detachable bits began to come into vogue. The idea had been worked on for some time, and a number of designs were experimented with. Finally success was achieved, the surviving bits being screwed on the drill-steel "rods" by special threads. The superiority of detachable bits for some kinds of mining work has been well demonstrated. They permit of special designs to suit the ground where they are to be used, and make possible great uniformity, but, at mines where there are well-equipped and well-run drill-sharpening shops, they have not yet replaced the older type of forged bit. Detachable bits are often resharpened more than once, being heated in electric furnaces, then hot-milled or cold-ground, and retempered.

In the early days of piston drills air pressures were usually 40 to 60 pounds per square inch, and later were raised to 70 to 80 pounds. When the hammer drills came into use, it was found that drilling speed increased rapidly, when the air pressure exceeded 70 pounds per square inch, and experiments were made with higher pressures, until a pressure of 150 pounds per square inch was reached. At this high pressure, however, although the drilling speed, when the drill was working, increased proportionately, the breakage of steel and of the machine itself increased to such an extent that the overall drilling speed decreased. In mining work it is now general practice to maintain a pressure of 90 to 115 pounds, and in contract tunnel work, 115 to 125 pounds. As improvement is made in material for both drill steel and machines, the pressure undoubtedly will go higher.

Although the original drills used in the Mont Cenis tunnel were mounted on a carriage that would now be called a "jumbo," our "jumbos" did not come into general use, even in driving large tunnels, for at least 70 years. They were used in driving the tunnels of the Colorado River aqueduct in 1933, and now are used in mines for drifting. Their use has been made possible by mechanical loading.

For the last 40 years repeated attempts have been made to build an electric rock drill, but all have failed until recently, because the inventors tried to convert the rotary movement of an electric motor into a reciprocating hammer stroke. With the improvements in diamond-drill bits, however, diamond drills have come into wide use in stoping, and it is not unlikely that they will be used in drifting and tunnel driving, if the cost per foot of hole can be reduced to that of percussion drills. The diamond drills used in mining are small and light, and are driven by either electric or compressed-air motors. For soft ground bits may be made of hard alloys.

Another new development, the success of which has not been fully demonstrated yet, is burning holes in ore and rock with an oxyacetylene blowpipe.

LOADING

In recent years many improvements have been made in shovels for hand loading, both in material and design, with the result that most of the hand-loading records are held in this country. In spite of the fact that in many of our western mines long-handled shovels are preferred, the best shoveling records have been made with short, D-handled shovels, which are standard in the majority of places. It is disheartening to see the effort wasted in many foreign countries by men working ineffectively and uncomfortably with the local brand of shovel, which looks like the shovels shown in pictures more than 100 years old.

In spite of these improvements in shovels, loading by hand is the greatest drudgery in mining, and a great effort has been made in recent years to eliminate it. The effort has been almost completely successful, and in large mines almost everywhere comparatively little loading is now done by hand. Experiments with power loaders underground began about 1914, but were held up to a large extent by the war. Shortage of labor, however, revived them, and in 1918 many different devices and designs were experimented with.

For drifts, tunnels and flat breast stopes the surviving loaders all have the same characteristics, in that the three motions—thrust, lift and swing or overhead throw—are under independent control. Three examples may be mentioned, the St. Joe shovel, used in large breast stopes, the Conway loader, used in stopes and in large drifts and tunnels, and the Eimco loader, used in small drifts and stopes. All three obtain their thrust by tractive effort. The first two are powered by electric motors and the third by compressed air. There are other successful loaders on the market, but there is not space to mention them all.

For sublevel work and for inclined stoping and drifting the drag scraper hauled by a double-drum or triple-drum hoist, driven by an electric or compressed-air motor, has taken the lead over all other types of loader, and, when equipped with a portable slide, holds its own in drifting. Some slides are mounted on caterpillar treads and are self-propelling. More than 90 per cent of the scraper hoists in use are electrically driven, and most of the failures of the early types were due to the low power of the compressed-air hoists used. The designs of scrapers have been pretty well standardized, the hoe type, except in very large sizes, being almost exclusively used for handling coarse or hard ore.

TIMBERING

It is a surprising fact that very little change has been made in timbering in the last 75 years. Square sets have changed but little, only the size of the sets having been increased. Drift sets, cribbing for raises, and stulls remain about the same. In raises it is now usual to timber the compartments separately instead of using long wall plates with dividers. "Battery stulls," which are groups of three stulls used to support the back, are one change in design, but they may be the revival of an old idea.

The preservation of timber has followed two paths, the first of which is to reduce breakage. To this end a block of softer wood, laid on its side, is placed under each leg of a set. Its resistance to transverse pressure being less than to longitudinal, the block compresses and relieves the pressure on the set. For the same reason, lagging may be crisscrossed above the sets, or large stulls may rest on cribwork.

The second is to prevent rot. After timber has been framed, it is treated with a hot solution of zinc chloride or arsenic soap under pressure, zinc chloride being the most widely used. Creosote is used on timber for surface structures, but its inflammability is against it underground. Zinc chloride is a fire deterrent.

There has been comparatively little change in timbering in drifts and raises, the principal advance being in the use of steel and concrete for lining main openings. Some satisfactory arched steel sets have been adopted, and another innovation has been the use of flanged, corrugated, steel arched plates, which can be bolted together. These are often backed and supported by concrete.

The cement gun was quite in vogue 20 years ago, and under certain conditions "gunite" has proved to be a very satisfactory lining, especially when used to build a gunite lining in layers applied radially instead of circumferentially. This method was used very successfully in bad ground in the Hetch Hetchy aqueduct.

Concrete has been used as a monolithic lining, both with and without reinforcing, and equally successfully as rings separated by unsupported ground. Precast sets have also been used, but they are heavy to install. Concrete slabs as lagging for steel sets are another variation used, where fireproof construction is desired.

When square sets were so generally used, it was customary to frame the sets in special sawmills; but framing of drift sets, raise cribbing and shaft sets is more cheaply done by hand, even with hand tools. Recently power saws of various types—reciprocating, chain and circular—in sizes suitable for hand use have been developed, and these are replacing hand saws to a large extent.

Much progress has been made in building chutes. The design of the chute itself has improved with better understanding, and the size of the opening has been greatly increased to match the increase in the size of cars used. This has reduced secondary blasting and sledging, and has increased the speed of loading. With a modern undercutting arc or finger chute handling free-running ore, a 5-ton car can be loaded easily in 15 seconds, whereas it might take more than a minute to fill a one-ton car with one of the old stopper-board chutes.

The simplest chute is the "Chinaman" chute. It consists merely of a hole in the floor, at the foot of a pile of ore, closed by planks or poles. It is still used. The next in simplicity is a wooden chute, closed by stopper boards or poles. This is the type most commonly seen. A variation sometimes used in coarse ore is a heavy pole or two attached to the uprights of the chute by short chains. When the poles are lifted by the ends, they allow the ore to run out underneath. This chute stopper is very effective in coarse ore, and is cheap to build.

Where a large amount of ore is handled through one chute and speed of loading is a prerequisite, undercutting arc chutes and finger chutes are the best devised. Finger chutes were developed at the Alaska Treadwell mine, on

Treadwell Island. The fingers are shaped like a bent human finger, and press down on the top of the ore. Undercutting arc chutes are closed by a steel arc-shaped plate, which rises through the stream of ore at the lip of the chute. Overcutting arc chutes were tried, but they are very troublesome in anything but the softest ore. Both undercutting arcs and fingers may be operated by hand, but are more likely to be operated by compressed-air cylinders. A new type of chute closer, originating in Canada, consists of heavy iron balls hanging on chains. When allowed to lie on top of the stream of ore, they stop it very much as fingers do.

Most chutes are still made of wood, but under special conditions, as in the asbestos mines or where service is severe, or where a large tonnage is to be handled through one chute, steel and concrete have taken the place of timber.

TRANSPORTATION

Cars pushed by men or pulled by mules or horses are still used in small mines, but there have been great improvements in the design and construction of the cars, especially in the use of ball or roller bearings.

In a few places, such as the Tri-State zinc district, which was started in 1870, tramming is still done at the smaller mines in "cans" (buckets) set on small trucks, but both mules and locomotives are used for hauling.

The first mechanical haulage underground was an endless rope system put into use in England early in the last century. From England the system spread all over the world, and is still used in England and Africa. It was brought to the United States in 1870, and was still in use in metal mines as late as 1901. Soon after that it gave way to locomotive haulage.

Compressed-air locomotives appeared early and were quite in vogue for a time, but there have been no new installations in many years.

Trolley locomotives were first introduced about 1890. At first they had heavy frames and comparatively light motors, but this was soon changed, the frames being made lighter and the motors larger. Standard practice is now 12½ horsepower per ton of weight. The standard track gauge used to be 30 inches but is now 36 inches for the larger locomotives. Metal mines have not adopted the wide gauge prevalent in coal mines. Link-and-pin couplers have been superseded by automatic couplers, and many other improvements have been made to increase the safety and convenience of operating.

Storage battery, or "S.B.," locomotives followed trolley locomotives by some years, and did not come into general use until a short time before World War I. Both lead batteries and Edison batteries are used, with little choice in popularity. Although some S.B. locomotives are large, they are generally of intermediate size, and in large mines, with a few exceptions, are used for gathering and for short hauls. A combination of S.B. locomotives for gathering and making up trains and large trolley locomotives for long hauls is an almost ideal arrangement for handling large tonnages.

A boon for the small mine was the development of a one-ton S.B. locomotive small enough to be carried from level to level on a cage built for one-ton cars. These little locomotives are scattered all over the world in all kinds of mines. They have interchangeable batteries, and can be used 24 hours a day.

Gasoline locomotives made a bid for mine haulage, but, although they achieved a certain degree of success on surface, they were a failure underground, partly because they are too delicate for underground conditions and partly because of obnoxious fumes. Their place has been taken by diesel locomotives, which have proved reasonably satisfactory in tunnels and in some well-ventilated mines. They have not yet been adopted generally for underground use.

Cars have passed through a long cycle of change, and there is no sign that the evolution has ended. Seventy-five years ago most cars were small, were made of wood, and had plain bearings. Now they are made of steel, and have ball or roller bearings, and for mechanical haulage the size has increased from one-ton capacity or less to five tons or more. Originally cars were mostly end-dump, and were dumped individually, whereas nowadays it is the endeavor to dump cars one after another without uncoupling the train or even without stopping it, and to dump and right cars without human exertion.

In order to reach these objectives many different designs of car have been tried. Among the first came bottom-dump cars, most of which were failures. They were followed by gable-bottomed cars, which had swinging doors on both sides, suspended by hinges at the top. They worked well with dry ore that was not too coarse, but leaked when carrying wet fine ore, and jammed when carrying coarse ore. To overcome these disadvantages, rotary dump cars came into favor, the bodies being solid boxes without doors. They were dumped by being overturned in a cylindrical dump. When properly designed, whole trains could be dumped without uncoupling. Many cars of this type are still in use, some of them fairly large.

Rocker-dump cars, in which the body rolls to one side as it overturns, were originally of small capacity, 15 to 20 cubic feet being the rule, but they work well up to 5 or 6 tons. They can be designed to dump and right themselves as they move along.

For handling heavy, coarse ore rapidly a special type of car was developed at Granby, B. C., that is known as the Granby car. It is a side-dumping car, and has a door that rises as the body is dumped. Underneath the side opposite the door there is a small wheel that runs over an inclined ramp and tips the body. Trains can be dumped while traveling at speeds up to six miles an hour, and the ramp can be withdrawn so that empty cars can pass it without being tipped. In order to obviate the trouble caused by big chunks catching under the raised door, another type of door, called a "drop door," hinged at the bottom, has been successfully substituted for the rising door.

Mine cars must operate within much narrower limits than those on surface. Their height and width are limited by the height and width of the drifts and their length by the curvature. In order to get the maximum capacity possible within the limits imposed, some of the new cars sit very close to the track and have independent self-aligning trucks.

Getting away from tracks almost entirely, shuttle cars traveling on pneumatic tires and powered by storage batteries, trolley, or trailing cables, make possible the movement of large tonnages of ore in flat-lying deposits, such as beds of zinc and lead ore, potash ore, or limestone. Shuttle cars are not used for long-distance tramming, but deliver their loads to main haulage either directly or through chutes or pockets, replacing gathering locomotives and cars. Shuttle cars require openings 8 to 9 feet wide and curves of 15 to 20-foot radius. They operate successfully on grades of 8 to 10 per cent, and for short distances negotiate steeper grades. The typical shuttle car has four pneumatic-tired wheels, each axle being driven by an electric motor, and steers with both axles. The body is open at one or both ends, and the bottom is an endless belt driven by a separate motor. The belt is used in both loading and unloading.

Tractor trailer trucks with bottom discharge, driven by electric or diesel motors, are in use instead of shuttle cars in handling ore, but they lack the shuttle car's ability to dispose of waste.

Conveyors, both belt and shaking, are also used as gathering agents. In undercut block caving, shaking conveyors are used to deliver ore from finger raises to main chutes, thereby materially reducing the amount of development required, and are also used in top slicing and other sublevel work. Belt conveyors have been more widely used in coal mines than in metal mines, one reason being their limitation as to size of material handled. Moreover, they must be laid out in straight lines, and there is difficulty in maintaining them in heavy ground. They have been successful, however, in distributing fill. Under favorable conditions, such as delivering crushed ore from an underground crusher to a storage pocket, they have few equals, and many an operating engineer has had pipe dreams of sending his entire product to surface over a system of belts. Such dreams have much better chance of realization now that the strength of belts has been so much increased.

HOISTING

Nowadays, with very few exceptions, buckets are used for hoisting only in shaft sinking and exploration. Even in shaft sinking they are on the way out, their place being taken by skips or cages with extension guides or double crossheads. A number of automatic dumps have been devised for buckets, but are not much used. The best known survival of hoisting with buckets is in the Tri-State zinc district, where such an efficient method of hoisting with "cans" was developed that it has largely withstood the competition of skips.

Skips were used on inclined skip roads built down the sides of open pits and in inclined shafts 75 years ago. Improvements in design have been made, but inclined shafts and skips have largely been displaced by vertical shafts and Kimberley skips. The latter took their name from the diamond mines at Kimberley, South Africa, where they originated. The general design has not changed a great deal, but there have been many improvements in detail, some of which may be mentioned. A housing or hood has been added just above the body of the skip, to prevent spill in loading. Roller bearings have been added to the dump-rollers both on the skip and on the dump, places that are very hard to lubricate. On some skips a bonnet or platform has been built on top of the frame, so that men can ride, and safety catches have been added. The bottoms have been rounded and sharp corners eliminated, so that ore does not stick in the skip, and new materials, nickel steel and aluminum alloy, have been used in construction, reducing the weight 30 per cent or more. At the same time size has increased, until now skips with a capacity of 12 tons each are not uncommon. Bottom-dumping skips, although used for coal for many years, have only recently been tried for ore.

Cages

Cages are used much less than formerly for hoisting ore and rock. In a few places—for instance, the Rand, South Africa—some of the large shafts still use cages, hoisting cars holding as much as 8 tons each, but their capacity is much less than it would be if skips were used. The era of cage hoisting may be put between 1870 and 1900. Since then most hoisting of ore has been done with skips, and cages have been used for handling men and supplies.

The design of cages has been much improved. Modern cages all have safety catches and bonnets, and are entirely enclosed with either thin plates or heavy wire netting. Wherever possible, they are made large enough to carry a truck of timber, a main-level car or a locomotive. Many have two decks and some are large enough to carry 50 men on each deck. In some of the old shafts, with small compartments, five-deck cages replace the skips for handling men at the beginning and end of the shift, but this is at best only a makeshift.

One of the most popular hoisting arrangements is to have a "square" or circular shaft with two skips and a cage and counterweight. The cage and counterweight is better than two cages in balance, if there are many levels to serve.

Many devices to add to the safety and convenience of cages have been invented. Among them are telephones and bell signals, which can be used while the cage is in motion, and in a few instances the hoist can be controlled from the cage, as is done with passenger elevators on surface. Push-button control is also used. Lilly hoist controllers are widely used. They prevent overspeeding and overwinding, and shut off the current and stop the hoist, if the operator fails to do so.

Ropes

At the beginning of the period many wire ropes were made of soft or Swedish iron, and cast-steel ropes were just beginning to be used. Steel of higher carbon content and higher tensile strength and elastic limit are now the rule. Cast-steel ropes are still made, but most hoisting ropes are either plow steel or extra strong plow steel. The higher elastic limit of the ropes permits a smaller diameter for the head sheaves.

Flat ropes for hoisting with reels enjoyed a short popularity 50 years ago, but passed completely out of the picture because of their high repair cost. A very few old reel hoists still survive, which should have been scrapped many years ago.

All ropes are now round. Originally they were laid up like hemp ropes, with the wires twisted in one direction in the strands, and the strands twisted in the opposite direction. Later both wires and strands were laid in the same direction, and this is called Lang lay. Lang lay has an advantage in presenting a larger wearing surface on the outside wires, and is used where wear is due to external friction. It had a tendency to untwist, however, until "preformed" ropes came out about 20 years ago. In these ropes the wires are shaped before going into the rope, and there is no tendency for the rope to unwind.

Sheaves

Hoisting sheaves have gone through many changes. First they were cast integral or made of cast-iron segments bolted together. Then the bicycle sheave with cast-iron rim and hub and wrought-iron spokes came into vogue. About 30 years ago removable steel liners were placed in the cast-iron rims of the bicycle sheaves, and more recently all-steel sheaves have been cast or welded. Alloy steel is used in sheave shafts, and bearings are often ball or roller bearings. In spite of these improvements, all types, except possibly the segmental cast-iron sheaves, are still in common use.

Motive Power

Hoisting engines have also gone through many radical changes in design. At some of the mines in England some large hoists were in use 75 years ago, and there were large hoists on the Comstock Lode in Nevada, but it was not until the Michigan copper mines and the gold and diamond mines in South Africa were developed that really great hoists were built.

Until after the turn of the century the motive power was steam. In the seventies and eighties unbalanced hoisting was the rule, and drums loose on the shafts were geared to the engine. Sometimes as many as four drums would be driven by a single-cylinder engine with flywheel. First-motion engines direct-connected to the drums replaced the geared hoists, and some splendid engines were built. Bruno Nordberg, in Milwaukee, built many of the best of the large steam hoists and introduced many new ideas. He built probably the largest steam hoist in the world for the Quincy mine, at Hancock, Michigan, in 1921. This hoist has a double conical-cylindrical drum, 30 feet in diameter, weighing 258 tons, driven by four steam cylinders, two 32 inches in diameter and two 60 inches in diameter, by 5½-foot stroke. The skips weigh 5 tons each and carry a load of 10 tons, and are hoisted from an inclined depth of 10,000 feet.

Interest in electric hoists began about the turn of the century, but they did not displace steam hoists for several years. The first electric hoists were driven by direct current, but as alternating-current motors and controls improved more and more hoists used wound-rotor a.c. motors. The large hoists, however, are driven by d.c. motors with Ward-Leonard or amplidyne controls, and receive their power from motor-generator sets equipped with flywheels, in order to reduce the peak load on the power line. The flywheel sets are usually driven by slip-ring motors, which allow a small amount of slip as the flywheel slows down; but the latest practice in large units is to use a synchronous motor and to put a hydraulic coupling between the motor and the flywheel.

A large electric hoist with flywheel set often has a large, slow-speed d.c. motor mounted on the end of the drum shaft, but later practice is to drive the drum through herringbone gears. Most of the large hoists have two drums, one or both of which are loose on the shaft and held by clutches. In the United States these are friction clutches, but in Africa and Australia they are of the internal-and-external gear type. It is a moot question, however, whether it is not just as good practice to drive both skips from one drum, which is fixed on the shaft.

Drums

Originally most drums were cylindrical, but in deep mining cylindroconical drums came into fashion, and, when most of the hoisting was from the bottom level, they were an improvement, especially on steam-driven hoists. On medium sized hoists with motors up to 1000 horsepower, it is customary to take up the variation in load electrically through the flywheel set rather than to do so mechanically by the drum. This arrangement is to be preferred, if hoisting is not all from one level.

One of the latest ideas is to start hoisting with a small diameter of drum, and to wind the rope on this same diameter until the moving parts are up to speed. The acceleration up to this point is provided by increasing the speed of the motor. When the motor is up to speed, the rope starts to climb a cone on the drum, acceleration being given by the large diameter of the drum without changing speed of revolution.

Loading Skips

In the early days skips were loaded directly from cars, or the ore was shoveled into them from a platform, and cars were put on and taken off cages by hand (as is still done). With large cars, however, this became impracticable, and pockets were used for loading the skips and mechanical cagers were used for cages. The latest practice is to draw ore from large storage pockets into measuring pockets, in which the exact amount of ore that the skip will hold is cut off by a rising gate. A properly designed measuring pocket will fill the skip in 3 to 4 seconds. If pockets of this kind are combined with push-button control of the hoist, one man can load and hoist several thousand tons of ore per shift without overexertion.

HEADFRAMES

There has been great progress in headframe design. The old headframes were modest wooden affairs, and often were built by rule of thumb, depending on weight rather than design for stability. Two general types were found at small mines, those built along the lines of the Australian four-post, "poppet-head," and the "A-frame" of the western states. The "derricks" in the Tri-State district were in a class by themselves. Having the hoisting engine on the "derrick," they had almost no side pull and needed no braces.

Headframes have been built of steel for 45 to 50 years, but it is only in the past 20 years that light, steel headframes, which can be moved from one shaft to another, have become common. At large mines headframes 150 feet high, or higher, having passenger elevators to serve the upper floors, are not unusual; and loading pockets and crushing plants are often included in the structure. In cold climates they are enclosed in galvanized iron, and the workmen have heated rooms.

Of late a number of reinforced-concrete headframes have been built. Some are frameworks of concrete beams, but others are completely enclosed concrete buildings, having concrete beams for the head sheaves. These are an enlargement of the idea, often encountered in Europe, of building a small steel headframe on top of a large masonry or concrete building at the head of the shaft.

In the best practice, not only are the headframe and shaft collar fireproof, but no building that is not fireproof is allowed within 100 feet of the shaft.

DRAINAGE

The old Cornish pumps, so widely used in deep mines in the last century, are now a thing of the past. Their place was taken by duplex and triplex plunger pumps, some of which, like the Riedler pump, were large and efficient engines. Fred M. Prescott led the field in the manufacture of steam pumps for high heads. He used duplex triple-expansion engines, and his pumps lifted water 2700 feet or more in one lift. However, loss in steam lines was high in spite of improved insulation, and steam pumps gave way to electric pumps as soon as electric power became available underground. Large electric plunger pumps followed the design of steam pumps, being horizontal, duplex and double-acting. In the smaller sizes they are vertical, single-acting, and triplex.

As soon as electric power came into use, centrifugal pumps entered the field of mine pumping, and nearly monopolized the low-lift field; and multistage centrifugal pumps are used for high-lift pumping especially abroad, single lifts being as high as 3200 feet. Some of the new centrifugal pumps have motors with speeds as high as 3500 revolutions per minute. There is a saving in first cost, but lubrication is difficult.

Automatic pumping stations are becoming commoner, the priming troubles of centrifugals being overcome by the use of small pumps with submerged impellers, which discharge into the suctions of the station pumps.

Vertical, multistage deepwell centrifugal pumps that operate inside column pipes have taken the place of air-lifts for unwatering flooded shafts, and have proved effective in pumping from surface at mines less than 600 feet deep. They are also used to drain wet ground through boreholes ahead of sinking.

In this connection should be mentioned improvements in pipes and joints. Spiral-welded and seamless pipes are stronger than butt-welded pipe and lighter than lap-welded pipe. Rust-resisting coatings are used both inside and outside the pipe where the water is corrosive, but corrosion by mine water has not been as great a problem in metal mines as in coal mines. New joints—for instance, Victaulic joints—have taken the place of flanges, except for very high pressures.

VENTILATION

Artificial ventilation was almost unknown in metal mines until after the turn of the century, except in a few hot mines. Natural ventilation is still the rule in most mines, but large and deep mines have installed fans and doors for controlling the flow of air. In the mechanical operation of these doors metal-mining practice is farther advanced than coal mining, and door tenders are unknown.

The large centrifugal fans formerly so much used in coal mines are unknown in metal mines, although they may have been used on the Comstock Lode. Multivane impulse fans are common, and there are a few propeller or Aerodyne fans, where high pressures are required. Aerovane fans, copied from airplane propellers, are the latest development, and are very popular.

In secondary ventilation for drifts and raises, small high-pressure fans and cloth or metal tubing are used. For long drifts and tunnels, where the resistance increases as the breast advances, positive blowers of the Root type have largely replaced fans. At the breast, inspirators and water sprays of the Olds type have made it possible to clear powder fumes from the breast in a very few minutes.

In very deep mines, such as those on the Rand and at Butte, air-conditioning underground has been highly successful. On the Rand it has made possible the extension of the workings to a depth of more than 9000 feet.

In the fight against silicosis in mines, ventilation has been the most effective weapon, and air conditioning has been very helpful. Heating of the intake air in cold climates has done much for the comfort of those working underground.

LIGHTING

Improvements in lighting have been conducive to greater comfort, safety and efficiency underground. Until the late nineties light underground was furnished by candles, and in many places tallow dips were held in place on the miners' hats by balls of clay. Then candlesticks came into general use, followed by lamps burning kerosene, fish oil or paraffin wax. About 1909 carbide lamps began to replace candles and oil lamps, and in turn they were largely replaced by electric cap lamps between 1930 and 1940.

As soon as trolley locomotives came into use, main haulageways were lighted by electricity and this practice has spread to other drifts and to stopes, where floodlights supplement cap lamps.

Placer Mining

Placer mining has made less progress in the past 75 years than any other kind of mining. The principal reason for this is that most placer-mining methods and machinery were developed before the period began. There was a renewal of activity in 1898 with the discovery of the Klondike, and a few new methods were devised to work frozen ground, the principal one being thawing frozen ground with pipes or "points" containing steam or water.

Washing beds of gravel with jets of water directed by giants or monitors reached its full development before 1871, although some of the greatest activity came after that date. The principal improvements have been the building of dams for catching debris and the use of electric power and centrifugal pumps for furnishing water under pressure.

The most important advance is in the technique and equipment for dredging. Suction dredges and dipper dredges were total failures, and dredges are now all of the close-coupled, chain-bucket type. Bucket capacity has increased to 18 cubic feet, and occasionally is larger. To meet special conditions very deep ladders have been constructed and depths as great as 135 feet below water level have been reached. Recovery equipment consists of sluices, tables and jigs, but varies with the material handled. Most dredges are now driven by electric power, but under favorable conditions steam is still used. Since 1912 hulls have been made of steel, and late practice has been to make them in sections to facilitate transportation. Many dredges used for tin mining in Algeria and the East Indies are towed across the Pacific. The most spectacular transportation of dredges has been in New Guinea, where the Bulolo company flew all its equipment into the interior in airplanes.

When the price of gold was advanced to $35 an ounce, there was a temporary boom in placer mining in the West, and new equipment was devised for mining gravel deposits too small for dredging. Various kinds of equipment and various arrangements were tried, and the most successful was a dragline operating from the bank and dumping into a floating washer, which was equipped with a stacker.

Deep lead mining—that is, the mining of old river gravels that have been covered by later sediments or laval flows—has changed but little. The field is small, and a rather complete and successful technique was developed in California and Australia for mining this kind of deposit. When the price of gold was increased, there was some revival of deep lead mining, but few changes in technique were made. The material mined is soft, and the conditions under which it is mined do not lend themselves to mechanization. The principal advantage that modern miners have over their predecessors is the use of electric power for hoisting and pumping, and the higher wages now paid more than compensate for the increase in the price of gold.

Power

During the first half of the life of the Institute, steam was the principal source of power. Both wood and coal were burned, and hand firing was the rule. Few mines had automatic stokers until after 1900. The early boilers were of the Lancashire type, and these are still used in Lancashire and Cumberland. In the United States they were replaced by tubular and locomotive boilers, water-tube boilers not having been popular, where hoisting was done by steam. High-pressure, water-tube boilers and steam turbines have come into general use, however, for generating electric power in places where water power or commercial power lines are not available.

Auxiliary power-generating plants at large mines in the western states are usually diesel driven, and small diesel power plants for small mines are gaining in popularity. Diesel power has been used in a few instances for small hoists, and the new variable-speed diesel engines may prove useful in this service.

AIR COMPRESSORS

Much progress has been made in the design of air compressors. Seventy-five years ago air compressors were single stage only, and were driven by steam or water power. Maximum pressures were 40 to 60 pounds per square inch. Now pressures range from 90 to 125 pounds.

The first improvement was the use of cross-compound steam engines, and that was followed by compressing the air in two stages with an intercooler between them. Some of the big air compressors of this type, using Corliss valves on both steam and air cylinders, were very economical. A few three-stage air compressors were built, but this was an unnecessary refinement for the pressure used in mining.

About 30 years ago electricity replaced steam as driving power, and changes were made in the design of the compressors. New light valves, made of spring steel, took the place of poppit and Corliss valves, and made higher speeds possible; and "step unloaders" were introduced to regulate the amount of air compressed, because the motors ran at constant speed. The highest type of air compressor is now a two-stage machine, run at a speed of 200 to 250 revolutions per minute, direct-connected to a synchronous motor. It has a five-step unloader, an intercooler and an aftercooler, and there is an air filter on the intake. The cooling water for the air cylinders is pumped to them by a small centrifugal pump, and is cooled in a spray pond. It has been found to be more economical to have several medium sized compressors than to have a few large units.

Centrifugal compressors have been tried, and are economical if there is a large and steady demand, because they must be run at constant speed and output; but they have not been satisfactory for ordinary mine work.

A few hydraulic compressors have been built, in which air is trapped and compressed by falling water. Their first cost is high, and the operating cost is very low, if water power is available, but the water dissolves much of the oxygen out of the air, and renders it unfit for underground use.

Shops

With improved transportation and greater proximity of commercial machine shops and foundries, mines generally do not require as large repair shops as formerly, and the use of oxyacetylene and electric-arc welding has made foundries unnecessary, except in very isolated places. Standardization of machines and machine parts has brought with it a greater use of factory-made parts, so that making parts in the mine repair shop is comparatively rare.

Welfare

Great as have been the improvements in production methods and equipment and in the amount of ore produced per man, this progress has fallen far short of the increase in the interest taken in the welfare and health of employees. This interest has more often originated with the employers than with the employees. It has often been difficult to raise the workmen's standards, and education has been necessary.

One of the first improvements was the building of change houses, where workmen could wash and change into dry street clothes at the end of the shift, and leave their wet clothes to dry overnight. Yet there are many instances of miners refusing to use the change houses, and even burning them down. In the early days being dirty was considered a sign of strength and virility.

Improved sanitary facilities both underground and on surface followed the building of change houses, and the training of men in first aid and the provision of facilities for the treatment of the injured came soon after. Thorough guarding of machinery and education in safe working methods resulted not only in a gratifying decrease in both the number and severity of accidents, but also in an increase in the productivity and earning power of labor. At the same time hospital care was improved, and compensation of injured workmen was regulated by law. Strange as it may seem, this program originated not with the workmen or their unions, but with the employers, mostly the large corporations, which are popularly supposed to "grind the faces of the poor." One of the first states to pass a comprehensive workmen's compensation law was Michigan, and this came about as a direct result of the recommendations in 1909 of M. M. Duncan, then General Manager of the Cleveland-Cliffs Iron Co. and President of the Lake Superior Mining Institute.

The worst offenders against health and safety are the small mines and prospects, which are in a class with the "family mines" and "wagon mines" of the coal regions. At these mines lack of facilities may be due to lack of money, but unsafe methods of working cannot be excused on that basis.

A Glimpse at the Future

Our high-grade ore bodies are largely a thing of the past, and most of our large ore bodies are known and developed. Much of our future production must come from smaller mines. For these mines to be operated efficiently, they must be properly developed and equipped, even though the reserves are not large. Development cannot be moved from one mine to another, but equipment can be so moved, if it is properly designed. We now have "package" power plants, both steam and diesel, and it is not a long step to "package" hoists and compressors, headframes and crushing plants. There is a good field for unit construction both on surface and underground, to the advantage of both the manufacturer and the mine operator.

One of the greatest signs of progress and of hope for the future is the large number of educated men engaged in mining. About 90 per cent of graduated mining engineers go into operating, and it is not unusual, especially in our western states, for the mine foreman and many of the shift bosses to have college educations. Such a dissemination of knowledge of the principles of engineering and the application of that knowledge to the art of mining cannot but result in improvements in technique and equipment far beyond that which we know today; improvements that, unless hampered by artificial restrictions, may make profitable many of the low-grade ores that are worthless at the present day. ◆

Seventy-five Years of Progress in Ore Dressing

BY ARTHUR F. TAGGART

ARTHUR F. TAGGART
Professor of Mineral Dressing at Columbia School of Mines since 1919, Arthur F. Taggart is a recognized authority on ore dressing in all its branches. He played a particularly important role in the development of the flotation process and has been consultant to many important corporations. His Handbook of Ore Dressing, published in 1927 and revised as a Handbook of Mineral Dressing in 1945, is a standard work on the subject.

PROGRESS in a technical art is of several kinds. It springs from many diverse sources. It comprises invention, mechanical improvement, operating advance, analytical study, education. Invention is, by definition, a relatively great, essentially individual step, taken quickly. Operating advance is the slow, cumulated march of practice; in contrast, it moves at the pace of the tortoise, but over the years its effects rival and, in some cases, surpass those of invention. Mechanical improvement is a usual concomitant of the reduction of invention to operating practice; thereafter it is a primary tool of operating advance. Analytical study is the process of mental digestion of the fruits of invention and practice. Its purpose is to render these into a form assimilable by the art as a whole, and by the perennial crop of would-be practitioners. Education, disseminating the results of such study, consolidates and maintains the positions gained. Thus, slowly at first, but continuously accelerating, the tide of progress grows to flood.

Such growth, in mathematical parlance, is expressible in the general form $y = mx^n$, where x is time, n is some positive number greater than one, m is another positive number, and y is the state of the action at instant x. When n is 2, the readers will recognize the graph of the equation as one branch of the familiar square parabola, whose property it is to become parallel to the y-axis; i.e., to move at an infinite rate, in that never-never land that we call infinity. A little graphical experimentation will reveal, if the reader has forgotten, that the acceleration of y is determined by the value of m; the smaller m, the longer y remains in familiar territory.

This type of equation, in its own dry way, has told many familiar technical stories. But it has other uses: It can tell the tale of the snowball and the avalanche. It can predict the courses of such trilogies as Rooseveltism, national political corruption, and totalitarianism; the Wagner Act, the labor barons, and anarchy; or grossly expanded government debt, controlled inflation, and repudiation. It also, in more honest fields, with small and decent values of m and n, and reasonable values of x, can portray and predict the paths of normal industrial production, and of the technical advances on which healthy growth depends.

For such use in ore dressing, it is necessary to extend the time scale backward, in order to determine from history the values of m and n that prevailed in the past, and to locate the present on the curve.

The first real value of y that we can record corresponds to a value of x some time prior to 4000 B.C. As of then, Hoover* finds evidence of the washing of placer gold. Mining of gold veins, undoubtedly followed by crushing and washing, is indicated as of 2400 B.C. In the Third Century B.C.† there was extensive milling of lead-silver ore in Greece according to a flowsheet comprising successively: hand sorting of milling rock; hand stamping with a stone mortar and pestle; grinding between horizontal buhrstones, hand-driven and adjustable for product size; washing on an inclined paved area, cemented smooth, to make finished concentrate and a tailing; and scavenging of this tailing in a riffled canal, from which the scavenged concentrate returned to the inclined washer and the tailing went to clarification ponds for recovery of the water. In the Second Century B.C., treatment of these ores further included four-stage crushing with intermediate jigging. The first use of amalgamation, with gold ores, is accredited to the Romans.

Agricola (1556) summarized the flowsheet of his day as follows: Hand picking in the mine; breaking with hammers, with prior burning and quenching to render breaking easier, if necessary; spalling and cobbing; screening and jigging; stamp milling; grinding to a powder in buhr mills; washing on a variety of sluices, blanket tables, buddles, strakes, and the

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* References listed on page 125 are indicated by the names of the authors, as here. Unreferenced facts with occurrence dates later than the publication of Volumes III and IV of Professor Richards' Ore Dressing are, in general, based on the author's Handbook of Ore Dressing or the Handbook of Mineral Dressing, wherein due acknowledgment of source is made, or they come within the scope of the author's personal experience.

† This and the subsequent statements dealing with progress prior to 1556 A.D. are taken from the footnotes by the Hoovers in their classic translation of Agricola.

like; drying and smelting. Both stamp mills and buhr mills were driven by water power.

It is probable, although the support lies in legend rather than history, that preferential oiling of metallic particles in the presence of water was practiced in concentrating gold in early times. Thus, according to Strabo, the Golden Fleece of the Argonauts consisted of sheepskins used to line sluices; Rickard (1944) directs attention to the fact that these are full of natural wool greases. Herodotus, citing legend, writes of maidens who dragged feathers daubed with pitch in the sands on a lake shore, and collected gold thereon. In 1860, William Haynes described a process of selective agglomeration of the sulphides in a finely ground ore by puddling a thick mixture of ore and oily or bituminous matter in warm water. These operations were far removed, of course, from what we presently call flotation, but a germ of the idea certainly preceded 1871.

Milling as of 1871

Immediate pre-Institute practice abroad may be described best, possibly, by the following summary of a description of the then new Clausthal mill as given by Randolph. The flowsheet is shown in Fig. 1. Capacity was 500 tons per 24 hours. It was the largest mill in existence at that time, and represented the latest in equipment and arrangement. The ore was low-grade argentiferous galena, finely disseminated in a gangue of calcite and barite, and more or less intimately associated with chalcopyrite, pyrite, marcasite and zinc blende.

Ore came from the mines by tram and entered the second floor of the breaking house. The breakers were Blake type, six in number, and were fed by pushing grizzly oversize down a slight slope. Capacity was 5 to 7½ tons per hour each, thus affording the necessary excess capacity at this point to equalize somewhat between mine and mill. The screens following the crushers were conical trommels, 42-inch maximum diameter and 9 feet long, 12 revolutions per minute. Six operated dry and six wet. The coarse rolls were 25 by 12-inch, geared, one roll with movable boxes; set was 18 millimeters; speed, 24 revolutions per minute, and capacity 5½ to 7½ tons per hour. The middle and fine rolls, six of each, were 12½ by 12-inch, set at 6 and 2 millimeters, respectively, run at 60 revolutions per minute with capacities of 2½ to 3 tons per hour. The 40 coarse trommels were cylindrical, 36 and 24 inches in diameter, and 9 and 6 feet long, respectively, set on a slope of 1:24. The 40 fine trommels were conical, 24 by 27 by 72 inches, run at 12 revolutions per minute, Each of the sizes from 1 to 18 millimeters, ten in all, was jigged on separate jigs, Harz type, of which there were 4 single-sieve, 28 two-sieve, and 5 four-sieve, working on sized products, and 36 one-sieve, two-sieve and three-sieve jigs working on classified sands from the minus 1-millimeter material.

There were 176 stamps, 450 to 475 pounds. Classifying apparatus comprised a large number of inverted pyramidal boxes or spitzkasten, and hydraulic water was used sparingly, as needed, in the coarser sizes. The buddles were both convex and concave, in vertical pairs or triplets, some convex both above and below, others concave above; diameters were 10 feet for the upper and 15 feet for the lower. Four were two-deck and three were three-deck. The so-called tables were rectangular bumping-type building buddles. Mill treatment was preceded by hand sorting of waste in the mine.

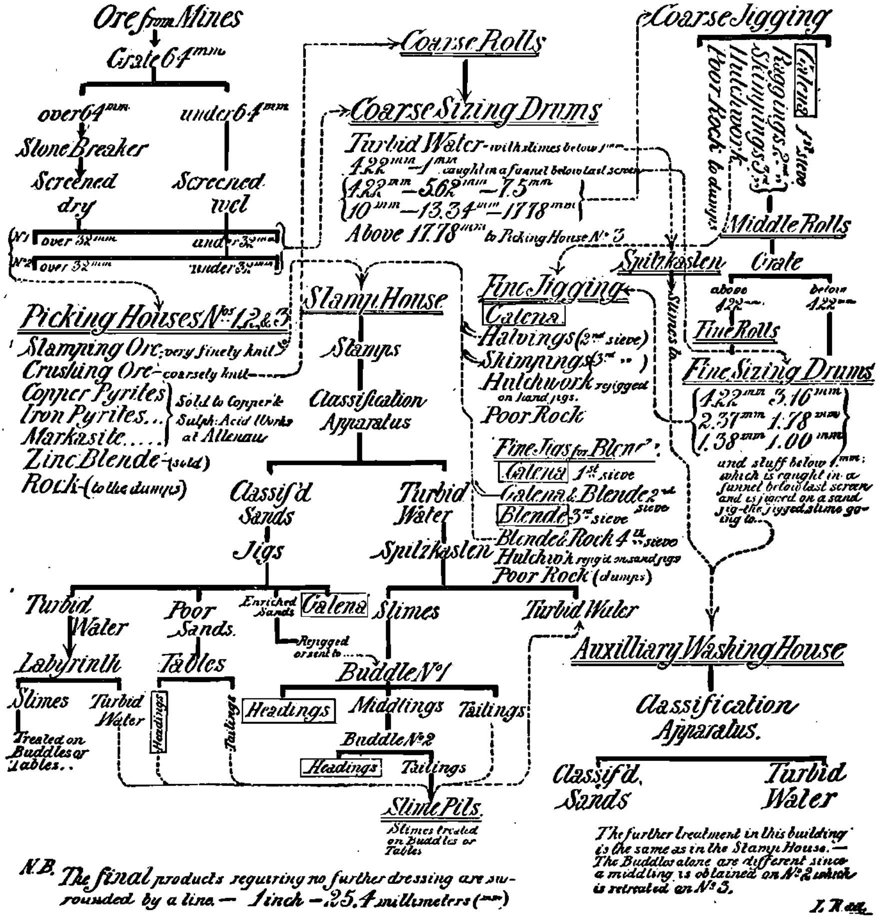

FIG. 1—*Plan of dressing operations of Clausthal mill in* 1871 (*from Randolph*).

In the United States at that time there were four major types of milling activity, each of which had developed substantially independently to reach a form peculiarly adapted to the local problem: that is, gold placering in California; lode-gold milling, primarily in California and Colorado; silver milling in Nevada, Utah, and Idaho; and the milling of native copper in Michigan.

GOLD PLACERING

As of 1871, the heyday of the deep placer had arrived in California, with the invention of hydraulicking. Egleston, not calloused as we are by the astronomical figures of government expenditure, put so much of wonder and enthusiasm into his description thereof that I quote him for his joy in the technical accomplishment.

> To work these deposits [he says], careful surveys of the whole country must be made so as to be able to reach with a tunnel the lowest point of the bed-rock, which must be determined by sinking shafts upon it. The cost of this preliminary work may often be [more] than $100,000, and instances have been known where from want of proper judgment in the outset the whole of this sum has been lost. The location of the tunnel must be such that the pay dirt can be washed through it, and that it may form an outlet for all the material which is deposited after the extraction of the gold. Its construction involves the building of miles of sluices to catch the gold and carry the dirt away; the damming of streams to save the winter's water supply; the storing up of billions of gallons, and conducting it in ditches, flumes, and wrought-iron pipes; sometimes forty, fifty, or even a hundred miles in length, the ditches alone costing in some cases from half a million to a million dollars, . . .
>
> The water is discharged through iron nozzles with a velocity of 150 ft. per second, and at the rate in some instances of 4,220,000 cubic feet in 24 hours, against a bank from 250 ft. to 300 ft. high, and washes the earth into wooden sluices paved with rock or wood. To make the action of the water more effective, the bank is mined and fired, single blasts of from 1500 to 2000 kegs of powder being made.
>
> As everything in the bank must come down, huge cranes with booms 90 ft. long, worked with hurdy-gurdy water-wheels, are set up to lift the boulders, undercurrents to catch the gold, grizzlies to carry off the stones, drops to break the materials up. The sluice itself has to be paved with stone or wood and furnished with branches, so that one part may be repaired without stopping the work on the rest. . . .
>
> The gold is caught in mercury, put into the sluices between the pavement and riffles. The greatest difficulty is not so much to catch the gold as to get rid of the tailings or material that has been treated. This involves the construction of miles of tail-sluices and the destruction of land and of streams by depositing on and in them stones and sands to great depth, but it saves for the use of the country the very large amounts of gold deposited in exceedingly small quantities in the ancient river beds of California. . . .

Raymond (1874) gives the physical picture:

> Standing at the mouth of one of these long sluices (up to 6 ft.wide), in full action, one unaccustomed to the process is filled with a sense of amazement, amounting almost to

> terror, as the muddy mass sweeps with great velocity onward, bearing in its course bowlders which add their din to the roar of the waters, the whole being precipitated down a series of falls or dumps at each of which it is caught up again by a new sluice of timber, lined as before explained, and so onwards and downwards many hundreds of feet, until the level of the river is reached, a mile or more from the 'bank.' At each of these falls of 25 to 50 ft. the process of comminution begun in the first, is carried forward, and a new portion of gold obtained.
>
> Rude as this method of saving gold appears, experience shows that more gold is saved by it than by any other method of washing yet devised; while the economical advantages it offers are incomparably greater than any other. In fact, it would be entirely impossible to handle so vast a body of material in any other way now known. . . . taking a miners wage at $3 per day, the cost of handling a cu. yd. of auriferous gravel is as follows: with the pan, $15; with the rocker, $3.75; with the long tom, 75c; with the hydraulic process, 10c.

Egleston states that yields at eight of the largest mines ranged from 2½ to 19½ cents per cubic yard and costs from 2 to 6 cents. He also writes that subsequent investigation indicated losses upward of two thirds of the original gold content of the gravels.

The first of the permanent injunctions against this type of mining in California was handed down in 1884.

LODE-GOLD MILLING

Lode-gold milling as of 1871 comprised, after mine sorting, primary crushing in jaw crushers; further crushing in gravity stamps, usually through 20 to 30-mesh screens; amalgamation on plates; and concentration on blanket tables. Often amalgamation in the mortar was also practiced, and at just about this time vanners were introduced instead of or ahead of the blanket tables. Amalgam was worked up to bullion; concentrate was shipped to a smelter. Milling costs ranged from $1 to $3 per ton. Recoveries in some cases were upward of 90 per cent with ores containing coarse gold and but little sulphide; when, however, the gold was fine, or rusty, or largely in the sulphide, it is doubtful whether much over 70 per cent was obtained. Mills cost from $1000 to $2500 per stamp.

The battle between sledges and jaw crushers as primaries was not yet settled. Adams cites a comparative test in which twenty 650-pound stamps had a maximum production of 28 to 30 tons per day when fed with sledged rock, and 33 tons per day when fed with Blake product. This was in answer to an assertion that despite the higher cost of sledging, stamp production was greater with sledged feed, because of the concomitant manual feeding of the battery. The argument was that a skillful stamp feeder worked by sound and fed each stamp separately according to need.

SILVER MILLING

Milling of the rich silver ores of the Nevada-Utah-Idaho belt pointed up the inadequacy of available dressing methods. These ores, carrying native silver, silver halides, and silver sulphides, together with notable amounts of gold, ranging from fifty to several hundred dollars per ton in value, were milled with recoveries that often did not exceed 50 per cent of the assay values, and that probably never much exceeded 80 per cent of the gold and 70 per cent of the silver. Treatment differed according to the silver-sulphide content of the ore. Ores in which this content was low were treated by the so-called Washoe process of pan amalgamation, as described by Hague (1870). Run-of-mine ore of head size or slightly larger was broken by sledging or by Blake breakers, then stamped wet through punched-plate screens of about ¼0-inch aperture. Stamp product ran to a series of settling tanks 5 to 6 feet square and 3 to 4 feet deep, overflowing one to the other, sufficient in number to permit cleaning out of one or more while others were loading. Settling-tank overflow was collected in ponds and returned periodically for work-up with the settled sandy product. Settled products were amalgamated in pans, in batches of 1200 to 1500 pounds, by a complicated schedule comprising essentially shoveling into a pan partly filled with water, the mullers revolving meanwhile but raised off the dies; turning in live steam until the temperature of the pulp was near boiling; lowering the mullers and grinding until the proper fineness was attained, and at the same time, by controlled evaporation, bringing the pulp to a consistency that would hold fine droplets of mercury in suspension; then raising the mullers slightly, adding some 60 or 70 pounds of quicksilver (the pan already being charged with some 200 to 300 pounds of quicksilver), and continuing the agitation for about two hours. Thereafter the charge was diluted with water, stirred to settle as much amalgam in the pan as possible, and flushed out to tanks in which further suspended amalgam was settled in a dilute pulp with slow stirring. Meantime the pan was again charged and its cycle repeated. After several cycles the amalgam in the pans and settlers was collected, cleaned up, strained and retorted in the usual fashion. Mercury-settler tailing, comprising plant tailing, was sent over blanket tables in the cañons below the mills.

It was customary to add common salt and/or copper sulphate in small and variable amounts to the pulp in the pan, but, according to Arnold Hague, the same results were in general attained with or without such additions.

Ores that contained little or no oxidized silver minerals were dry crushed (at this time in stamps but later in rolls), roasted with salt, and amalgamated in barrels or pans, by substantially the procedures described above.

Costs ranged from $10 to $20 per ton for the Washoe process and from $20 to $30 by the roasting-amalgamation process. Ten years later these costs had been better than halved.

Church evaluated this early silver milling in the words:

> . . . the much vaunted method of the Washoe process consists in extracting 72 per cent of the gold and silver by one operation, and then repeating this operation half a dozen times to get about one third of the remainder. With all of the advances of twenty years of milling, there is nothing more crude in metallurgy than the treatment of tailings in many of the large mills of the West.

COPPER MILLING

Dressing of Lake Superior copper ores consisted in hand sorting combined with sledging and cobbing when coarse copper was present; primary crushing in jaw crushers, sometimes in two stages; stamping mill rock through 3/16-inch screens with steam stamps; classifying roughly in hydraulic classifiers to make coarse, medium and fine sands, and a slime product; jigging the sands separately to make screen concentrate, tailing, and a hutch middling, which was rejigged to make concentrate and tailing; settling the slimes to a thickness that permitted working them on buddles and strakes, and then subjecting them to a maze of buddle roughing, strake cleaning and kieve recleanings, until either copper or patience was worn away. Actual recoveries were unknown because of inability to sample either feed or tailing. They were estimated, probably flatteringly, at about 70 per cent. Concentrate grades as given by Egleston were, in order from coarse to fine: No. 1, Cu 90 to 98 per cent; No. 2, Cu 80 to 94; No. 3, Cu 60 to 79; No. 4, Cu 30 to 37; No. 5, Cu 25 to 40. The ranges of copper content cover variations from mill to mill. Costs ranged from about 75 cents to $1.75 per ton of rock stamped, and the yield on stamped rock was of the order of 1.5 to 2.5 per cent copper. Mill tonnages were of the order of 100 to 500 or 600 tons per 24 hours.

Study of these flowsheets from the standpoint of basic operations and machines rather than that of ores and pulp flows, and comparison with 1946 on the same basis, shows remarkably little now that is fundamentally new. This suggests the rather interesting conclusion that inventive advance of anything approaching pioneer nature and wide applicability is comparatively rare in the art, and that advances in practice have been in very considerable part due to the availability of larger machine units. These have been made possible by developments in metal manufacture and in machine design, for which our own art can claim but little credit. A summary of the facts is given in Tables 1, 2, 3, and 5; discussion of them is amplified in the pages following.

TABLE 1—*Developments in Comminution*

General Principle Employed	Method or Machine	Extent and Character of Use		Character of Change
		1871	1946	
IMPACT	Sledging, spalling, and cobbing	Extensive for primary breaking and (in Europe) in concentration	Sledging in stopes and occasionally on primary-crusher floor	Decrease in use owing to mechanical substitutes.
	Stamping	Almost universal for fine crushing and coarse grinding	Vestigial; for medium to fine crushing	Decrease in use owing to improved substitutes
	Water jets	Hydraulicking and screen washing	As 1871; little change in methods or apparatus	Decrease in hydraulicking owing to legal restrictions
	Dropping	Occasional, except as in hydraulicking and screen washing	Hardinge cascade mill; little use	Decrease in use owing to limited applicability
	Mechanical sledging	Centrifugal-impact mill, corrugated rolls	Sledging rolls, knobbed and corrugated; single-roll crusher and hammer mill widely used for soft rocks	Great increase in use owing to greater forces made available by improved mechanization
GRADUAL PRESSURE	Jaw crusher	Limited use in western U. S.; little elsewhere	Universal as a limited-capacity primary of large receiving ability	Great increase in use owing to increase in size
	Gyratory crusher; cone crusher	Unknown	Universal as a large-capacity primary and as a secondary	Invention
	Rolls	Universal in Europe for intermediate crushing; little used in U. S.	Almost universal for fine crushing of hard rock	Great increase in use owing to improved design and availability of better steels
	Roller mills	Chilean mill; fine intermediate crushing and coarse grinding in Mexico and Europe; little use in U. S.	Many forms of vertical and horizontal roller, and large-ball types in extensive use for fine dry crushing and coarse and fine dry grinding in nonmetallic fields	Great increase in use owing to improvement in mechanization, and to growth of a new need, thus particularly well served
SHEARING	Buhrstone mill	Horizontal type; generally used in Europe for the finest grinding	Vertical and horizontal types used to a limited extent for fine dry grinding of nonmetallics	Decrease in use owing to development of improved substitutes
	Grinding pan	Variety of types widely used in U. S. silver milling	Limited in cyanidation and amalgamation of concentrates	Decrease in use owing to development of improved substitutes
	Ball and tube mills	Unknown in ore dressing	Universal for medium and fine wet grinding, and widely used for dry grinding of nonmetallics	Adopted from an allied industry; design improved
	Rod mills	Unknown	Increasing use in coarse grinding or fine crushing	Invention
	"Coffee-mill"	Cracking of friable ores; mantle and bowl both corrugated	Laboratory use only; little change in design since 1871	Adaptation to a specific minor need
PHYSICO CHEMICAL	Heating and quenching	Not uncommon in Europe as a prelude to sledging	Unused	Abandoned in favor of cheaper mechanical substitutes
	Solution	Soaking of clays prior to washing; unusual		No change
	Chemical reaction	Weathering of certain ores; unusual		No change
	Explosion	Mud-capping, etc.; just starting	Mud-capping; limited. Explosive shattering; experimental	Rise and fall of mud-capping; latter owing to superiority of large crushers.

Progress in Comminution

The major inventive advance in crushing was the gyratory principle, embodied in the gyratory crusher and in its outgrowth, the cone crusher. The gyratory was the answer to a demand for more capacity in a single crusher of a given gape and set than could be obtained with a jaw crusher. In it the additional capacity, sought in the jaw crusher by increasing the length of receiving opening, was obtained, with notable structural and operating economies, by winding the fixed jaw around the movable jaw, as it were. Thus a frame was obtained in which the high stress-resisting ability of a cylindrical member in tension was substituted for the relatively low strength of a beam in flexure. As an added but actually incidental advantage, power draft was equalized to a certain extent. This is not, however, particularly important in a primary breaker. Irregularity in feeding, and the large variation in instant-to-instant range in feed-particle sizes, causes great power-draft fluctuations in both machines.

The great increase in size of the hard-rock primary crushers, both jaw and gyratory, constitutes probably as great an actual advance as the invention of the primary gyratory itself. The need arose with the development of mammoth blasting in quarries, and the parallel increase in size of steam shovels. First the mammoth blast broke rock that the steam shovels of the day could not handle. Then, when the steam shovels could take the bite, the crushers were not equal to the job, and much of the economic advantage of the large blast was frittered away in the labor of blockholing the boulders. Today's big crushers could readily receive the largest crushers of 1871 vintage.

The large primaries themselves created a need almost as great as the one that they had satisfied. Their product was too coarse for rolls to handle, and intermediate crushers, in most cases moderate-sized gyratories, had to be installed to provide roll feed. These gyratories had small working reduction ratios and relatively small capacities, hence two secondary gyratory stages, the second comprising two or more machines in parallel, were often needed. Further, if a roll product finer than, say, $\frac{3}{8}$-inch limiting was required, two roll stages were necessary. The cone crusher, with a large working reduction ratio and surprisingly high capacity, answered this need—how well is adequately shown by comparison of crushing-plant flowsheets of 1925 and of today.

CHARACTERISTICS OF CONE CRUSHERS

The essential elements that differentiate the cone crusher from its predecessors in the gyratory field are: (1) a tremendous increase in area of discharge opening for a given limiting size of product; (2) a much higher speed of gyration; (3) a much larger throw; and (4) a much more acute convergence of the crushing zone throughout its lower part. These differences work together admirably to produce a machine of large capacity and greater than average reduction in limiting particle size. The contribution of each of these elements to the result is interesting. The key factor in increased capacity is the large discharge area, of course. To obtain this it was necessary to have both great length of opening and a large open setting. To obtain the length without great depth of crushing zone and consequent excessive weight and height of machine, it was necessary to make the crushing head much more obtusely conical than was usual in the then existing gyratory machines. This would slow down flow and thus sacrifice the gain from the obtuse cone, unless some means was introduced to accelerate travel on the low slope. Such aid could be had by increasing the movement of the head by longer throw or greater speed, or both. The greater throw was desirable in that it gave a greater width of discharge opening; the greater speed was necessary with this greater open setting in order to ensure pinching of every lump at some point near the throat, to reduce it to something near the closed setting in size. This end was made more certain of attainment by so conforming the fixed crushing surface that the lower half of the crushing zone had substantially parallel sides. High reduction ratio was then obtained by horizontal corrugations in the upper half of the zone. This had the effect of periodic reduction in nip angle at distances so short that any small movement of an unnipped particle tended to cause it to slip into a nippable position. The whole design constitutes as fine a piece of fitting a number of old and well-recognized principles into a mosaic of new and useful properties as one often sees. Mechanical construction was excellent from the first—a most important element in heavy-duty machinery—so that the machine did not get the usual initial black eye on this score. Its adoption was substantially immediate.

Possibly as an outgrowth of the advantages of the parallel zone in the cone crusher, a similar conformation has been adopted for both jaw and primary gyratories. It is attained by curving one or both of the crushing surfaces.

CRUSHING ROLLS

Crushing rolls as of 1871 were 24-inch maximum diameter, and were limited to low speeds because of light construction. Richards (1903) mentions one pair of 42 by 12-inch size and speed up to 950 feet per minute. As of the present, 84-inch rolls are in use and peripheral speeds are up to 40 miles per hour (3520 feet per minute). Reputable manufacturers offer 90-inch machines.

From the mill standpoint these big rolls are as different in their performances from those of 1871 as though they constituted new types. They are capable of large reduction ratios on feed sizes on which the old machines would have been limited to ratios of 2 or less. One such machine has the capacity of 20 or more of the small ones. The tonnage life of shells is immeasurably greater. Power utilization is much more efficient, and the comparative attendance requirement per ton is better than inversely proportional to relative unit capacity.

The single-roll crusher is essentially a slugger, its prototype the slow-speed corrugated roll of 1871. It answers two long-existing needs. It makes a larger reduction from run-of-mine size in one step than is possible in either of the standard hard-rock primary types, and it can handle sticky feeds better than they. It is limited, however, to relatively soft rocks; i.e., limestone or softer. The slugger action obtained by the lugs on the roll does not constitute inventive advance within the limits self-imposed in this discussion, since the slow-speed corrugated rolls exert the same kind of crushing action. This was amplified in the Edison giant rolls.

The hammer mill is the companion and in some respects the competitor of the single-roll crusher in the soft-rock field. In series the two machines constitute the counterparts of the jaw or gyratory and the cone in the hard-rock field. The hammer mill had its predecessor in the centrifugal crusher described by Rittinger, in which rock was thrown from a rapidly whirling ribbed horizontal disk against a vertically corrugated cylindrical wall. But the force of the impact in the hammer mill is so much greater than it could possibly have been in the early machine as to justify characterization as inventive advance. The apparent ability of the machine to produce a crushed gravel of a more cubical shape than is produced by some other machines operating over the same reduction range gives it a present importance probably undreamed of by its inventor, owing to the value of such shape in the compounding and placing of concrete.

THE TUMBLING MILL

In grinding, the outstanding advance has been the adoption (*circa* 1905) from the cement industry of the tumbling mill, and its adaptation to high-capacity grinding of hard rock through the use of steel balls, ribbed liners, large diameter, high speed, and of water as an in-process transport aid. This mill, used in conjunction with the mechanical classifier to guard the product, return oversize, and control size range and pulp consistency in the mill barrel, makes the present-day wide application of flotation economically possible.

Substitution of rods for balls as tumbling media, originally for the purpose of decreasing the proportion of fines in the feed to gravity concentrators, was largely abandoned with the widespread adoption of flotation. Of recent years, however, rod mills, operated at high speed, have been reintroduced in some plants as competitors of rolls in fine crushing. Some imaginative operators are today seriously considering the use of giant high-speed mills for one-stage reduction from ¾ or 1 inch to flotation-feed size.

In dry grinding, progress has been away from rather than toward the tumbling mill. The gainer has been the roller-type mill in one of its many forms, in which rollers or large balls crush against suitable dies in more or less cylindrical chambers, while air currents of suitable velocity sweep out finished material. The product is guarded by an air classifier, either within the mill housing or external thereto; the choice of position depending largely upon the sharpness of the cut desired. The tumbling mill suffers in competition by reason of inability to do a thorough job in discharging finished material from the grinding zone as quickly as it is made. Hence the proportion of ultrafine in its product is higher. When this is an advantage, the tumbling mill cashes in, for in actual utilization of energy in grinding it would appear to be superior to its competitors.

MICRONIZING

Micronizing is a new word in fine grinding and a happy choice to describe the process of attaining 100 per cent yield to a limiting size of 10 or 5 microns, or even finer, on a commercial scale. The apparatus comprises essentially an annular tube of a few inches to two or three feet annular diameter, and a fraction of an inch to, say, six inches tubular dimension. The annulus is circular or oval; the tube is circular, oval, or rectangular; the setting of the annulus may be horizontal, vertical, or at an angle between. A plurality of fine nozzles admits gas jets along the periphery of the tube. These are directed at such angles that they cut diagonally across the tube. The velocities of the jets range up to sonic. Feed is injected in another gas stream, so directed as to set up a current in one direction around the annulus. Annular gas velocity carries much of the solid load forward in suspension. Centrifugal force causes the coarsest material to go to the outer wall of the annulus. The sweep of the current pushes this coarse material along the wall. As the layer moves over a nozzle the material is projected, as shot from a gun, across the stream of suspended material. The resulting collisions cause particle reduction by shattering and abrasion. Separation of finished from unfinished material is made by an air classifier, which may either be an integral part of the machine or external thereto. Capacity is low and the cost of production of the high-pressure air, steam, or other gas is high. But for expensive materials, such as cosmetics, insecticides, fillers, or pigments, where high yield on the feed is an economic necessity, the problem is solved. If history repeats itself, cost will decrease with time.

PRESENT USAGE

The 75 years has seen the disappearance of heating and quenching as a means of comminution. Sledging is reaching a seemingly irreducible minimum as a guard against clogging of underground transport conduits; there are relatively few mills nowadays without primary crushers capable of receiving any size that the mine can ship out. Skull crackers, readily handled by the mine loader, are displacing powder for breaking down boulders in open pits. The gravity stamp, in modern heavy high-speed form, had its greatest flowering in the Rand gold mills; except in small isolated gold mills no new installations have been made for 25 years or more. The steam stamp served its purpose for the coarsely disseminated native copper ores, but never was a real competitor elsewhere. It is not improbable that discovery of another such ore deposit would revive the old machine, since nothing was ever able to displace it in such service. Roller mills, buhrstones and grinding pans have all been finally and decisively displaced by the tumbling mill in wet grinding. The lunatic fringe of crushers and grinders has maintained a relatively even tenor throughout the period.

Progress in Separation

The important separations now, as in 1871, are those according to size, according to chemical composition, and of solid from fluid.

Size separations, as in the earlier day, are effected by screening and by sedimentation. The only advances in screening are those involving new mechanisms for effecting old motions of the screening surfaces. Of these the principal are the various electrical and gyroscopic methods for effecting screen vibration. These are important from the standpoints of screen capacity and cleanliness of product, but involve improved applications of known screening principles rather than any basic advance. Screening units are larger, and the screening surface is more resistant to wear and to deformation, which has important implications in mill operation. No new uses for screens in flowsheets have been devised; their occasional use to close circuit on a tumbling mill is novel only in that the grinding mill is different.

Sizing by sedimentation in fluids has shown important progress in several directions. First, of course, in the mechanical classifier (*circa* 1905), with the various forms of drag, spiral, and rake for the combined agitation and sand-transport functions. The slow progress of the spiral type as compared with the rake type would seem to demonstrate that salesmanship can be more important than economics in determining the purchases of engineers. Recent exhaustive comparative tests seems to have demonstrated substantially equal performances of the two types in closing grinding circuit on sulphide ore, with considerable advantage in favor of the spiral in the way of first cost and available slope for sand return. It is to be noted that although the adoption of tube mills and the invention of the mechanical classifier were substantially coincident, closure of tube-mill circuits with hydraulic and diaphragm cones apparently preceded the use of the mechanical classifier in this service.

Augmentation of sedimenting force by centrifugal action, for increasing capacity in fine-size separations, constitutes an outstanding advance in both dry and wet fields. In the wet field the centrifugal force is developed by revolving the container, the pulp following because of its viscosity and the friction between it and the container wall. The separation is effected by the action of a spiral rake working against the general flow of the liquid, just as in the gravitational spiral machine. When air is the suspending medium, viscosity and wall friction are insufficient to set up the requisite rotation of the fluid. Hence the fluid is caused to rotate by tangential introduction of the carrying current into a circular chamber, or by internal impellers or fans. Since angular velocity for a given flow increases with decrease in diameter of the container, and centrifugal force increases with angular velocity, the finer the separation demanded, the smaller the container. Separations are made at sizes well below 10-micron limiting, with reasonable efficiency as far as undersize grade is concerned, but with considerable extraneous undersize in the coarser product.

The hydro-bowl type of sizer, which first appeared in the bowl-rake type of sand-slime separator, has been generally adopted in one form or another for fine desliming in wet pulps. The apparatus is essentially an overgrown teacup, with its relative shallowness accented. The rotor is the spoon, which sets the entire body of pulp in relatively slow rotation. The lowest layer of liquid, in contact with the bottom of the tank, is retarded by friction and thus slowed down in relation to the upper layers. Its centrifugal force is thus decreased, and with this reduction the pressure against the wall at the bottom is less than that above. Hence the flow of liquid is outward at the top, downward along the walls, and inward along the bottom. Deposited solid is thus carried to the central bottom outlet. The separation is simple gravitational settling; the conveying means is the centrifugal circulation induced by the raised stirrer. When the apparatus is used for the finest separations, the slow-moving rakes substantially scrape the bottom of the container, making the action of the apparatus the same as that of the ordinary continuous thickener.

Hydraulic classification, as the desirable sorting step prior to final separation by film sizers, has substantially passed out of the milling picture. Its near demise is not the least of the benefits for which we may thank flotation. Its crankiness is attested by the fact that, even prior to flotation, mill practice was adopting two means of self-protection—locking the regulating valves against the operators, thus reserving the headaches of regulation for superintendents and shift bosses, and throwing the machines out bodily, substituting rougher-cleaner flowsheets on the tables, making sand-slime separation on the roughers.

ADVANCE IN METHODS

Separation of solids from fluids has made but one important inventive advance since 1871; viz., charging of the particles by exposing them to a stream of electrons in a gaseous suspension, and thereafter causing them to move toward an oppositely charged surface under the influence of electrostatic attraction. Otherwise the old methods, sedimentation and filtration, still prevail. But these have undergone various improvements, which enable the handling of larger tonnages with less labor. Thus the continuous thickener was a great advance in large-scale water recovery over the old-style settling pond, though it is far from an efficient apparatus when judged from the standpoint of complete separation at either end. Centrifugal augmentation of sedimentation has developed from the hopeful patent to practical operation. The continuous filters of the drum and disk types show great mechanical advance over the intermittent pressure and vacuum-leaf types that preceded them; their inadequacy becomes apparent, however, when solutions concentrated in some valuable constituent are to be separated from a worthless cake. The baghouse is a continuing abomination on almost all scores.

Recognition of the importance of separation of rock dust from the air that men must breathe and that machines must work in, and doing something effective about it, does, however, mark progress in solid-gas separations, despite the inadequacy of the tools employed and the results effected. The evil was recognized before 1871, but, like the weather, little or nothing was done about it. It does not reflect much credit on the profession that such progress as has been made did not start until the expense of continued neglect was upped to a prohibitive point by legislation. We could now oppose more effectively the accelerating movement toward paternalistic regulation in all human activity if we had a better record in this and some other equally flagrant abuses of freedom.

The outstanding advance in the way of separation on the basis of chemical constitution has been the flotation process. An improvement almost equally important in its original scope and in its effect on mill flowsheets and recoveries was the riffled table, but that comprised a relatively simple improvement on an existing machine, rather than a new concept of separation. Pneumatic separation on riffled surfaces was a natural corollary. The cyanide process was a practical improvement on an old idea, the concept of leaching out ore values and recovering them from the solution having come to commercial fruition earlier in the hyposulphite process for silver, and in scrap-iron precipitation of copper from mine water. The vanner completed a rise and fall within the period under review.

The electrostatic process is entirely new as a commercial operation. After a long period of comparative ineffectiveness, it is only now beginning to show signs of more than narrowly limited applicability. The sink-float methods show no novelty in basic idea, since the effectiveness of mercury in collecting gold has been sporadically attributed to the sink-float phenomenon from the time of the Romans, but the manufacture of the heavy medium and the development of apparatus and methods by which to effect the separation are new.

SEPARATING DEVICES

Chronologically the first new separating device of the period was the air jig. It met with the usual reception from competitors. Engelmann (1872) in TRANSACTIONS-page advertising of an obscure water jig, condemned the newcomer with the words:

> Air jigs will remain an ingenious expedient, advantageous only under the most abnormal and exceptional circumstances.

Bartlett (1877), obviously inspired by recent development of the Krom air jig, came to its defense and, applying the Newtonian equation for free fall to galena and quartz in air and water, showed that spheres of the two minerals equal-falling in water could, theoretically, be separated in air, the quartz falling the faster. He concluded therefrom, with all the enthusiasm of a recent convert, that air would make much more delicate separations than could water. On the record, Engelmann has had the better of the argument.

Pneumatic tables, which differ from pneumatic jigs in the same way that wet tables differ from wet jigs—viz., in the effective densities of the beds in which the separations are effected—have also lived up to Engelmann's stricture as to use. Invented after the Wilfley table had pointed out the use of the riffles for supporting the heavy grains against the crossflow of the light, these tables had some success in separating rocky matter from cereal grains and other seeds but were not commercially useful in ore separations. They did, however, eventually find a field in coal dressing in regions where water was unavailable, and that is, at present, their principal field. They are reported to make a variety of rock-mineral separations, but unbiased and dependable records of performances are lacking. Such lack, in these days, leads to the suspicion of "secret processes," which usually is properly interpretable as meaning inefficient treatment of high-priced products that will stand the cost.

The vanner, which appeared in the mills very shortly after 1871, first in the side-shake and later in end-shake form, was a development of the strake. The earliest form comprised simply an endless belt of canvas stretched around a strake frame, sliding on the upper surface thereof. The belt was fed near the upper end. It dragged the settled material upslope, then dipped in inverted position into a wash box and passed thence, over another roller, to the tail roller again. But without a shaking motion, if the belt was run fast enough to build a bed, there was very little selection, while with higher slope or slower belt travel, although a layer of concentrate might form, it could not, without the protection of a bed, survive the impact of the feed stream. If the belt was shaken while being run fast enough to build a bed, the bed itself was made sufficiently fluid to permit the heavier grains to penetrate and pass down to the belt surface. In this position, with sufficient bed above to protect it, the settled material was dragged under and through the feed stream, after which the overlying layers could be washed away and leave reasonably enriched concentrate.

The cyanide process, patented by McArthur and Forrest in 1890, was next in the list of milling improvements. Its utility and efficiency are so well known that discussion here is unnecessary. We should note, however, that this revolutionary forward step in the treatment of gold ores, like the agitation-froth process for flotation of sulphides, was the result of inventive thought on the part of foreign colleagues.

The Wilfley Table

The riffled table followed closely on the heels of the cyanide process. It produced a revolution in gravity concentration similar to that brought about in gold and silver mills by cyanidation. It had been foreshadowed by the Rittinger bumping table, on which heavy mineral, settled out of a shallow stream of pulp flowing over a smooth inclined surface, had been moved across the deck, transverse to the flow, by a periodic bump applied to one side of the table. The essential advance made by Wilfley was the formation and maintenance of a semifluid bed of grains on the inclined reciprocating surface. This was done by placing riffles thereon in a direction at right angles to the flow of the pulp stream. Solids settled between the riffle cleats, and were semisuspended by the shaking motion. As a result, the bed stratified according to size and specific gravity. The fine and heavy particles at the bottom were led by the riffle cleats to the unriffled portion of the deck for final washing as on a strake. Tapering of the riffles served to progressively withdraw support from the upper layers of the bed, and they were washed down slope. Termination of the riffles along a diagonal line was, in a way, a refinement. The Garfield and Butchart rifflings later demonstrated that this is in no way essential to separation.

It is interesting to examine, at this point, the knowledge that was available to Wilfley, irrespective of whether he availed himself of it. The so-called shaking table of 1871 comprised an inclined trough, usually 3 to 6 feet wide and 8 to 12 feet long, inclined in the direction of the length, having sides and a back (at the upper end) 4 to 6 inches high, and fitted with three or four cross cleats, 1 or 2 inches high, spaced along the length, the lowest being across the lower end. This box was suspended by rods at the corners, and was reciprocated in a substantially horizontal plane in the direction of its length, each reciprocation being stopped suddenly by a bumping block at the upper end. Feed was at the upper end. Settled material built up until tailing grade increased beyond the set limit, when feed and motion were stopped, and the settled material was dug out into batches according to metal content. The shake and bump served to maintain the settled solids in a thick suspension through which the heaviest grains could sink. These were then held by the riffles until they could be excavated. Here was the idea of the shaken bed as the separating means and of the riffles to hold the settled material against the force of the carrying water. The vanner had also used the shaken bed as a separating medium. The Rittinger bumping table had disclosed the use of rapid deceleration for moving material in contact with the deck (and other material above and in general contact therewith) in the direction of deceleration, at right angles to the general flow. The combination of the two machines, coupled with an improved decelerating device (the head motion), was the Wilfley table.

Some idea of the effect of the Wilfley table on the art is to be gained from the following excerpt from the preface to Volume I of Ore Dressing, by Professor Richards (1903):

> The appearance of the Wilfley table, while a most fortunate event for the cause of ore dressing, has been most unfortunate for the preparation of this book. It could not have happened at a more inopportune moment, for in the summer of 1895 the author visited nearly 100 mills, obtaining careful data from them; on returning home the data were written out in systematic form, mailed to the managers for their correction and criticism, and, when it had all been returned and placed on file for the preparation of the book, the first Wilfley table appeared. From that day to this it has been finding its way into the mills of almost all descriptions. Where it has been possible the author has put in the mill changes and has so indicated in the text. The appearance of the Wilfley table is an event of such importance that the book should either have been put on the market in 1896, before the first Wilfley table appeared, or have waited until 1905, when the adaptation of the mills to the newcomer would be complete.

When the tumult and the shouting that had greeted the first Wilfley table had died down somewhat, it became apparent that the vital problem in concentration of those and earlier days had not only not been solved but had not even been alleviated. What the Wilfley table had done had been to take from jigs the treatment of fine-sand sizes, for which they were not suited, and to treat this material more efficiently and at higher capacity than before. But for the treatment of slimes, the new machine was little, if at all, more effective than the old. The vanner, therefore, was not displaced, and a horde of other devices for mechanizing the strake appeared. Of these the best known were the Wilfley slimer and the Deister tilting slimer. Better than these for the production of clean concentrate was the Deister slime table, which comprised essentially a combination of a riffled shaking table and a large, shallow dish-shaped bowl, mounted on the same shaking deck. The bowl settled the finest sands. The differential shake moved them in a thin sheet, supported by riffles, across a sloping deck, and through a cleaning spray to the concentrate launder. But the tailing of this table yielded a rich harvest on strakes. Whether the obvious solution of using the slime table and some form of strake in a rougher-scavenger series, with scavenger concentrate returned to the table, was ever tried is not known to the writer. Such a sequence of slime treatment was well established in the pre-1871 mills, as is shown by the summaries given earlier of the lead-zinc and native-copper mills, but in general, in the United States at least, slimes were considered a necessary evil; what could be saved from them at little expense was velvet; operating profits were made from the sands.

FLOTATION

As of 1900 to 1910, therefore, the picture in American mills, which were preeminent in the nonferrous concentration field, was that sand and gravel sizes could be treated to produce high-grade concentrates, and that satisfactory tailing could be made at sand sizes. Slime was like crime, ignored by busy people in so far as it was possible. But the complex lead-zinc ores of the world, and the zinc-bearing tailings from ores with heavy gangues (e.g., pyrite, barite, and siderite) were aggravating sources of unavailable profit, and as such constituted challenges to every up-and-coming millman and metallurgist.

Surprisingly enough, the common solution to both problems lay in utilization of a phenomenon that had constituted a milling difficulty since time immemorial—the unwanted flotation of metallic values into the tailing in substantially all wet-dressing operations. Raymond (1874) speaks of float-gold losses as a part of the game. Munroe (1879) finds similar loss of copper in the Lake Superior mills. Egleston (1880) comments on the float loss in amalgamation due to grease. Kunhardt (1893) speaks of large float losses of soft sulphides when crushing and screening are done dry, and then goes on to say:

> The loss of float mineral from partial drying, familiar as this must be, seems frequently to be regarded with insufficient appreciation.* Its production is strikingly noticeable in every case where fine, dry or merely moist material is mixed with water and being borne off by the current . . . to large, final settling basins, where they form a scum, sometimes quite thick, on the water surface. This loss is inevitable . . . ; to avoid its effects it should be a rule in wet slime dressing that when a finely comminuted ore has once been mixed with water it must . . . never be completely deposited from it until the moment of the final separation . . .

Richards (1903) writes:

> There are two sources of loss which may occur and which it is proper to speak of here: Valuable fine mineral may escape by being attached to coarse waste in the form of dust or slime. Comparatively large sizes of concentrates may be carried off into the tailings by greasy flotation.
>
> Greasy flotation is a source of slime loss which may be partly prevented by making sure that the ore is thoroughly wetted at the start and that during the course of its treatment it does not have an opportunity to partially dry again.

About 1905, the use of certain surface-active compounds added to the pulp to reduce float loss on shaking tables was patented. Chalcocite float in the gravity pilot mill at Miami in 1910 provoked the argument as to whether such loss was properly chargeable against the gravity machines under test.

Methods of Flotation

Inventor recognition of the incidental float phenomenon as useful rather than a hindrance in concentration should, on the record, be credited to Bessel Brothers (1877). They described methods of floating graphite by adding an oily substance to a finely ground aqueous pulp of a graphite ore, and either boiling the mixture or generating carbon dioxide in it by the

* The writer, endeavoring on one occasion to make this source of loss very evident, treated some rich gold concentrates in a pan, and after collecting the fine native gold into a pure heading that was separated from the tailings of coarser pyrites and quartz, he exposed this gold to the air and then swept a sheet of water in gentle current over it. An exposure of a few moments on the pan had no effect in producing float mineral, but with a drying action of half a minute a very appreciable portion of the gold was carried over to the tailings as float; the operation on the headings was repeated quite a number of times, with the final result of washing away all the gold, which then continued to float indefinitely on the surface of the wash water. The adhesion of a thin envelope of air to each fine mineral particle, changing for the time its specific gravity, and the action of capillary repulsion observable upon close examination on the non-wetted surfaces of the mineral, are the productive causes of float mineral. (This footnote is part of the quoted matter.)

action of acid on a carbonate. Either treatment precipitated bubbles on the graphite particles, and these bubbles rose with adhering graphite to the surface and floated there as a clotted froth. The oily substances named as reagents comprise most of the classes of oils, fats, and greasy substances known today. Prior to the unearthing of the Bessel records, Everson was credited as the mother of modern flotation. Her patent described the use of sulphonated fatty oils and of hydrocarbon oils for selection, the use of inorganic acids to aid selectivity, and agitation of a type that would introduce air into the pulp and effect a combination of froth and skin flotation of metalliferous sulphides and, according to her claim, of oxides. Neither the Bessel nor the Everson discoveries went into any recorded commercial use.

Active prosecution of the search for a working method of flotation concentration began just prior to 1900, and from then on for 20 years or more literally hundreds of patents poured out of the patent offices of the world. F. E. and A. S. Elmore described a process in which substantially equal weights of ground sulphide ore, water, and a specifically light but viscous fuel oil, doped with oleic acid, were mixed with sufficient vigor to break the oil into not too small droplets. These, on contact with the solid particles, adhered selectively to the sulphides. On cessation of agitation the droplets, if not too heavily laden, floated to the surface of the aqueous pulp and there coalesced, transferring their solid load to the interface between a floating mass of oil and the pulp. The upper layer of oil was first overflowed, then, lowering the overflow lip, the interface was removed by overflowing the remaining oil and a thin slice of the underlying muddy water. Froment applied the carbon dioxide process of the Bessels to sulphide flotation. Potter and Delprat described a process in which the Bessel methods of gas generation were used without adding oil. The reader should not, however, assume that no oil was present. The Potter-Delprat pulps had been mined underground in the usual fashion, and put through the usual crushing and grinding procedures of the mill, whereby substantially all of the lubricants that had been used in both places had gone into the pulp. The pulp had then been partially or completely deslimed and dried, either as part of a current process or by being placed on mill dumps and thereafter reclaimed. Such treatment served to oil any surfaces that had not hitherto been oil-coated. Finally, the pulp was heated by exhaust steam, which carried and dispersed further hydrocarbon oil mingled with fatty acid. When it is considered that only by the most rigid cleaning of specimens and apparatus in the laboratory, and absolute prevention of exposure of cleaned specimens to laboratory air before testing, is it possible to prevent precipitation of gas on the specimens in water, any conclusion that the Potter-Delprat pulps were even approximately oil-free is completely untenable.

F. E. Elmore was the next to disclose a different method of effecting selective gas precipitation on oiled sulphides. His method was to subject the oiled pulp to a vacuum. An alternative and less effective form of the same operation was invented by Sulman, Picard, and Ballot; in this the water was supersaturated with gas by subjecting it to superatmospheric gas pressure in a closed vessel and then releasing it to the atmosphere.

The early Elmore bulk-oil, the Potter-Delprat, and the Elmore vacuum processes each had more or less commercial use. The Potter-Delprat was used in Australia for several years. Frothing was recognized as the solution of difficulties in separation of sulphide and heavy gangue but the finest slimes had not yet yielded to treatment, since each of the processes mentioned above required at least partial desliming of the pulp before anything resembling acceptable recoveries could be made. In 1904, however, Cattermole, working with slimy Australian pulps and using from 20 to 100 pounds of oil (mostly oleic acid) per ton, found that vigorous agitation would cause the sulphide minerals to flocculate preferentially, and that subsequent slow agitation would roll these aggregates into shotlike masses that separated readily from the nonagglomerated gangue in a rising current of water. This process was put into commercial operation in Australia.

As soon as the operation began to smooth out, the engineer in charge naturally began to try to lower costs by reducing oil. All went well for awhile, as with the darky who substituted sawdust for normal mule fodder. Finally, however, major proportions of the agglomerates began to float on the surface of the separating boxes. The mill experiment was discontinued and the news was forwarded to London, where the experimentation was carried further. There, when oil reduction reached the point of 0.32 per cent of oleic acid on the ore, the bulk of the mineral floated, and granulation had completely ceased. The results of the experiment were patented by Sulman, Picard, and Ballot, claim being made to an operation involving the use of less than 1 per cent of oil on the ore, violent agitation, and the production of a froth concentrate. The violent agitation was later soft-pedaled when it was discovered that the froth concentrate could be made more cheaply and effectively by blowing air into the pulp through the porous bottom of a separating cell.

An apocryphal tale, never told in court, has it that the invention was the outcome of a banquet attended by two of the patentees. Bored with the speeches and surfeited with champagne, one of them dropped a grape that he had been fingering into his recently replenished glass. Shortly his attention was caught by movement of the grape, first slowly upward, stationary for a second at the surface then downward more rapidly. This was repeated several times. The immediate cause was quickly localized as the bubbles of carbon dioxide precipitating on the grape and adhering, causing it to rise when enough had collected; loss of bubbles at the surface of the liquid, as the bubbles on the top of the grape merged with the atmosphere; followed, of course, by sinking of the now partially delevitated grape. As the story further runs, the active minds of the inventors next localized the fingering as the cause of the bubble precipitation, by casting in a grape that had not been so handled. Application of the phenomenon to the tailing piles of Broken Hill now flashed full grown as a possibility, and reduction to practice was but a matter of days.

The bubble-column method of effecting froth flotation, which today has almost completely superseded the agitation method of Sulman, Picard, and Ballot, actually was invented twice, first by Sulman and Picard and later by Towne and Flinn, before its value was recognized and it was rendered into practical form by Callow. Its outstanding utility did not and could not become apparent as long as the relatively insoluble oily collectors such as oleic acid, fuel oil, and the tars and tar oils were used, because these overloaded the bubble column so heavily with oil that the normal delicate control of this separating zone was impossible. It was not until soluble collectors, together with separate frothers of high surface activity, began to be used, that the bubble-column machine came into its own.

It is the irony of things mechanical that as a corollary to the very change that made bubble-column operation preëminent, there came the change from acid to alkaline pulps which, because of blanket clogging, rendered the then existing pneumatic form of bubble-column operation substantially unworkable. The moving blanket, the matless cells, and the subaeration machines were the answers devised. The moving blanket, in the form invented by MacIntosh, eliminated the layer of settled sand that forms on a stationary blanket and holds pulp water stagnant, so favoring build-up of carbonate deposits on blanket fibers. The matless cell, first invented in practical form by Forrester, is actually a cascade-type machine in essential principle, since the bulk of bubble-column air is entrained by plunging the pulp raised by the air-lift into the body of pulp outside the air-lift column. It avoids clogged blankets by eliminating blankets.

The subaeration machine, incorrectly dubbed an agitation machine, also avoids blanket troubles by doing away with blankets. According to the speed and conformation of the impeller, and the slime content of the pulp, such machines either function wholly by bubble-column action or utilize pulp-body action merely as an aid in presentation of mineral to the bubble column. Their action in deslimed pulps, such as the pre-oiled pebble-phosphate feeds, has not been clearly established. The clotted froths that are formed look like the products of gas-precipitation action. But similar froths are formed in the same pulps in cascade-type machines, in which gas precipitation in any effective quantities is impossible. The probability, therefore, is that even here most of their action is bubble-column in nature.

Soluble Collectors

The discovery of the soluble collectors was connected with so many interesting incidents that it is hard to know which to include in this history and which to leave out. It is probable that the first discovery was that of Martin, working in the laboratory of the Utah Copper Co. in 1915. He mixed together carbon bisulphide, ethyl alcohol and potassium hydroxide in proportions that would form potassium ethyl xanthate, and then used the mixture to float the Utah ore. He obtained good recoveries and grades of concentrate, but no better than those obtainable with the "reconstructed" Barrett No. 4 creosote, which was then being used as a collector at Utah. There is, of course, no reason why there should have been any particular improvement. The process of reconstruction loaded the tar oil with mercaptans, and probably also with sulphur-nitrogen compounds containing an acid hydrogen, so that the active collectors in the reconstructed oil were of the same general nature, as far as flotation was concerned, as that in Martin's mixture. In any event, the test was duly recorded in the laboratory ledger and filed away, not to come to light again until 1928, when the Perkins patent was asserted against the Anaconda use of xanthate.

The first recognition of the utility of the soluble collectors was by Corliss, who described the use of α-naphthylamine for sulphide ores. Perkins was the first to disclose publicly the utility of the modern thio compounds, the specific useful one which he listed being thiocarbanilid.

The progress that flowed from the adoption of the soluble collectors was more by way of operating efficiency than in recovery, grade of concentrate, or the flotation of hitherto nonfloatable minerals. By their use it is possible to control intensity of collecting effect and frothing independently, using with them a nonoleaginous, noncollecting frother. This makes machine control much easier. Again, it is possible to determine exactly the dosage of collector, which is impossible when the collector is an unknown constituent of some oil, usually present in a quantity that varies from shipment to shipment. Finally, addition of the small quantities of these reagents that are effective can be made much more easily in dilute water solutions than in oil solutions, as formerly. The overall result is more uniform behavior of the flotation machine. This makes, of course, for increased capacities and decreased attendance.

Next in chronological order of important discoveries was that by Sheridan and Griswold, that separation of lead sulphide from zinc sulphide can be effected by "depressing" the sphalerite by use of a soluble cyanide. This, coupled with an earlier unpatented discovery by McDonald at Nacozari that pyrite can be depressed by lime, even with coal tars and creosotes as collectors, immediately turned a large number of known lead-zinc-iron complex deposits into lead-zinc ores of the first order. Formerly, if coarsely disseminated, these had been good only for lead; they were substantially good for nothing when finely disseminated.

Understanding of the phenomena involved in this separation has been much slower in coming than the operating mastery of it. It has been established that copper in solution exchanges with zinc at sphalerite surfaces, and that the sphalerite is then floatable with small quantities of the lower xanthates, whereas without some such activation it is not. It is also known that cyanide ion forms a metal-complex ion by reaction with copper ion, and that the concentration of free copper ion in equilibrium therewith is extremely low. The easy explanation, therefore, of the action of cyanide in depressing sphalerite is to say that all lead-zinc ores have small traces, at least, of copper minerals, and that the cyanide ties up such copper as dissolves from these in the complex, so preventing it from activating the sphalerite. But lead ion is also an activator for sphalerite, and forms no such complex with cyanide ion, yet here also cyanide is a depressant for sphalerite as against the lower xanthates. As against a fatty-acid collector, cyanide is not an effective depressant in either case. The cyanide, therefore, must do more than simply lower the concentration of activating ions, or than merely coat the sphalerite with a cyanide compound.

Cyanide is also a depressant for pyrite. Here even less is known than in regard to sphalerite. As to lime depression of pyrite, it is easily shown that some depression is possible with calcium ion alone Hydroxyl ion supplied by sodium hydroxide is also effective. If one is satisfied simply with these facts, he can run a differential mill satisfactorily as long as nothing goes wrong. If he is satisfied to call the action adsorption, with the implication that he thus knows something about it and can use what he knows, it is seriously recommended that he try prayer instead. If he is convinced by now that his ionic collectors, activators, and depressants act at the mineral surfaces according to the same general laws that they do when he mixes solutions containing them, it behooves him, if he has a differential problem on his hands, to brush up on his chemistry as a start toward understanding and intelligent operation. All of which is a prelude to saying that the flotation man who unravels the chemistry of pyrite in flotation pulps is going to do the industry a great service, as well as run a good chance of getting himself some improvement patents that should stand up. The relatively high tailings that are being made on zinc roughers are in large part caused by the things that we now have to do to keep pyrite down. Our copper concentrates reflect the same difficulty at the other end, because we cannot afford to throw copper into tailing in order to improve concentrate grade.

Use of Fatty Acids

Christensen showed that differential flotation of the rock-forming minerals —the sulphide-ore gangues—is also possible. In truth, what he did was to put to use the bane of early-day flotation operation, just as the discoverers of flotation had put to use the float phenomenon that had been the bane of gravity concentration. Early flotation with fatty-acid collectors in acid pulps was reasonably successful when the gangue was quartz or a silicate mineral. The quartz was either unaffected by the fatty acid, or, if activated by heavy or earth-metal ions, the activating coating could be destroyed or its ionization substantially completely suppressed in the strongly acid pulps that were used —but if the gangue was one of the salt-type minerals such as calcite, magnesite, rhodochrosite, siderite, barite, or fluorite, the acid was either consumed in such large quantities as to make the operation uneconomic, or it was not effective. With this difference known, it is surprising that a flotation man faced with the problem of separating calcium phosphates or fluorite from quartz would not immediately think of using the old fatty acids in a neutral or slightly alkaline pulp. Yet even after the Christensen patent telling how to do it was issued, it was not done. In fact, Christensen's patent was so little noticed that later "inventors" were able to get patents through the patent office and courts for applying the essential disclosures of Christensen to the flotation away from quartz of specific minerals of the group mentioned above. The moral would seem to be either not to discover before the art is ready for your discovery, or to have enough money to fight your way through several courts when the need arises.

The effect of the Christensen discovery was to change the entire outlook of the art toward the possibilities of flotation. Whereas theretofore these possibilities had been accepted as limited to separation of elemental minerals, solid hydrocarbons and sulphides from nonsulphides, and of sulphide from sulphide, it is now legitimate to expect that any given mineral can be separated from almost every other mineral or group of minerals. The development of knowledge of the chemical mechanism of conditioning and collector-coating reactions since Christensen's time has made possible the confident assertion now that such separations will not involve any basically different procedures from those already known. The campaign to find the particular combinations of reagents and time factors in any particular case may be a long one, but if the investigator has a sound knowledge of chemistry, knows how to use the chemical literature, has a reasonable amount of imagination, and is persistent, the battle can certainly be won with the tools already at hand.

The Amines

An important tool for such a campaign was furnished by the discovery that the amines, which were found by Corliss and by Perkins to be applicable, under certain conditions, to the flotation of some heavy-metal sulphide minerals, are, as salts, capable of reacting with and forming collector coatings on quartz, other silicates, and certain other salt-type nonmetallic minerals. The only considerable use of this knowledge to date has been in the flotation of the pebble phosphates, where a rough phosphate concentrate is made with a fatty-acid collector, and silica is then floated out of this concentrate with an amine salt. Other applications await only reduction in price of suitable amines.

Flotation of relatively soluble salts from mixtures of them in their saturated brines is now well established commercial practice. The possibility of such treatment was far from obvious, although, with hindsight, it is easy to see that it is exactly what has been done in all flotation from the beginning; that is to say, the water of every ore pulp is a more or less saturated solution of the mixture of minerals comprising the ore. But, on account of the relatively low solubilities of the usual ore minerals, their solutions are very dilute, and such solutions have little or no effect on the solubilities of the various flotation reagents and their reaction products. Solubilities in the saturated brines are far different. As one instance, calcium ion added to a sodium chloride brine containing solid sodium chloride precipitates at the surface of the solid sodium chloride, and thus activates it for soap flotation, the calcium soap also being insoluble in the brine. The activation reaction depends upon the fact that calcium chloride, although highly soluble in water, is substantially insoluble in saturated sodium chloride solution. Similarly, lead chloride is relatively insoluble in a potassium chloride brine, and is an effective activator for soap flotation of potassium chloride in such a brine.

Progress in United States

Flotation is being increasingly employed in other arts for the separation of solid matters of different chemical natures from each other. It is also being used for separation of fine suspended solids and immiscible liquids from water. Further, the suspending medium may be an organic liquid instead of water; e.g., galena can be floated from suspension in nitrobenzene, using oleic acid as a combined collector-frother, if anyone has such a mixture to separate.

Progress in flotation in the United States was both hindered and aided by the litigation that raged for some 15 years after its introduction. Ignorance on the part of mining-company staffs and attorneys as to the history of the development of the process, and ignorance on both sides as to the phenomena involved, resulted in presentation to the courts of incomplete and distorted pictures of the facts. On these, the first controlling decision was that froth concentration effected by violent agitation with less than one per cent of oil on the ore present came under U. S. Patent 835120. When the Callow pneumatic cell came along, its action, coupled with the incidental splashing of oiled pulps in launders and other transport means, was held to add up to the equivalent of violent agitation. To escape the impact of this second decision, many operators loaded up their flotation circuits with just in excess of 20 pounds of oil per ton, the bulk of it a crude petroleum. The effect of this on concentrate grade and on operating control is pleasanter to imagine than it was to experience. The effect on immediate progress, of course, was wholly bad. Yet the operators who battled with and overcame such conditions, like pre-instrument flyers, developed a "feel" and a knowledge of process idiosyncrasies that has contributed greatly to subsequent operating development. At the same time mining executives learned that the results of unsuccessful litigation can be much more expensive than successful research on process principles, expensive as that may be. The result of this education was that a sufficient amount of fundamental knowledge was uncovered to put licensors and prospective licensees on a reasonably equal bargaining level, and thus to diminish litigation.

ELECTROSTATIC SEPARATION

Electrostatic concentration is a complete newcomer since 1871 in the field of separation on the basis of chemical constitution. In its early days (1905 to 1935) it was weather-bound, as it were; it worked after a fashion on clear days, but went on strike when it was humid. Now it has been improved to the extent that the ordinary range of atmospheric humidities has little effect on its operation; the machines have progressed from Rube Goldberg contraptions to streamlined creations that look more at home in a chemical show than in a mill, but which, nevertheless, are built on sound mechanical, electrical and mineral-separating lines.

The fundamental basis of electrostatic separation is that the rate at which electrons will flow to or from solid particles in an electric field (the particle thereby becoming charged) depends on the conducting character of the particles, their size and possibly their shape, and upon the nature of the field. Once charged, the particle path in the field is the resultant of the effects of electrical forces and any other force or forces (gravity and inertia being the usual ones) that act upon it. The relative strength of the electrical force depends upon the magnitude of the charge on the particle and upon the field strength. By suitable control of the latter, of particle size, and of the velocity of particle approach to the separating zone, grains of sufficiently different conductivities may be made to follow paths widely enough separated to permit insertion of a splitter between them, whereupon they may be led to different receiving boxes.

Conductivities are affected by impurities, as is, of course, to be expected. It has been found, however, that they are even more affected by surface coatings on the minerals, the effective coatings being, in some cases at least, the same as the collector coatings in flotation. By this means, differences in conductivity and, therefore, in charge time and charge strength, may be so modified as to accentuate or diminish differences existing in the solids initially.

Reliable performance figures for the new electrostatic machines are not as yet available. Those claimed by the manufacturers are in no way modest either as to separating efficiency or cost of separation. Available tables presented by Johnson indicate sufficient spreads in electrical properties of various common minerals to constitute promise of success in many desirable separations. The process suffers under the fundamental disadvantage, from a present-day viewpoint, that the feed must be at least dry enough so that mineral dust does not stick to the larger grains, and must, for any close work, be closely sized. Rough sizing can be done electrically in the machine itself.

SINK-FLOAT SEPARATION

Sink-float separation, as a process in which a medium with a density purposely controlled to fall between the densities of the minerals to be separated, was characterized by Engelmann (1872) in the words:

> Two-mineral separations in fluids of intermediate specific gravity would be perfect, without any machinery. The difficulty in obtaining such fluids and their cost precludes their use.

As early as 1891 Lurie proposed using various halogenated carbon compounds. The majority of Lurie's followers suggested other similar compounds, and various means of economizing in their use.

The first commercial application of a recognized sink-float operation was in the separation of anthracite from slate by the Chance process. The separating medium employed was a fine sea sand maintained as a quicksand suspension in a conical separating vessel by means of a stirrer and rising water currents. The method was soon adopted for washing bituminous coal also.

Although Chance and those who proposed improvements on his suspension claimed utility for their processes in separation of heavy-mineral ores, actually no real progress was made in this direction until the development of a galena-water suspension about ten years ago. Whereas the Chance suspension was limited to an upper mean specific gravity of about 1.7, galena will make a workable suspension with a specific gravity of 4.3 if pure, although, with the normal contamination introduced by use, it is not possible to maintain a suspension at working consistency at a specific gravity higher than about 3.3. This is, however, ample to reject the great majority of gangue minerals as float. A working medium of substantially the same density can be maintained with ferrosilicon, which has two great advantages over galena from the standpoint of mill operation: it does not abrade so rapidly, and therefore does not so rapidly increase the viscosity of the suspension and its consequent tendency to float middling; and it can be recovered, purified, and thickened by magnetic means. Galena, on the other hand, requires concentration by flotation, with relatively high loss in subsieve sizes, and thickening must be accomplished, relatively slowly, by gravity.

Performances in sink-float treatment of ores have been sufficiently good in the places where it was applicable to lead to an expectation that its use will spread. Its demonstrated utility to date has been in the treatment of heavy-metal ores in which the aggregation of the valuable mineral is coarse; and in the treatment of crudes of low unit values, such as iron ores and nonmetallic minerals. Its disadvantages are the elaborate plant required for recovery and reconditioning of the separating suspensions, its inapplicability to finely disseminated crudes, and the limitation to fine gravel sizes as the minimum treatable. The high-density suspensions have such high viscosities that viscous resistance prevents settlement of the fine heavier minerals in the time available in commercial operations. Intensive experimental work is under way, however, on the treatment of fine sizes. The method has already reached the stage of development at which any crude that shows a possibility of profitable enrichment by roughing at any size greater than 4-mesh should be subjected to test.

CENTRIFUGAL CONCENTRATION

Centrifugal concentration would appear today to be a lost art. Thus Church said as of 1880, discussing a then familiar concentrator:

> The theory . . . is undoubtedly to be derived from the laws of centrifugal force, which has been shown to be the most powerful agent applied in the treatment of ores by water.

Many inventors since then have tried to prove the statement of that last clause.

SUMMARY

Painted in broad strokes, the progress in mechanical separation over the past 75 years has consisted in: (1) demonstrating the possibility of separation, within a relatively narrow particle-size range, of any two solids that differ chemically to the extent that one contains an ion that the other does not; and (2) in widening the size band over which separation is possible. Flotation is the means for the first; as to the second, sink-float handles head-size coal or larger, and flotation is successful down to finest sand sizes on most mineral mixtures. Wet magnetic separation is also effective on these finest sands with strongly magnetic materials.

But mechanical separation of minerals at subsand sizes has not yet been touched. Sizing-sorting analyses of flotation tailings, especially those made in operations in which concentrate grade is held high, all show high assays in the slime fraction. This can be obviated, of course, by throwing slime into concentrate, but that is not separation.

Table 2 shows that, as was true of comminution, separating processes and machines known prior to 1871 have shown remarkably little change in anything but size and mechanical engineering in the interim. Possibly this is because the 1871 processes had all been known for such a long time that knowledge of the best methods of operation had fully developed. The slow growth in effectiveness of the electrical concentrators points the same way. But the weight of the evidence seems to point to relatively rapid maturity in the application of new ideas and processes, and thus to lead to the conclusion that solution of existing problems will involve inventive insight.

Recoveries have definitely improved in the period under consideration. Comparison as to mills for which 50-year records are available (1895–1945) shows: Bonne Terre (lead), 85 per cent vs. 92 per cent; Bunker Hill and Sullivan, lead 76 vs. 90, silver 72 vs. 92, zinc 0 vs. 78; Anaconda, copper 80 to 85 vs. 95, silver 80 to 85 vs. 94; Quincy, native copper, 84 vs. 95; Idaho-Maryland, free-milling gold, 97 vs. 98; Homestake, gold, 75 vs. 95.

Progress in Transportation

As of 1871, no dressing mill had continuous operation throughout; as of today, almost no such mill is discontinuous in any part of the treatment, once the primary breaker is passed. Even the discontinuity here, when it occurs is, due to irregularity in the mine-supply systems in vogue; the breakers themselves thrive on continuous feed, and mill transport equipment can feed continuously anything that the breaker can receive.

The first step that had to be taken to achieve continuous mill operation was to make the separating processes wholly mechanical, particularly as regards the discharge of the separated products. Thus the jig did not become continuous simply with the change from manpower to mechanical power for reciprocation; man skimmed the screen by hand for many years thereafter. It required the development of automatic screen discharges, tailing over-

TABLE 2—*Developments in Separation*

General Principle Employed		Method or Machine	Extent and Character of Use		Character of Change
			1871	1946	
HUMAN SELECTION		Cobbing	Universal on coarsely disseminated complex ores in Europe; very limited in U. S.	Vestigial; where labor is cheap	Substantial disappearance owing to improvements in machine concentration
		Hand sorting	Universal for coarse to fine high-grade and for discard of country rock	Limited for discard of country rock where labor is cheap; still more so for selection of high-grade	Substantial disappearance except in special cases; these are now subject to re-evaluation in the light of sink-float
SIZING		Screening	Universal in Europe as first step in size-sort concentration with jig as sorter. (U. S. at this time followed English practice of long-range jig feeds.) Universal in washing of clayey ores	Universal in preparation of coarse aggregate; in washing clayey ores; and in scalping feeds and guarding products of crushers. Limited use for closing circuit in grinding	Principal changes have been increase in size and improvement in mechanical construction of old forms, and in development of vibratory movement of screening surface
		Film sizing	Strake and buddle universal for fine sands and slimes	Limited use for fine feeds not yet amenable to flotation	No essential changes in apparatus; great decrease in use owing to development of flotation
GRAVITATIONAL SETTLING	IN LIGHT FLUID	Free settling	Universal for desliming and common for sorting fine sands prior to jigging and straking	Universal for very fine sand-slime separations; some use for sand-dust separations	Decrease in use owing to superiority of hindered settling
	PULSATED BED	Jigging	Universal for concentration of all but the finest sands and the slimes	Universal for gravel- and coarse-sand sizes; common for heavy-duty long-range roughing or skimming of fine concentrate. Air jig has had limited use	Superseded for concentration of fine feeds; recently revived for roughing fine concentrate from long-range feeds. Pneumatic jig has not proved useful
	SHAKEN BED	Tabling	Substantially unknown in the modern sense; unriffled longitudinal-slope side-bump Rittinger table for fine sands just invented	Universal for medium and fine sands. Pneumatic table used for some coal treatment; claimed useful in special heavy-mineral separations	Invention. Curve of use reached a peak just before the adoption of flotation. Pneumatic table still in unproved class
		Vanner	In process of invention. Shaking building buddle and traveling-belt strakes widely used in Europe	Substantially abandoned	Peak of use reached about 1895 to 1905 with the development of the "porphyry coppers"
	STIRRED BED	Log washer (Diamond washer)	Unknown	Widespread for rough concentration of long-range gravel-sand feeds of low unit value, high assay, and relatively low cohesive strength	Invention. More effective than screen washers for tough clays, and where some gravitational differentiation is desirable
		Riffled sluice	Universal for long-range feeds of gold and tin ores and widely used for fine feeds of all ores	Almost universal for roughing long-range feeds of gold and tin ores; some use for coal	No essential change in use
		Mechanical classifiers	Unknown	Almost universal for sand-slime separations, and common for concentration of log-washer overflows	Invention, despite prior use of the trough washer and the kieve
	QUICKSAND	Hindered settling	Unrecognized. Unused except to a minor extent for the same purposes as free settling	Universal in hydraulic classification	Increase in use, largely owing to greater machine capacity and greater potential effectiveness than free settling
		Sink-float	Unrecognized, except as one function of mercury in amalgamation of gold	Use increasing. Presently applicable to sizes coarser than coarse sands, when rough concentration suffices	Invention. Too new for accurate definition of field or prediction of final mechanical form

TABLE 2—(*Continued*)

General Principle Employed			Method or Machine	Extent and Character of Use		Character of Change
				1871	1946	
DIFFERENTIAL WETTING	ADHESIVE SURFACE	SURFACE SUPPORTED	Table amalgamation	Universal for lode-gold ores	Used for roughing free-milling lode-gold ores containing some coarse gold	Decrease in use owing to invention of cyanide and flotation processes
			Diamond table	Not known	Used for cleaning diamond-bearing concentrates	Invention
		SURFACE UNSUPPORTED	Sluice amalgamation	Universal both in roughing and clean-up	As 1871	No change
			Pan amalgamation	Universal on U. S. high-silver ores	Limited use for roasted gold concentrate	Superseded for general use by cyanidation, flotation, and barrel amalgamation
			Barrel amalgamation	Probably unknown	Universal for clean-up of free-milling gold concentrate	Adaptation
	GRANULATION		Haynes	Probably no use	See Trent	Died an embryo death
			Trent	Unknown	Outgrown	Invention; superseded by froth flotation
			Cattermole	Unknown	Outgrown	Invention; superseded by froth flotation
			Murex	Unknown	Limited use for separation of sulphide too coarsely granular for froth flotation	Invention
	FLOTATION	FROTH	Pulp body	Unknown	Substantially unused except as adjunct to bubble-column process	Invention; superseded on grounds of cost and efficiency
			Bubble column	Unknown	Substantially universal for all types of ores and industrial minerals	Invention
		NON FROTHING	"Table flotation"	Unknown	Substantially limited to granular phosphate and coal but applicable to granular separations generally	Invention
ELECTRICAL DIFFERENTIATION			Magnetic separation	Known, but used only experimentally; limited to strongly magnetic minerals and those so renderable by roasting	Used generally, both wet and dry for strongly magnetic, and dry for moderately magnetic minerals. See also Murex	Use of stronger fields due to development of electromagnet and special magnetic alloys
			Electrostatic separation	Unknown	Just becoming practical after a long period of exexperimentation	Invention, coupled with advances in electrical and mechanical fields
MISCELLANEOUS			Differential comminution	Generally used for coarsely disseminated metallics	As of 1871 plus limited use in grinding	Control of ball milling
			Decrepitation	Unutilized	Limited	Operating advance

TABLE 3—*Development in Transportation*

Where Employed		Method or Machine	Extent and Character of Use		Character of Change
			1871	1946	
IN-PROCESS	Comminution	Crushing	Gravity feed and discharge in all machine crushing except dry stamping	Automatic transport through all crushers; dry stamping abandoned	No essential advance in in-process transport
		Grinding	Batch work in pans and Chilean mills (mostly); wet stamps and buhrstones continuous	Continuous grinding universal in dressing mills	Operating advance
	Hand Sorting	Manual	Almost universal for complex ores in Europe	Unused except in primitive districts	Superseded by machines; operating advance
		Revolving table	Common	Unusual	Superseded by conveyors; operating advance
		Conveyors	Traveling chain-bar type occasional	Belt or (occasionally) pan substantially universal	Operating advance
	Gravity Concentration	Jigging	Manual skimming common; automatic discharges known and use increasing	Manual skimming unusual except in primitive operations	Operating advance
		Film sizing	Use of building buddle in some form common, with manual removal of concentrate and middling	Manual discharge of concentrate survives in most strakes; otherwise all apparatus are automatic	Operating advance
PROCESS-TO-PROCESS	Crushing Plant	Belt conveyors	Nontroughing type known	Troughing type almost universal for dry material	Invention of rubber belting and improved idlers
		Articulated-tray conveyors	Apron type known but practically unused	Usual for coarse dry material	Mechanical developments
		Bucket elevators	Chain types relatively common; belt type unknown	Chain and bucket types used when conveyor elevation not practically feasible	Operating advance in supersession by conveyors
	Wet Pulps	Sand wheel	Usual for coarser materials	Unusual, except for low lifts	Superseded by elevators, etc.
		Bucket elevators	Unusual	Unusual for coarser sands; rare for fine pulps	Superseded by pumps
		Pumps	Usual for slimes	Usual for fine sands and slimes; not uncommon for coarser sands	Mechanical improvements

flows, and series-multiple sieve arrangement to permit middling segregation, before a continuous feed stream was automatically divided into satisfactory product streams, and one man could attend to several jigs. Even now hutch discharge is noncontinuous on most jigs making a coarse hutch product.

What is true of the jig is true of all other separators, with appropriate difference in detail.

It is instructive to recall at this point the concentrator adage, that it is impossible to produce clean concentrate and clean tailing as the sole products of a single treatment. Stated another way, one treatment of a feed stream can produce only one finished product. It follows that a concentrating machine designed to deliver both concentrate and tailing continuously must provide for re-treatment of one of the products of the initial treatment. The first mechanical concentrator to embody this principle was the two-sieve jig, already known in 1865, as described by Gaetschmann.

Once having continuous separators, the need for continuous transport between machines throughout the plant was obvious, and was rapidly answered; but, so far as the present review is concerned, the answer comprised principally improvements of apparatus already known in 1871. Thus our present belt conveyors, bucket elevators, sand wheels, spiral and centrifugal pumps, apron, bar, scraper, shaking and screw conveyors were used in essentially their modern forms as of that date, while chutes and launders are prehistoric. Materials and designs have improved, of course; but so far as basic concepts are concerned, probably the only new method is that flowing from the discovery that a mixture of finely divided dry solid and a gas, in suitable proportions, will flow like a fluid of not too high viscosity, and that this mixture can be forced through long pipes, either vertically or horizontally, by suitable initial impelling means such as a rapidly revolving spiral in an enclosed chamber. Such pumps deliver cement through 5-inch to 8-inch pipes over horizontal distances up to 4000 feet and over vertical distances up to 300 feet. A summary of developments is given in Table 3.

Progress in Mill Design

The principal improvements in mill design since 1871 are strikingly suggested by visiting, in succession, first a small mill, 10 to 20 years old, in a relatively isolated mountain location, originally built for about half its present tonnage, and then a modern large-tonnage mill. The first will almost certainly have a steeply sloping site; the latter, one that is definitely on the flat side. The first will resemble a timber maze through which pulp, operators, and superintendent seem to pursue each other in an endless chase; in the latter, the pulp proceeds in orderly alternations of gravity flow and conveyor or pump elevation, the operators can keep most of the machines for which they are responsible in sight at all times, and the superintendent's office can be and is placed so as to afford him a reasonably complete vista of at least the entire concentrating plant. In the first mill it is a major operation to effect a repair; in the other the repair part moves in with a minimum of disturbance and manual labor, there is plenty of room around the machine to permit comfortable access and handling of tools and machine parts, and above to allow the necessary swing and play of suitable hoisting equipment. There is light in the second, perhaps less on the basis of wattage per cubic foot of mill volume than in the first, but it can be and is so placed as to aid rather than hinder vision. Dust is substantially absent in the second; in the first the murk grows in intensity as one moves up through the mill until finally is entered a region of perpetual gloom, sparked at intervals by dimly incandescent bulbs, made dangerous by unseen belts, pulleys, steps and other pitfalls, inhabited by gnomes with muddy noses, and decorated with respirators of assorted vintages hanging on the walls.

The larger mill has advantages flowing from its size that permit it to utilize another advance in design, which, although realized as desirable in 1871, was, in general, not practiced. This is the arrangement of the machines in parallel sections, with independent pulp streams. The capacities of the various sections are those of the machine of largest individual capacity in the flow following the last preceding pulp-storage reservoir, or some small integral multiplier of this capacity. In most cases the reservoir in question is the fine-ore or mill bin, situated between the crushing and grinding steps. The obvious advantages are: (1) a range of reasonably economical mill capacities with all of the machines in use at any one time operating at full capacity, and (2) only fractional loss of capacity when any major machine is down for repair.

A further advantage inherent in the larger mill, not even yet utilized to the full, is that adequate shops for much of its repair and minor new construction are justified. Also, by suitable restraint in purchases of new equipment, its supply room may carry, at reasonable expense and at moderate overhead cost, such a stock of replacement parts that only abnormal runs of breakage will cause delay for lack of parts.

Progress in operating control since 1871 seems great by comparison with that time, largely because there was no control then in the modern sense of the word. Head assays were substantially unknown. Feed tonnage was "guesstimated" by the time-honored method of tallying the number of cars or wagons delivered. Moistures were agreed upon, often in the Russian sense. Tailings were similarly manhandled. Concentrate *was* sampled, assayed, and weighed. Yield was then reckoned as weight of metal in concentrate divided by the estimated weight of feed, the quotient being expressed as a percentage.

Now we usually weigh in feed at the first convenient point, and we sometimes moisture-sample at the same point. We do normally have shift or daily samples of heads, tailing, and concentrate, but frequently they are not of the same materials, owing to intermediate storage. We have elaborate ore bookkeeping, which works up to a frenzy of activity around the first of the month. The results are often reported to the limits of the calculating machine, although usually they contain inventories of ore in bins and normally neglect concentrate in thickeners, filter sumps, and the like.

Let us give credit where credit is due. The continuous weighers represent a great advance in control tools, as do the weighing feeders. The electric ear is, unquestionably, the forerunner of a family of similar controls. The automatic density controllers are a move in the right direction. Automatic pH recorders may readily be hooked up electronically to control alkali addition, and thus arranged should be in every differential-flotation mill. Similar conductivity control for collector addition has already been installed by Myers at the Tennessee Copper Co. The automatic steel guards before the crushing machines pay out in short order, as do electrical interlocks in the crushing plant. Automatic sampling is new, as are also, of course, electrical timers. When the progressive superintendent has all these in his plant, working properly, then, before he rears back and elevates his feet to his desk, let him visit the control room on the cracking stills in a modern oil refinery and thereafter go back and study his plant again—because in the refinery he will find indicators, recorders, and controllers both of the remote-manual and automatic varieties, for flow, stream nature, pressure, temperature, storage levels, and what not. Two or three men stroll back and forth before these and *from that point* control the entire intricate operation of topping, cracking, and distilling the cracked products of petroleum at tonnage rates that rival those of all but our largest mills. Except for scattered watchers constituting essentially a safety crew, the furnaces and stills themselves are unattended. Similar boards in chemical plants indicate, record, and control similarly. Milling has much to learn as to the possibilities of this means of reducing attendance.

The necessity for such reduction needs no emphasis to the man who is fighting costs, but for the benefit of the general reader, the comparison of milling costs per ton some 50 years ago, from Richards (1903), with those immediately prewar is given in Table 4. Admitting that averaging of such data is meaningless, there is no blinking the fact that increase in size of units and in mill tonnages, and simplification of flowsheets, all with corresponding increases in tons per man-shift, have not kept up with wage increases over the years. In other words, all potential profit from labor saving has gone to labor. Effect stands, of course, before cause in that statement. Actually, as the unit cost of labor has risen, operating improvement and mechanization have worked together to reduce labor use.

TABLE 4—*Comparison of Milling Costs (from Richards)*

Ore	*Circa* 1900	*Circa* 1940
Lake Superior native copper (conglomerate)	$0.22	$0.44
Copper sulphides	0.35–1.00[a]	0.20–1.17[b]
Gold: placer, large scale	0.02–0.06	0.015–0.03
Concentration and amalgamation	0.40–1.00	0.65–1.50
Concentration and cyanidation		1.00 (aver.)
Silver, concentration	1.10	1.07
Iron, Eastern magnetite	0.50–0.80	0.20–0.25
Lead-zinc	0.20–0.50	0.50–1.50
Average	$0.43	$0.66

[a] Butte.

[b] Average of 10 was $0.53.

Comparison of elements of mill design and operation as of the beginning and end of the period under review is given in Table 5.

Elements of Progress

As the past unrolled through the pages of periodicals and textbooks, during the preparation of this paper, it became an engrossing game to hunt for repeating patterns in the history of improvements. Five stand out:

1. The steady, day-to-day advance, which goes largely unnoticed except in reviews like this, is principally the result of improvements in construction of existing machines and apparatus, permitting them to be made larger, to be run faster, to get along with less attention, or, generally, to render their accustomed service a little better than before.

2. Once a need for a new process or procedure becomes acute and generally recognized, and fulfillment promises a considerable financial reward, some solution, basically an answer, shortly appears.

3. The first solution is rarely the final one; it is almost always followed by a flood of variants, most of them comprising little or no novelty and no improvement, but a few adding piece by piece to the first.

4. Practically all the basic processes peculiar to ore dressing are harnessed counterparts of familiar geological phenomena, or of simple everyday human activities. As such they are readily apparent, *after the fact*, to any alert observer of the everyday world around him.

5. Some of the most valuable advances have been made by combining old procedures of the art in such a way as to produce a new or greatly improved result.

TABLE 5—*Developments in Mill Design and Operation*

Item	Practice		Character of Change
	1871	1946	
Flowsheet	Multistage concentration the rule	One-stage concentration the rule	Invention of flotation; recognition of operating advantages in simplification
Tonnage	Maximum mill tonnage, 500 tons per 24 hours	Maximum mill tonnage, 50,000 tons per 24 hours	Design; made possible by larger capacities of unit machines; dictated by operating economies
Mill sectionalizing	Independent parallel sections practically unknown	Parallel sectioning substantially universal whenever mill capacity exceeds that of largest milling unit applicable	Design; dictated by advantages of flexibility in economic tonnages thus gained
Machine tonnages	Primary breakers, 5 to 7 tons per hour; rolls, 4 to 6 tons per hour to ¾-inch set	Primary breakers, 2500 to 3500 tons per hour; cones to ¾-inch, 300 to 350 tons per hour; exceptionally higher	Design; dictated by economy in labor and power in large units; made possible by improvements in alloys, casting and fabrication
Mill site	Steeply sloping wherever possible	Slightly sloping preferred	Improvement in elevating means, and easier supervision and maintenance
Mill building	Wooden frame; wood, brick or masonry walls; normally crowded; criss-cross flows. Lighting and heating haphazard and inadequate	Steel and concrete; roomy; straight-line flow. Lighting good; heating arrangements could be improved generally	Design; dictated by easier supervision and maintenance and better fire resistance
Machine drive	Mostly by long line-shaft transmission from prime mover	Largely unit, with remote control, and with electrical interlock in crushing plant	Largely owing to universal adoption of electrical power transmission and invention of effective short-center belting
Control	Accurate head and tailing sampling and weighing of heads practically unknown and economically impossible. Other operating controls unknown	Automatic weighers and samplers on all key streams in most large plants. Automatic control of machines and unit operations in veriest infancy	Invention of weighers; design of automatic timers; realization of effectiveness of automatic controls in reducing labor costs

The histories of the jaw crusher and rolls, recorded herein, and of the pneumatic and subaeration-type flotation machines, familiar to most present-day operators, illustrate, the first pattern.

The gravity stamp illustrates the second. So long as coarsely disseminated ores satisfied the small demand of the day, the sledge, the spalling hammer, and the cobbing tool were ideal for breaking, since they were actually a part of the only means of concentration, hand picking, suitable for coarse-mineral separation. When finely disseminated ores required to be treated if the demand for metals was to be satisfied, the first answer was hammering to fine size with iron-headed flails on a rock floor. The crushing cost is easily imagined. Then the much more powerful sledge was mechanized into the gravity stamp. (Mechanization of the flail in the form of the thresher was delayed, incidentally, some 300 years, until available farm labor was no longer equal to supplying the world's demands for cereal grain. It was later adapted to milling as the hammer mill, in rapid answer to a demand for breaking soft minerals such as clays, bituminous coal, and cement rock.)

The Wilfley table was the answer to American demand for capacity treatment of sulphide sands—but it did not come until concentration of relatively low-grade sulphide ores had become widespread; when the fine jig, the vanner, and the unriffled Rittinger bumping table, which had served satisfactorily for relatively small tonnages of gold and native-copper ores, had proved completely inadequate for the increased tonnages. Flotation was the answer to slime and heavy-gangue problems that became acute with the diminishing supply and increasing demand for lead and zinc. Its subsequent adaptation to copper ores was incidental, since copper at the time of the discovery of flotation was in good supply. Actually the application to copper ores was not worked out until war demands had skyrocketed copper prices.

The third pattern is to be seen in the great variety of forms of jaw crusher, of roller-type grinders, of hammer mills and other machines described in our catalogues and technical publications; also, in more recent times, in the multitude of flotation machines, reagents and reagent combinations, flowsheets for specific minerals, and the like, that are recorded in some several hundreds of patents.

The fourth pattern is the interesting one. All our crushing machines are mechanizations of the primitive breaking methods of prehistoric time—hammering, dropping from a height, squeezing, and rubbing—and these are, incidentally, the ones that every male youngster utilizes, almost instinctively it would seem, when seized with a desire to break something. When, as in the jaw and gyratory crushers, the forces required for a break are beyond the capacity of a single simple machine, two or three or more are used in series. Thus, in the jaw crusher the big lumps are pushed against a projection as kindling is broken over the knee. The push is exerted by a lever, which itself is powered by what is essentially a curved-face wedge (the toggle). This in turn is actuated by a curved wedge (the eccentric) driven continuously between the fixed main shaft and the pitman head by another lever (the pulley).

The multiplication of the initial force thus effected is tremendous. Our screens derive from the crude baskets in which ore was carried. Our settling devices are harnessed lakes, and chemical flocculation our adaptation of one aspect of the phenomenon of delta building on ocean shores. Nature beat us to sluicing and film sizing by millions of years. Jigging just happened when a miner tried to help the fines of an ore through his basket screen by shaking it under water. The shaking table is a mechanized pan, the pan a localized sluice, and the sluice a mountain-stream bed. Even flotation is simply the harnessed form of what nature did to plague us when we accidentally mixed lubricating oil with our ores, ground them together in water, and splashed the mixture around in the mill.

It is, of course, the trite answer to this catalogue to say, "Certainly; all engineering is harnessed nature." But ore dressing is closer to nature than most of her sister arts. The harness is less complicated and less apparent. No better advice could be given the would-be inventor in the art than to study how nature herself, in the field or in the mill, is doing the thing that he wants to do.

The fifth pattern is exemplified by the Wilfley table and cone crusher, as already described.

If the patterns of past progress have been properly cut, they should serve as guides to the form of the future. A trial application follows. Primary crushers of essentially the present type can and will be built to receive any lump that mechanical excavators and transport means can handle. They will be built as soon as the cost of field breaking with explosive renders their operation profitable. It is probable that such primary crushers, as portable units, working with one or two large-bucket long-reach high-lift excavators, will move into the open pits, in the endeavor to utilize conveyor haulage directly from the working face.

Secondary crushers will move toward higher speeds and larger individual units. Immediate change in types is not to be expected, since the operation is already low-cost.

Fine crushing and grinding, constituting together the most expensive operation in most large-tonnage concentrators, may be expected to be continually fluid, insofar as methods of operation of existing apparatus are concerned. Actual final size reduction, in wet work, will probably long continue to be done in tumbling mills. Since these mills consume as much or more power when idling as when working, the obvious direction for improvement is to decrease their product of *time* × *tumbling weight*. This, in turn, can be done only by reducing the product of *feed diameter* × *feed tonnage*, which points toward finer limiting feed size, quicker and more effective removal of finished product, and, in the tumbling zone, more certain subjection of particles to grinding action. Accomplishment of any one of these aims is likely to involve material changes both in apparatus and flowsheet.

The greatest changes in concentration should come in the electrical methods, since they are of proven operability yet are the most backward in their development. The great advances made during wartime in harnessing electrical phenomena, the recent developments in wet-magnetic treatment of fine sands and slimes, and the increasingly insistent demand for an efficient method for treatment of the lower grades of iron ore, provide both direction and impetus for one such development. Work is already underway on the problem.

Specific flotation methods will be worked out for the separation of any or all mixtures of comparatively pure mineral species, as far as the sand sizes are concerned. The techniques of attack are already well known; the attacking force should include a physical chemist and an analytical chemist, both well trained and ingenious, and a flotation man who is convinced that chemical reactions obey the same fundamental laws wherever they occur.

The greatest of the unsolved practical problems in flotation today is the behavior of slimes. The high tailing assays in the subsieve sizes in sulphide flotation are tolerated perforce, and in most cases are cheerfully ignored on the basis that the tonnage is low and that overall recoveries are comfortably high by comparison with those that were made with gravity concentration. But we have had 30 years to get accustomed to this improvement, and it is about time that we began to compare subsieve assays with those made in the fine-sand sizes. Where the trouble is that all-around ionic exchange has taken place between gangue and valuable-mineral slimes before mining, solution of the problem probably will not be effected by flotation, because there are no ionic differences to work with. But when the exchange is a post-mining phenomenon, there is no reason why it cannot be solved.

Now that the basic problem of effecting continuous discharge of deposited solid from the walls of a rapidly revolving centrifugal machine has been solved, there is every reason to expect that centrifugals with effective forces exerted on the sedimenting particles at an angle to the present force will be designed, to cause particles of different properties in the feed to follow different paths. Such forces might be magnetic, electrostatic, centrifugal, or, conceivably, buoyant as in present-day flotation. Certainly, the possibilities in the use of centrifugal force as an aid in making slime particles act in much the same way as sands do in a gravitational field have barely been explored. The $\times g$'s are tempting.

One hardly need enter the realm of prophecy to say that all ore-dressing operations in the larger mills are going to be on instrument control within a very few years, unless present population and social trends take an unexpected turn. Low-priced products, such as crude minerals, cannot be concentrated out of low-grade ores, which are increasingly the only ones available, with labor forming any larger part of the cost than it does at present. Since there is probably no operation in an ore-dressing mill that cannot be readily placed on instrument control by a good instrument man, the answer is almost obvious.

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Seventy-five Years of Progress in Smelting and Leaching of Ores

By Frederick Laist

FREDERICK LAIST

Probably no organization in the world is concerned with the metallurgy of as many nonferrous metals as the Anaconda Copper Mining Company. For many years Dr. Laist was General Metallurgical Manager for the parent company and its subsidiaries, and is now Vice President in Charge of Metallurgical Operations. He was the recipient in 1923 of the James Douglas Medal for achievement in nonferrous metallurgy.

In the course of the past 75 years the treatment of copper ores has undergone the most profound changes. To a lesser degree, this is true of all the nonferrous metals, but the rapid increase in the demand for copper due to the phenomenal growth of the electrical industry, and the discovery of vast new ore deposits in Michigan, Montana and Arizona, provided an exceptional incentive for improvements in smelting practice and for large-scale operations. Because these must perforce be carried on in regions where labor was scarce and wages high, the need for mechanization and larger smelting units soon became apparent. At a later date the porphyry coppers were discovered, with ores so low in grade that enormous tonnages had to be treated daily if they were to be made to pay at all. In some instances these ores were associated with, or overlain by, oxidized ores, which could not be concentrated mechanically and, of course, could not be smelted directly. This led to the development of the copper-leaching process. While the principles of the various smelting and leaching processes are for the most part of European origin, and have long been known, modern practice is essentially American and was evolved on this side of the Atlantic.

The ores of copper may be divided into three general classes; viz, native copper, sulphide and oxidized ores. By far the greater number of commercially important ore deposits come under the classification of sulphides.

Commercial deposits of native copper are limited to the Lake Superior district. At one time these supplied practically all of the copper produced in the United States, but they are no longer of major importance. The treatment of native copper ores preceded that of sulphides in this country but the methods employed were simpler and have undergone fewer changes than those employed in the treatment of sulphide ores. The leaching of oxidized ores in a large way dates back only about 30 years.

During the period covered by this article the metallurgy of copper in all its various branches of ore dressing, leaching, smelting, converting and refining, has been revolutionized and operations are now carried out on an unprecedented scale. The world's production has increased 30 times, from about 100,000 to about 3,000,000 tons per year.

Copper Ores and Milling Methods

The Lake Superior deposits consist of beds of sandstone, traprock and conglomerates. Occasionally pieces of massive copper are found, but most of the metal is disseminated as fine particles throughout the rock and in the cementing material of the conglomerate. At first the ores were quite rich but by 1890 they averaged about 3 per cent copper, and this grade was maintained until recent times. They were crushed in steam stamps fitted with 3⁄16-inch screens and the copper "mineral" was recovered from the resulting ore pulp by means of jigs and tables in the form of concentrates assaying about 70 per cent. From these concentrates, metallic copper could be obtained by a simple smelting operation, which was carried out in small reverberatory furnaces. After sufficient copper had accumulated on the hearth of the furnace, the slag was skimmed off and the impure copper was refined by flapping and poling, after which it was cast into shapes desired by the trade.

The steam stamps were effective and are still used. They made it possible to crush large tonnages of ore in a limited space. Since the copper particles were tough, they were not much reduced in size and the problem here was merely to comminute the ore as expeditiously as possible so as to liberate the "mineral" and enable it to be separated from the worthless gangue by washing with water. Because of the high specific gravity of the copper particles and their coarseness relative to the gangue particles, a satisfactory separation and a high recovery by means of jigs and tables could be easily effected.

Lake Superior ores were notably low in impurities and the simple smelting process just outlined, which in modified form is still in use, sufficed for the production of copper of a quality which for many years commanded a premium. As the demand for copper grew, the Lake companies increased the magnitude of their operations and enjoyed a virtual monopoly of the copper market in the United States until the discovery of Butte about 65 years ago.

When first discovered, the Butte mines produced exceedingly rich ore from the so-called "zone of secondary enrichment," which commenced at a depth of from 100 to 300 feet beneath the surface. The secondary ores were so rich that they required no concentration but it was not long before the workings were extended into the primary ores below, which at first averaged about 6 per cent copper. The minerals of the Butte ores are chalcocite, chalcopyrite, bornite, covellite and enargite associated with iron pyrite in a granitic and siliceous gangue. It was soon found that the crushing and concentrating methods of the Lake district were not applicable to those ores. Steam stamps were installed in the first mill at Anaconda but it was found that they reduced the brittle copper minerals to particles of such fineness that they floated off in the jigs and were lost. These slimes were too low grade and too siliceous to be smelted and attempts were made to impound them for future use, but for the most part they were wasted.

In order to avoid this loss as much as possible, crushers and rolls were substituted for stamps and instead of crushing the ore to the final size all in one operation, this was done in stages followed by concentration after each stage, so that the copper concentrates were removed as they were broken away from the gangue and before they became reduced to slimes. This practice remained in use in Montana and elsewhere until after the introduction of flotation. It consisted of crushing the ore in gyratory or Blake crushers to about 2 inches, at which size it was passed through large jigs known as "bull jigs," the concentrates from which were smelted in blast furnaces. The tailings from these jigs were then crushed in rolls to approximately ½ inch, at which size a second separation of concentrates was made in smaller jigs. The tailings from these were crushed in a second set of rolls to about ⅛ inch and again jigged. The tailings from the fine jigs were ground in Huntington or Chilean roller mills to about 20 mesh and passed over Wilfley tables, the tailings from which went to waste. Fine concentrates from jigs and tables were smelted in reverberatory furnaces.

This was the so-called water or gravity concentration process and was used generally throughout the world for the enrichment of sulphide ores of all kinds. It was complicated by the fact that in order to get satisfactory results from the jigs and tables it was necessary to repeatedly screen and classify the ore on its way through the mill, and in spite of the care taken to remove the concentrates as rapidly as they were liberated, it was impossible to avoid sliming of a very considerable percentage of the sulphide minerals. At Anaconda, for example, the loss in slimes approximately equaled the loss in tailings. The loss through concentration for an ore containing 4 or 5 per cent copper was about 20 per cent, and to this had to be added the smelting loss, which was almost 5 per cent more.

The gravity concentration process depends on differences in specific gravity between the minerals and the gangue but was quite unable to take advantage of such small differences in specific gravity as existed between the copper minerals and iron pyrites. Hence the iron pyrites, which in Butte occurred to the extent of about three times the copper, were included in the concentrates and caused them to be of rather low grade. As a matter of fact, the concentrate produced from an ore containing about 4 per cent copper averaged less than 9 per cent and the concentration ratio was less than 3 into 1. Consequently, for every three tons of ore entering the concentrator, about one ton of concentrate had to be smelted. While the cost of the milling process was fairly low, the losses of copper were so large that when everything was taken into account, it was better economy to smelt ore containing 6 or 7 per cent copper directly than to mill it and smelt the concentrates, hence the extensive use of blast furnaces.

Copper Smelting

BUTTE AND ANACONDA

When smelting operations commenced at Butte, one of the principal smelting centers for sulphide ores was Swansea, Wales, and it was from there that the initial practice was borrowed. At first, no attempt was made to produce metallic copper and the process ended with the production of a high-grade matte assaying from 60 to 70 per cent copper, which was shipped for refining to Swansea. The first furnaces were like those used in Wales but were fired with cordwood. In 1880 two such furnaces, with hearths 16 by 10 feet, were built at the Colusa smelter of the Montana Copper Co. They smelted 12 tons of ore per day each. In the subsequent two years, several such furnaces were built at the Parrot works and at the smelter of the Boston and Montana Co. at Butte, and Rock Springs coal was substituted for wood. These furnaces smelted from 15 to 18 tons per day. The business expanded rapidly as the mines developed and the demand for copper increased, and before many years went by the plant that was established at Anaconda by Marcus Daly outstripped all others in size.

What a smelter was like in the '80s and '90s can perhaps best be illustrated by the following inventory of the equipment in the great Anaconda works. The first of these was built in 1883, and contained 34 hand-rabbled reverberatory roasters with hearths 50 feet long by 14 feet wide, and 26 reverberatory matting furnaces with hearths 18 feet long by 12 feet wide. There were also two 70-ton water-jacketed blast furnaces. The reverberatories smelted about 15 tons each per 24 hours. These works were destroyed by fire in 1889 and when they were rebuilt the hand roasters were replaced by 40 Bruckner roasters with cylinders 18 feet long by 9 feet in diameter.

A second plant was built near by in 1889 with 96 Bruckner cylinders and 28 reverberatory furnaces with hearths 22 by 16 feet, which later were enlarged to lengths ranging from 32 to 45 feet and a width of 18 feet. Later four Wethey and eight McDougall roasters were added.

A converter plant with 15 stalls of upright vessels, 10 feet high by 6 feet in diameter, was built in 1890. The matte from both smelting plants was melted in six blast furnaces, each 8 feet long by 42 inches wide at the tuyeres, in the same building with the converters. In the year 1901, just before these plants were abandoned, they produced 114,000,000 pounds of copper, or 9,500,000 pounds per month. To make this amount of copper, more than 200 furnaces and several thousand men were employed.

WASHOE SMELTER

In 1902 a new plant, called the Washoe smelter, was erected on the other side of the valley, consisting of blast furnaces, McDougall roasters, reverberatories and converters. The best practice at the old works and elsewhere was incorporated in the new works. Smelting furnaces were further enlarged and the movement of intermediate product between departments was mechanized. Up to this time, the practice of operating reverberatory furnaces had not greatly changed. They were charged at intervals, and when they were full of molten material the slag was skimmed, the matte tapped and the furnaces were recharged for another cycle.

Along with the enlargement of the furnaces minor improvements had been made and a considerable fuel saving had been effected by feeding the furnaces with hot calcine instead of cold material, but in general the practice underwent no radical changes until about 1904, when the type of reverberatory smelting furnace and the operating technique that is still used was developed at the Anaconda Works. The furnaces had been so placed that two of them could be joined together endwise, and the suggestion was made that this be done. The furnaces already had waste-heat boilers and the boilers of the two furnaces were arranged in tandem.

Accordingly, two of the 50 by 19-foot furnaces were joined to make one furnace 100 feet long. The width remained unchanged. The furnace was operated continuously instead of intermittently; it was still charged at intervals but it was never emptied of molten material. Small portions of slag were removed from the time and matte was tapped at intervals, but a large bath of molten material was constantly maintained throughout the length of the furnace. Moreover, the material to be smelted was charged near the firing end, where it was hottest, instead of being distributed over the entire hearth area, as had been the practice previously. The molten material in the furnace tended to scatter the charge but most of it remained where it was exposed to the intense heat. The latent heat in the bath helped greatly to accelerate the fusion and served as a heat reservoir, which made the smelting operation more or less continuous. The result of these changes was most gratifying. The tonnage smelted per furnace day increased from approximately 100 tons to more than 250 tons and the amount of material smelted per ton of coal increased by 50 per cent. The waste-heat boilers proved so effective that about 30 per cent of the heat generated by the combustion of the coal was recovered as steam. The new furnace utilized more than twice as much of the heat generated in the firebox as did the old furnaces.

Subsequently furnaces about 130 feet long and 22 feet wide were built, and were fired with coal dust, first successfully used in a reverberatory at Copper Cliff. These furnaces smelted more than 600 tons per furnace day and again increased the fuel economy by approximately 50 per cent.

The long furnaces were soon adopted in other smelting centers, and with some modifications have become universal. Recently such furnaces, fired with coal dust, oil or natural gas, have smelted in excess of 1000 tons of charge per furnace per 24 hours—certainly an astounding increase from the 15 or 20 tons per furnace day that was considered good practice in the early '80s. From the labor standpoint the results are equally noteworthy, since there was practically no increase in the number of men required to operate a furnace.

ROASTING

It would take too much space to describe or even mention the numerous improvements in methods of charging, in furnace design and in operating technique, that made these results possible; nor can I do more than sketch briefly the improvements in roasting practice. This was formerly a laborious but very necessary preliminary to smelting in the reverberatory and consisted of burning off some of the sulphur and simultaneously oxidizing a part of the iron, thus enabling the latter to form a fusible slag with the siliceous constituents. At first, the operation with coarse ore was carried out in roast heaps and with concentrates in hand-rabbled furnaces. The capacity of such furnaces was small and the work was extremely hot and exhausting.

Heap Roasting

Heap roasting, as the name implies, consisted of forming the coarse ore and concentrates into piles with enough wood to set the sulphur on fire. Channels were left to supply the necessary air for combustion. When such a pile was ignited, dense, sulphurous fumes were given off, which were very troublesome. This brought about the use of "stalls;" that is, brick chambers that held about 30 tons of ore each, and which were connected with a stack. The ore contained from 30 to 35 per cent sulphur and at the end of 30 days was burned down to about 4 per cent. Stalls were filled and emptied by hand. Aside from being laborious and disagreeable to operate, both stalls and heaps were suitable only for roasting coarse material and could not be used for roasting the fine concentrates, which were being produced in larger and larger amounts as the mines became deeper and more of the ore required milling.

Early Roasting Furnaces

The first roasters were hand-rabbled. Such a furnace consisted of a low brick chamber approximately 50 feet long. Openings, fitted with doors, were cut at intervals through the side walls and through these rabbles for moving the ore forward were introduced. There were fireboxes along the sides and a stack at one end. The ore was fed into one end of the furnace, moved along the hearth by the workmen and finally discharged at the other end. The degree of roasting was regulated by the rate at which the ore was advanced through the furnace. Such furnaces were used in Europe but were expensive and unsatisfactory in the West, where wages were very much higher and where the sort of skilled labor required for operating them was scarce and difficult to obtain. Much effort, therefore, was devoted to the development of furnaces operating on the same principle but in which the movement of the ore along the hearth was accomplished mechanically. Such furnaces were the Ropp, O'Hara, Wethey and others. In order to conserve heat and thus enable them to get by with less fuel, two hearths were superimposed. The makes of furnaces differed chiefly in the construction of the rabble mechanism. The length of the furnaces varied from 65 to 90 feet and they treated from 50 to 90 tons of ore per 24 hours.

A modification of the straight-line furnace was the Pearce-Turret, in which the hearth instead of being straight was circular. The rabbles were moved over the hearth by rotating a central shaft to which the rabble arms were attached and as many as six decks were superimposed. In all these furnaces the ore was fed continuously at one end or at one point of the circle and the calcine was discharged continuously after the ore had traversed the full length of the hearth. The diameter of a Pearce furnace was about 36 feet and it roasted about 60 tons of ore per 24 hours. Only about 2 per cent of coal was required to keep it hot, as compared with 5 or 6 per cent for the two-deck straight-line furnaces and 15 per cent for the hand-operated single-hearth furnaces.

Although a few furnaces of this type were used at Anaconda, the Bruckner cylinders appear to have been favored at that plant, probably because they required fewer repairs. They were not operated in a continuous manner but were charged and discharged at intervals. Such a furnace consisted simply of a brick-lined steel shell about 9 feet in diameter and 18 feet long, with an opening in the circumference for charging and discharging. A brick-lined door closed this opening during the roasting cycle. There was a firebox at one end and a flue connection at the other. Working off a charge required about six hours and a cylinder could calcine about 20 tons of concentrate per 24 hours. Fuel consumption was rather high, considerable labor was needed for charging and discharging and during the latter operation a good deal of smoke and dust escaped into the building. These were not satisfactory roasters but remained in use until the Old Works were shut down.

Evans-Klepetko-McDougall Furnace

In the meantime, a furnace had been undergoing development at Great Falls, which was known as the Evans-Klepetko-McDougall furnace. Several of these were given a thorough test and were adopted as standard at Anaconda when the New Works were built in 1902. The furnace consisted of a steel shell 16 feet in diameter and high enough to accommodate six superimposed dome-shaped brick hearths. The hearths were perforated at the center for a vertical shaft, which was rotated by means of a beveled gear at the lower end. Attached to the shaft were two rabble arms for each hearth. These were equipped with blades set at an angle so that the ore was moved from the circumference to the center and from the center to the circumference on alternate hearths while passing through the furnace from top to bottom. Openings were left at the circumference and center of alternate hearths through which the ore dropped from one hearth to the next below. In order to preserve the cast iron of the shaft and rabble arms from the heat, they were made hollow and were water-cooled.

This furnace occupied but little floor space. It operated continuously and roasted from 30 to 40 tons of concentrate per 24 hours. It was found to be economical as to operating labor and repairs and required no fuel, as the heat of the burning ore was well conserved and sufficed to maintain the roasting temperature. It utilized the principle of the McDougall furnace that had been used to some extent for the roasting of pyrite fines in the manufacture of sulphuric acid, but was mechanically better. The Herreshoff and Wedge furnaces, which are so generally used nowadays, are of the same type but are generally air-cooled and have a greater number of hearths of larger diameter.

BLAST-FURNACE SMELTING

For many years much smelting was done in blast furnaces, which had a larger capacity and were more economical to operate than the small reverberatories that were available at first. As a matter of fact, blast furnaces were at first more generally used than reverberatories except in Montana, where smelting was divided about equally between the two types. In Arizona the ores were partially oxidized and frequently occurred in limestone. Oxidized ores were smelted directly to black copper in blast furnaces operated under reducing conditions but sulphide ores were smelted to matte.

The early blast furnaces were constructed of brick but it was not long before the region in the immediate vicinity of the tuyeres was water-cooled, because of the rapid corrosion of the brickwork by the molten slag. Later, round or elliptical furnaces were built which were entirely water-cooled. These gradually gave way to the rectangular furnaces, which were constructed entirely of flat water jackets. This was the type generally used in Arizona and Montana.

Before the blast furnace went out of general use it had increased in length almost as much as the reverberatory furnace. The record was held by a blast furnace 87 feet long, built at Anaconda in 1906, which smelted about 2500 tons of charge per 24 hours. This may be compared with about 100 tons per day, which had been considered quite an achievement 20 years previously. The width of the furnace at the tuyeres remained narrow because of the limited penetrating power of the blast.

The blast furnace used coke as a fuel but it used much less coke per ton of ore than the early reverberatory furnaces used of coal. Moreover, it could be made to combine within itself the functions of roasting and smelting, as by proper adjustment of air blast and coke a great deal of oxidation occurred in the shaft of the furnace and in the region immediately above the tuyeres. This property of the blast furnace was carried to its ultimate conclusion at Mt. Lyell, and at Ducktown, where pyritic smelting was developed to such a degree that for considerable periods no coke whatever was used but all the heat required for smelting was derived from the combustion of sulphur and the oxidation of iron in the charge. Needless to say, such results could be obtained only on ores consisting largely of iron pyrites. The presence of free silica was important and there was much discussion as to the benefits to be derived from the use of hot blast. The field for this type of smelting was limited to pyritic ores that could not be concentrated by gravity methods. Now that such ores can be concentrated by selective flotation, the field for pyritic smelting is still further narrowed.

REVERBERATORIES

The blast furnace was excellently adapted for the treatment of coarse ores but it was not so good for the treatment of fines and concentrates. Therefore, as high-grade ores that could be smelted directly became scarcer, and more concentrating had to be done, the blast furnaces were gradually superseded by reverberatories. It was not, however, until the development of the long, continuous furnaces at Anaconda that the cost of reverberatory smelting was lowered sufficiently to make their use attractive. The flotation process made it economical to concentrate practically all copper ores, notably the porphyries, which began to come into prominence about 1910, and since the flotation process produced nothing but fines, the field of the blast furnace became more and more restricted. It is still used here and there for the smelting of ores that for some reason or other cannot well be concentrated, or for the smelting of secondaries, but its field has become so insignificant that it has been omitted entirely in plants constructed during the past 10 or 15 years.

PRODUCTS

The product from reverberatory and blast furnace is the same—copper matte—which is a compound of copper, sulphur and iron containing from 30 to 50 per cent copper. The production of copper from matte by the Welch process involved partially oxidizing the crushed matte and then fusing with siliceous material so as to slag off iron. The white metal resulting from this fusion was broken up and oxidized so as to convert part of the copper sulphide into copper oxide. The temperature was then raised to fusion, when a reaction occurred between copper oxide and copper sulphide by which sulphur and oxygen were eliminated as sulphur dioxide and metallic copper was reduced. The metal so formed was called blister copper and was further refined by blowing and poling.

The steps of this process were far more numerous than appears from this outline, as the reactions were not clean-cut and a considerable quantity of intermediate products and rich slags were made, which required resmelting and reworking. The capacity of the furnaces was small and their operation required a great deal of hand labor. Nevertheless, this process had produced virtually all the copper made from sulphide ores before the discovery of the copper mines at Butte and for several years thereafter. It was such a difficult and expensive process to carry out that an attempt to apply it at the Parrot works about 1883 was given up. It was cheaper to ship high-grade matte to Swansea, where labor skilled in the process could be obtained at low wages, than to make blister copper under the conditions then prevailing at Butte.

CONVERTERS

It had been suggested that the bessemer-steel converter might be used for the conversion of copper matte, but first attempts were unsuccessful because the holes through which air was blown, and which were in the bottom of the converter, became clogged with chilled copper as soon as the reduction started. Manhes partially overcame this difficulty by placing the tuyeres in the side of the vessel some distance above the bottom, thus allowing space beneath them for the copper to accumulate. Nevertheless, the first attempts to operate such a converter at Butte were not successful, as no means had been provided for clearing away obstructions that formed in front of the tuyeres. This difficulty was finally overcome by drilling holes in the outside wall of the air chamber directly opposite the holes in the shell and lining, so that these could be punched with a steel rod while the converter was in operation, the outer holes being kept closed with wooden plugs.

In 1884 an agreement was signed by the Parrot company with the Manhes interests and the first successful copper converter was installed at the Parrot works during that year, and commenced operation in September. It was a small, egg-shaped vessel, made up of three sections bolted together. The tuyeres encircled the lower section and pointed toward the center. The converter was tilted by means of an arrangement of pulleys and belts. This converter was so successful that soon afterward an installation consisting of three converters holding 3 tons of matte each, and a small cupola for remelting reverberatory matte, was constructed. This little plant had a capacity of about 2,000,000 pounds of copper per month and was followed by the larger plants at Anaconda.

The first Anaconda converters were square in cross section and held 4 tons of matte. They were followed by round, 10 by 6-foot vertical converters tilted hydraulically, and served by a crane. The Washoe smelter in 1902 contained fourteen 8 by 12-foot acid-lined converters of the horizontal or barrel type, developed at Bisbee, Ariz. These were served by a 60-ton crane and held from 15 to 20 tons of matte. A converter produced about one and one-half million pounds of copper per month.

The development of the converter process was one of the outstanding improvements in the art of copper smelting. It made the production of blister copper from matte a highly efficient and relatively inexpensive operation and one that could be carried out anywhere with comparatively unskilled labor. The necessary plant was compact and had a large capacity, which was a matter of great importance after the production of copper became a large-scale business. The process was promptly adopted at all smelters where sulphide ores were being treated and it is still universally employed.

Improvements in Converters

For the first 20 years after the process was introduced, the improvements were all of a mechanical nature. They consisted of enlarging and changing the shape of the vessel and improving the design of windbox, tuyeres and tilting mechanism. The lining continued to be made of a mixture of clay and siliceous material, as in the first Manhes converter, although it was not long before siliceous ores were substituted for barren siliceous material wherever these were available. The silica required for fluxing the iron of the matte came from the lining, with the result that it was rapidly cut away and consumed. The lining had to be replaced after six or seven charges and this was the most objectionable feature of the process. One or two attempts had been made to line the converters with basic brick but without success. Finally, this problem was seriously attacked at the Garfield smelter, Utah, and this time with success. The basic-lined converter came into general use about 1910 and by careful manipulation the linings of magnesite brick can be made to last for years. The silica needed for fluxing is introduced in the form of siliceous ore. The use of these linings has made it possible to still further enlarge the shells, so that nowadays converters 30 feet long by 13 feet in diameter, holding more than 100 tons of matte and producing seven or eight million pounds of copper per month, are common.

Refining Converter Products

The blister copper made in the converters cannot be used without further treatment. While it often contains 99 per cent of copper, it still contains small quantities of impurities and often considerable quantities of precious metals. It must be refined in order to remove the impurities and recover the precious metals. In the early process, the silver and gold were recovered by complicated methods involving repeated smelting and scorification or by treating the copper with metallic lead, which had a greater affinity for silver and gold. The impurities such as sulphur, iron, lead, arsenic, antimony, tellurium and selenium, were removed by oxidation and by treatment with soda ash. The methods were not only difficult and expensive but the quality of the copper was often inferior. Electrolytic refining, on the other hand, was simple, relatively inexpensive and produced an excellent quality of copper. It came into general use in the early '90s.

In outline, electrolytic refining consists of making anodes out of partially refined converter copper and then subjecting them to the action of an electric current in an acid bath of copper sulphate. The copper dissolved from the anodes is deposited by the current on thin sheets of pure copper, thus producing cathodes of a high degree of purity. The precious metals contained in the anodes, together with the impurities, are not deposited with the copper but settle out as slimes, from which they are subsequently recovered. The cathodes require no further treatment than melting and casting into shapes. They are melted in open-hearth furnaces and the "pitch" or oxygen content is controlled by "poling." The finished product is known to the trade as tough-pitch copper. It is cast into ingots, wirebars, sheet bars and billets, which are substantially free from all impurities but contain about 0.03 per cent oxygen as cuprous oxide. This copper has a conductivity of somewhat over 100 per cent and is the type of copper from which rods, wire and sheets are made. For some purposes, it is necessary to remove the oxygen completely. This is generally done by treating tough-pitch copper with phosphorus, but such copper has a lower conductivity and therefore is not suited for electrical uses. Recently oxygen-free copper of normal conductivity has been produced commercially by melting cathodes in electric furnaces and casting in an atmosphere of carbon monoxide. At one plant the electric furnace is employed for the production of tough-pitch copper.

EFFECT OF SELECTIVE FLOTATION

Before leaving the subject of copper smelting, it is in order to say a few words about the profound effect that selective flotation has had on smelting practice in general and on copper smelting in particular. When the flotation process first came into general use for the concentration of copper ores, its effect was to greatly increase the recovery although the grade or copper content of the concentrate remained pretty much as it had been when gravity concentration was employed. Butte ores containing 4 per cent copper concentrated only about 3 to 1 and yielded a concentrate running less than 9 per cent copper. Porphyry ores, with a more favorable ratio of iron to copper, yielded a higher grade concentrate, but what that grade was depended almost entirely on the mineralogy of the ore. All sulphides behaved pretty much the same in the flotation machines and were recovered with the copper.

Thus, when the ores contained much iron, large quantities of very fine concentrates were produced, which required roasting prior to smelting if a matte of too low a grade were not to be made and in order to flux the oxidized iron siliceous ore had to be added to the charge, or so-called insoluble matter had to be left in the concentrates so as to make them self-fluxing. Dust losses from the roasters became a serious problem, and the customary dust chambers proved utterly inadequate even when enlarged to fantastic proportions. Fortunately, a solution for this problem was at hand in the Cottrell process of electrostatic precipitation, which is too well known to require description here. But, even so, it was considered desirable at some plants to continue the use of gravity concentration and limit the application of the flotation process to the treatment of the tailings and slimes, thus avoiding the production of too much excessively fine concentrate.

With the advent of selective flotation, which makes it possible to reject iron pyrites, this is no longer necessary and a high-grade concentrate—that is, one containing from 20 to 40 per cent copper—can be made from almost any ore. At the same time the silica in the concentrate can be held around 8 per cent, and such a concentrate can be smelted without roasting. This has led to the so-called "wet smelting" method, first employed at Cananea, whereby the undried and unroasted concentrates from the filters are mixed with smelter secondaries and a small quantity of limestone and charged directly into the reverberatory furnaces. To do this successfully and without danger of explosions, the furnaces are charged along the side walls, which are thus also protected from corrosion. There is no bath of matte throughout the length of such furnaces, but only a pool of matte, preferably but not invariably at the skimming end. The fuel requirements for this procedure are naturally greater (about 50 per cent) than when calcine is smelted, but the avoidance of dusting and the better recovery of heat in the waste-heat boilers, not to mention the saving in roasting costs, generally compensate for the higher fuel cost.

DESIGN OF NEW PLANTS

Roasters are still used at a number of plants, for various reasons, but the tendency in designing new plants is to omit roasting furnaces, as blast furnaces were omitted at an earlier date, and to design the mills so that they can take up the burden that formerly rested on the smelters. Thus we have progressed to ever greater simplification. What the future may bring forth no one can predict, but it is difficult to see how a smelting plant consisting of a few reverberatories and converters can be much further simplified. Furnace construction will no doubt be improved and the suspended magnesite roof is, here and there, beginning to replace the arch of silica brick. New smelting records are still reported from time to time, and at Noranda a furnace with a suspended arch is said to have smelted more than 2000 tons per day. Natural gas is used as fuel wherever it is available and preheated air is being used in a furnace at Hurley. Boilers of improved design and higher steam pressures increase the yield of useful power. Converters probably are as large as it is worth while to make them, but there is still room for improvement in other ways. The electric furnace probably will be used more and more for the melting of cathodes.

NICKEL

The distribution of nickel is widespread, but since this metal has come into extensive use more than 90 per cent of the world's supply has been derived from the Sudbury area in Canada, and it is there that the methods used for its extraction have been largely developed.

Nickel coinage began in 1850 but it was some years later before its use for this purpose became general. Nickel silver was known prior to 1850 but nickel plating did not commence until about 1870. Nickel began to be used in steel about 1890 and from then on consumption increased at an accelerated rate. The growth of the nickel industry may be gauged by comparing the world's production in 1871, which in that year was about 500 tons, with the production in a recent year of nearly 200,000 tons. The Sudbury ores contain both nickel and copper as a mixture of pyrrhotite and chalcopyrite with pentlandite. Nickel metallurgy bears a curious analogy to that of copper and the smelting of nickel ores has been affected by the discovery of selective flotation in much the same manner.

Canadian Processes

In Canada the ores were first heap-roasted and smelted in blast furnaces to a copper-nickel matte. This practice is still carried on at the Conniston works, although the roast heaps have been superseded by Dwight-Lloyd sintering machines. The matte runs about 20 per cent of copper plus nickel and is blown in converters to an iron-free white metal containing about 79 per cent of copper plus nickel. The converter slag, containing substantially all of the iron, is returned to the blast furnaces. This blast-furnace plant may be the last of its type to continue in operation. It is enabled to do so by the occurrence of comparatively rich lump ores, which are substantially self-fluxing, and the solution of the problem of roasting and sintering fines by the use of Dwight-Lloyd machines. However, it appears that, as in copper smelting, the blast furnace is on the way out.

At Copper Cliff, where the principal Canadian nickel-reduction works are situated, the ores with about 4 per cent copper and 2 per cent nickel are concentrated by selective flotation and separated into a copper concentrate and a copper-nickel concentrate. The copper concentrate contains about one half the copper recovered from the ore; the copper-nickel concentrate contains the other half. The overall recovery of both metals is in excess of 90 per cent, with a combined ratio of concentration of about 2 into 1. The copper concentrate is smelted in the usual manner and the small amount of nickel it contains is recovered as nickel salts in the electrolytic refinery. The nickel-copper concentrates are roasted and smelted in exactly the same type of furnace used for copper; that is to say, large multiple-hearth roasters and long reverberatories fired with coal dust, and the iron-copper nickel matte is blown to a white metal containing about 80 per cent copper plus nickel. The converter slag is poured back into the reverberatories.

The departure from copper-smelting practice starts with the treatment of copper-nickel white metal from the converters. This cannot be blown to metal as copper is, because the nickel would oxidize. It is treated by what is called the "tops and bottoms" process—a process that depends on the fact that copper sulphide is soluble in molten sodium sulphide to an almost unlimited extent, whereas nickel sulphide is only slightly soluble. The specific gravity of the solution or mixture of copper sulphide and sodium sulphide is less than that of nickel sulphide, so that it is possible to effect a separation. The copper-nickel sulphide from the converter is chilled, broken up and smelted in blast furnaces with sodium sulphate, with coke as fuel. The coke reduces the sulphate to sulphide and the molten products flow into shallow cast-iron pots, where the contents stratify and cool. The top layer is broken away from the bottom layer, and contains most of the copper. This material is blown in a converter, where the sodium sulphide is oxidized to sodium sulphate, which is used again in the blast furnace. The copper sulphide is blown to blister copper. As is usual with processes of this kind, the separation is not complete, and has to be accomplished in two stages, and there are considerable quantities of intermediate products to be reworked.

The nickel sulphide resulting is coarsely ground, water-leached to remove sodium sulphide and calcined on Dwight-Lloyd machines. The sinter is crushed, mixed with coal and reduced to metallic nickel in small open-hearth furnaces. The slag from this operation is returned to the smelter. The crude nickel is cast into anodes and subjected to electrolytic refining. The nickel cells differ from copper-refining cells in that the anodes and cathodes are separated by canvas diaphragms. The required voltage is five or six times as great as for copper. The Sudbury ores contain considerable amounts of platinum and other metals of that group. These are recovered in the refineries and constitute a substantial portion of the world's supply.

Mond Process

A very interesting property of nickel is its ability to combine with carbon monoxide to form nickel carbonyl. This compound forms at a temperature of only 50°C. In practice, nickel oxide is reduced by means of water gas at a temperature of about 350°C., and the metal is caused to react in "volatilizers" with carbon monoxide at the optimum temperature for its formation. The carbonyl-laden gas is then passed through a chamber filled with nickel pellets, where a temperature of about 180°C. is maintained. The nickel carbonyl is decomposed and its nickel component is left as a thin plating on the surface of the pellets. This process produces a nickel of high purity and one that is free of cobalt. The method is known as the Mond process, and is carried out in Wales.

New Caledonia

The nickel ores of New Caledonia contain neither sulphur nor copper. The production from them is small although they have been worked since 1875. The method originally proposed for their treatment was to mix the ore with limestone to flux the siliceous gangue and with coke to reduce the nickel and furnish the necessary heat to produce liquid slag. The resulting alloy contained about 65 per cent nickel but its subsequent treatment proved to be very difficult, and the method that has been used for some time is based on the production of a matte by adding a sulphur-bearing material to the blast-furnace charge. Gypsum usually is employed but pyrite may be used. The ores contain from 4 to 6 per cent nickel. The matte is bessemerized and, since it contains no copper, it may be blown up to a product containing 80 per cent nickel and 20 per cent sulphur, which is then calcined and reduced in horizontal retorts to metallic nickel.

Various Processes for Nickel

Other processes have been proposed for the production of nickel. One of these, known as the Hybinette process, was operated on a large scale about 30 years ago but is no longer used. It attempted to avoid the cumbersome "tops and bottoms" process by a system of leaching and electrolyzing applied directly to the nickel-copper white metal from the converters. Another process, which is now in operation on low-grade nickeliferous, lateritic ores in Cuba, leaches out the nickel with ammonia after the ore has been subjected to a reducing roast. This nickel is precipitated as oxide by boiling the solution and may be used either in that form or as reduced to metal. It remains to be seen whether this process can compete with the Canadian nickel, but apparently it is a success technically. If it can compete, it opens up an important new supply of nickel, as there are very large quantities of leachable ores of this type in other parts of the world.

LEAD

Lead is one of the oldest of the commonly used metals. The growth of the industry has been much less than that of copper or nickel, partly because it started from a higher level. In 1871 the world's production was about 300,000 tons, compared with 2,000,000 tons in a recent year. It occurs in many places and its ores are relatively easy to mill and smelt. The specific gravity of lead minerals is high, so that high-grade concentrates can be made even with crude appliances. During the past 75 years the practice of roasting lead ore has gone through much the same evolution as that of copper roasting. Furnaces with various types of rabbling mechanisms have come and gone, in the end to be superseded by multiple-hearth furnaces of the McDougall type, but the small reverberatory smelting furnaces that were used in the early days have not undergone an evolution corresponding to that of the copper furnaces. On the contrary, they have almost gone out of use, at any rate in the United States. Various modifications of the Scotch ore hearth are still found here and there but for the most part lead ores are smelted in blast furnaces. Reverberatories and furnaces of the ore-hearth type do not make clean slags and are useful only for a preliminary smelting of very high-grade ores.

The lead blast furnace has gone through much the same evolution as the copper blast furnace and has taken the form of a rectangular chamber, water-jacketed along the tuyeres and for a variable distance up the shaft. Lead furnaces are higher than copper furnaces and are generally narrower at the tuyeres, because lower blast pressures are used. Reducing conditions are maintained and the products are lead, matte, and slag low enough in lead to be discarded. The matte contains such copper as may have been in the charge together with some lead, and at Tooele a method for converting leady matte was developed about 30 years ago and has enabled the treatment of cupriferous lead ores that otherwise would have been avoided. Since a blast furnace cannot be operated successfully on fine material, it became necessary to devise means for agglomerating the increasing quantities of fine concentrates that came to the smelting plants as the high-grade ores gave way to lower grade ores that required concentration, and particularly after the flotation process began to come into general use.

Sintering Lead Ores

Lead sulphide can be sintered easily and this was the basis of the Huntington-Heberlein pot sintering process, which came into general use about the beginning of this century. The process was developed at the plants of the American Smelting and Refining Co. First, the lead concentrates were roasted in a Godfrey roaster, or some other type of mechanical roaster, to eliminate some of the sulphur. The calcine, together with the fine material from a previous sintering operation, was charged onto an ignited bed of fuel resting on a perforated plate or grate in the bottom of the pot. Air blown in under the grate and through the bed of incandescent fuel oxidized the sulphur in the charge and generated sufficient heat to bring about the desired sintering. When a pot was finished, it was turned upside down and the sintered mass was broken up to a size suitable for charging into the blast furnace. This process was a fairly satisfactory solution of the problem of preparing fines for smelting in the blast furnace but was intermittent, required considerable hand labor, and was smoky and dusty.

It was superseded by a continuous process, which embodies the feeding of a layer of well-mixed and moistened charge to a thickness of about 5 inches on a traveling grate. The charge stream first passes under an igniter, which kindles it at the surface, and then over a stationary suction box, the draft from which causes the roasting, started at the surface, to progress downward and be finished when the charge reaches the further end of the suction box. The construction of the Dwight-Lloyd machine is too well known to require a description. The pallets travel on rails and dump their sinter by turning over at the end of the machine. The machine has been very successful and has replaced all other types of sintering equipment. It has a wide application and when it was first brought out it was thought that it might be adopted in copper smelting and thus give a new lease of life to the blast furnace. This, however, did not happen because in most localities the reverberatory furnace has definite advantages. In the lead plants, modern practice has been away from preroasting but it is often necessary to sinter in two stages, which is considered preferable.

Control of Dust and Fume

Both roasting and smelting of lead ores and concentrates are accompanied by the evolution of considerable dust and fume. These not only represent a serious financial loss but are also extremely damaging to the surrounding countryside. Since the lead blast furnace operates on a desulphurized charge, the gases are not especially corrosive and in the early '90s bag filters began to be used for filtering them. The baghouse in which this is done contains a multiplicity of long cotton or woolen bags, closed at the top and suspended from the roof structure. The open ends of the bags are tied around iron rings on what is known as the thimble floor. The dust-laden gases enter the chamber beneath the thimble floor and rise thence into the bags. Dust and fume collect on the inside of the bags and is shaken off at intervals. At first the shaking was done by hand, but lately mechanical devices have been perfected to do this work. Baghouses are very effective and collect virtually all the solid matter in the gases, including both dust and fume. They are universally employed and are inexpensive to operate but they cannot well be used with corrosive gases like those from roasters or sintering machines. The dust and fume from such gases are recovered by means of the Cottrell electrostatic precipitator.

Removal of Zinc

One of the most difficult elements in lead ore that the blast-furnace man has to contend with is zinc. It is sometimes difficult to separate from the lead even by flotation and when it gets into the blast furnace it affects adversely the physical characteristics of the slag and forms crusts in the shaft of the furnace. If the slag does not run more than a certain percentage of zinc, depending upon its composition, not much harm is done. The amount of zinc contained in lead blast-furnace slags ranges in various plants from about 5 to 15 per cent, and represents a considerable economic loss of zinc. The problem of recovering it was solved at the Tooele smelter by blowing coal dust through the molten slag contained in a water-jacketed rectangular furnace, thus inducing a reaction by which the zinc is first reduced to metal, which volatilizes and immediately reoxidizes in the atmosphere of the furnace above the slag bath. By filtering the gases from the slag furnace, the zinc is recovered as a fume running upward of 60 per cent. This process is operating at four smelting plants. The zinc may be recovered from the primary fume by the electrolytic process, but if it is to be treated in a retort plant it must first be deleaded by being heated with a small percentage of coke breeze in a revolving furnace. By this method, not only is the lead reduced to about 1 per cent but the fume is densified and nodulized.

Recovery of Precious Metals

Most lead ores contain silver in substantial amounts. Lead is an excellent collector for both silver and gold. The blast-furnace charge often contains both gold and silver ores that are free from lead, but which can be smelted to advantage because their precious-metal values are completely taken up by the lead reduced from the plumbiferous constituents of the charge. The function of the lead smelter, therefore, is greatly extended, but obviously it is necessary to have as an adjunct a refinery in which the lead and silver can be recovered. At one time the only way to recover the silver from argentiferous lead was to cupel it all. This, of course, meant that all the lead had to be reoxidized to litharge, which, after separation from the silver button, was again reduced to metal. However, long before 1871 two processes were discovered by which the recovery of silver was improved: (1) the Pattinson process, which depended upon repeated crystallizations of the lead; and (2) the Parkes process, which is generally used nowadays. The Parkes process is based on the fact that if from one to two per cent of zinc is stirred into melted lead bullion, it will deprive the latter of its silver and form an alloy, which, being less fusible than lead and having a lower specific gravity, will become hard and float on the surface of the lead, whence it can be removed and treated separately. This process is simple and effective and makes a very high recovery of both gold and silver, but it does not remove bismuth. This element can be removed by treatment of the desilverized lead with a calcium alloy. Bismuth-bearing lead is also refined electrolytically, using an electrolyte of hydrofluosilicic acid.

ZINC

Like lead, the ores of zinc are widely distributed and occur abundantly in Europe. The production in 1871 was about 150,000 tons as compared with more than 2,000,000 in a recent year. One of the early zinc-smelting centers was Silesia, but by 1871 the distillation of zinc from its ores was being carried on in many countries, including the United States. At that time, and until about 1915, all zinc appearing on the market as spelter or High Grade was produced by distillation of calcined ore in small horizontal retorts, which were arranged in rows in a fuel-fired furnace. These retorts were clay or carborundum cylinders, closed at one end, approximately 8-inch diameter by 4 feet long. They held only about 50 pounds of ore. The mixture of ore and fine coal was heated to bright redness and the zinc vapor resulting from the reduction of the zinc oxide was condensed in individual clay condensers luted to the open end of the retort. A distillation cycle took 24 hours. This practice is still used for the production of spelter but High Grade zinc is made by other methods developed during the past 30 years.

Roasting Zinc Ores

In order to obtain a satisfactory recovery from zinc ore, or rather concentrate, it must be completely roasted, as any sulphur remaining in the calcine causes the loss of an equivalent amount of zinc. It is understandable, therefore, that a great deal of attention was paid to the designing of a satisfactory type of roasting furnace, and, since many zinc smelters were situated in localities where sulphuric acid could be made and sold to advantage, furnaces were designed not only for the primary purpose of oxidizing zinc sulphide to zinc oxide but also to produce a gas with a sufficiently high percentage of sulphur dioxide to permit it to be used for the production of sulphuric acid in chamber or later in contact plants.

The first furnaces were hand-raked reverberatories of the type common in smelting plants for copper and lead as well as zinc. In order to prevent heat losses and thus diminish fuel consumption, furnace hearths were superimposed and hand-raked shelf burners were designed with half a dozen or more short, superimposed hearths. The shelf burners had working doors in the end, through which the operator drew the ore toward him on one hearth and pushed it away from him on the next one below, a long-handled rake being used for the purpose.

Particularly in the United States, attempts were soon made to substitute mechanical raking for hand raking, and we find in the zinc smelters the same types of roasters used in the copper plants, such as the Ropp, O'Hara, Wethey and Pearce. The Brown furnace was a modification of the O'Hara and was constructed as a straight-line furnace and also in the form of an ellipse and a horseshoe. The Keller furnace consisted of two parallel blocks of five superimposed hearths separated by a space in which traveled the raking mechanism. The ore was fed onto the top hearth and worked down over the hearths below, the rakes being actuated mechanically by a bar entering the ovens through slots in the side walls. These slots were closed by steel bands, wound and unwound by the back and forth movement of the rake carriage. Plows were turned so as to dig into the ore only when moving in the right direction.

In these furnaces the hearths were stationary and the ore was pushed along by movable rabbles. In the Godfrey furnace the hearth was circular, and revolved, the rabbles being stationary. There was the Bruckner revolving furnace and a continuous inclined cylindrical revolving furnace known as the White Howell. There were furnaces in which the ore was neither stirred by hand nor mechanically, but in which the passage of the ore through the roasting chamber was effected by gravity. In the Stetefeldt furnace the ore was showered through burning gas rising in a shaft. For zinc roasting, the descent of the ore through the shaft was too rapid, and in the Cermak-Spirek furnace it was slowed down by a series of A-shaped tiles, the apex of the tiles of one row coming directly below the opening between two tiles of the next row above. The ore, fed through suitable openings in the roof of the furnace, distributed itself over the A-shaped tiling.

Where acid was manufactured from the gases, muffle furnaces were employed. The Hasenclever and Helvig furnace was at one time widely used by zinc smelters in Europe and was characterized by an inclined muffle hearth sloping at an angle of 43°. Attached to the underside of the roof were projecting tiles that reached almost to the hearth. The ore descending over the hearth by gravity was retarded and spread in a thin sheet by the tiles. Roasting was completed on a hand-rabbled horizontal hearth. Other muffle furnaces, such as the Eichorn-Liebig, the Grillo and Hasenclever, were hand raked. In the United States the Hegler furnace, a mechanically raked, superimposed muffle type, was developed about 1880 and was used until quite recently. This furnace was seven hearths high with two blocks side by side. The ore was raked in opposite directions over alternate hearths and worked down through the furnace from top to bottom. The rakes were drawn through the ore at intervals by means of power-driven friction rollers, which gripped a long iron rod to which the rake carriage was attached. A hinged door at the end of each muffle permitted the rake and carriage to be withdrawn from the furnace after each passage, so as to give it a chance to cool off before making another trip.

Of course, all these furnaces required extraneous heat, which was supplied by combustion of coal in fireboxes or in gas producers. In the United States, natural gas was used wherever available, and this was such a cheap fuel that the zinc-smelting industry naturally gravitated to where it was obtainable, notably the Tri-State area, which was rich in zinc ores as well as in natural gas. Because the ores had to be dead roasted, the consumption of fuel was much greater than for roasting either copper or lead ore, and this, of course, was especially true for the muffle furnaces. These had the compensating advantage of producing a rich gas suitable for making acid. The value of the acid was a substantial credit to the operation where the market was not too far away. All the furnaces that have been mentioned in the foregoing pages have gone out of use and have been replaced by multiple-hearth furnaces of the McDougall type, notably the Wedge and Herreshoff, sometimes supplemented by Dwight-Lloyd sintering machines. These furnaces require so little fuel that they can be operated to produce a gas suitable for acidmaking without being muffled. They conserve heat sufficiently well so that a comparatively small amount of fuel suffices to finish the roast and, if desired, the gases from the lower hearths, which are leanest in sulphur dioxide, can be kept separate from the rich gases from the upper floors. At one plant an ingenious system of gas circulation enables such a furnace to operate without any fuel.

FLASH ROASTING

At Trail a McDougall furnace was converted into a flash roaster by taking out the intermediate hearths and blowing the dried flotation concentrates into the chamber thus formed. The fine dried concentrates burn in the chamber and develop a high temperature. The drying is accomplished on the top floor by hot gases from this chamber. These gases are very high in sulphur dioxide and are excellently suited for acidmaking. The two lower hearths of the furnace are left unchanged and the roof of one of them forms the floor of the combustion chamber. The calcines settle onto this floor and are raked away through ports in the circumference by means of the regular mechanism. Naturally, the furnace makes a great deal of dust, which is collected in cyclones and electrostatic precipitators. Aside from operating without fuel and making a rich gas, this furnace has more than double the roasting capacity of the furnace from which it was constructed. All the roasting at Trail is now done in such furnaces and they have been adopted at other plants.

Smelting Zinc Ores

While the roasting of zinc ores has progressed to much the same extent as that of copper and lead ores, this cannot be said of zinc smelting. To be sure, the past 75 years have witnessed considerable improvements in the design and construction of the smelting furnaces and the use of gas producers and heat recuperators has led to substantial fuel economies. The early Belgian furnaces were direct fired and contained only about 46 retorts. From these was evolved a direct coal-fired Belgian type, which was used abroad and in the United States, and contained from 229 to 280 retorts. In the western districts where natural gas was obtainable, long gas-fired furnaces containing upward of 600 retorts were employed. No attempt was made at recuperating heat from these because gas was so cheap that it would not pay to do so. With all the improvements in furnace construction and fuel economy, it was not possible to increase the size of the retorts, as their diameter was limited by the extent to which the heat could penetrate the charge and their length by the strength of the material of which they were made, and by the difficulty of throwing the charge to the far end. Thus the smelting unit was a very small affair and required a great deal of labor for charging and discharging. Mechanical charging machines have been devised and are being used, but even so there remains a great deal of hot and disagreeable work to be performed, and it is becoming increasingly difficult to procure men for that kind of labor.

Therefore, many attempts have been made at various times to substitute some other type for the ordinary distillation furnace, and much effort was expended in Norway on an electrically heated furnace. While it was found that such a furnace was operable, it could be used only under special conditions where cheap electric power was obtainable, and for that and other reasons it has never come into general use. The most successful development of this kind has been made during the past few years by the St. Joseph Lead Co., which not only improved prior methods of electric heating but developed a type of condenser that avoided the formation of the large amount of blue powder that formerly was produced. To what extent electric heating will come into use in the future remains to be seen, but there can be no doubt that many of the disadvantages encountered in the early experiments have been overcome, and the increasing availability and cheapening of electric power is a favorable factor.

Also, in recent times the New Jersey Zinc Co. brought out its continuous vertical retort system, which requires much less labor than the ordinary type of retort because the retorts are much larger and, being vertically disposed in the furnace, can be charged and discharged mechanically. However, the material to be smelted must be briquetted, and this adds considerably to the operating as well as the construction cost. The condenser has received a great deal of attention and not only accomplishes the condensation of the zinc vapor without the formation of blue powder but also separates any lead that may accompany it, so that zinc of very high purity can be made. Thus the New Jersey process is not limited to the production of spelter or Prime Western zinc, which ordinarily contains about one per cent of lead, but can produce high-grade zinc from ores containing lead. It is the most important advance that has been made in distillation furnaces.

LEACHING

The leaching of silver and copper ores has been practiced for a long time on a limited scale but only during the past 30 years has the latter acquired a prominence comparable to concentration and smelting. On the other hand, the leaching of silver ores has almost gone out of use. The processes of chloridizing roasting, followed by hyposulphite leaching or pan amalgamation, were suited only to so-called dry silver ores; i.e., those containing no base metals. Such ores were never plentiful and are largely exhausted. It is not worth while to further describe the methods employed for the leaching of silver ores.

Leaching Gold Ores

The leaching of gold ores, on the other hand, notably by the cyanide process, which came into use about 60 years ago, is very important, and cyaniding is employed either directly or following amalgamation for the treatment of nearly all dry gold ores both here and abroad. It is too well known to require much description and consists basically of dissolving the gold by means of a weak solution of sodium cyanide, from which it is precipitated by means of metallic zinc.

The process received its chief impetus in South Africa, where it was first used for the treatment of the gold ores of the Rand, and where it is still used on a very large scale. Originally the ore was crushed to about ⅜ inches and charged into large steel or wooden tanks, which contained a false bottom made of canvas or burlap, on which the ore rested. The solution percolated slowly through the ore, from which it dissolved the gold. The pregnant solution filtered through the porous bottom and flowed thence through a series of precipitation boxes that were filled with zinc shavings. As the zinc in the boxes was consumed and replaced by gold, they were cut out, cleaned up and recharged. The gold was melted and cast into bars.

The first difficulty encountered in the application of the process was the almost invariable presence of slimes, either in the ore itself or produced in the course of crushing. The slimes prevented uniform percolation and sometimes stopped it altogether. In some cases it became necessary to separate them by a rough classification, which was sometimes done extraneously and sometimes by filling the leaching tanks with water before charging the ore and letting the slimes overflow. The slimes, of course, represented a serious loss, as they contained just as much gold as the coarse ore, and sometimes more. In Africa, they were treated by decantation; a method that later was improved by the development in South Dakota of the Dorr thickener. This device is very important in hydrometallurgy, and has been employed for a great variety of purposes. It is almost universally used for the thickening of dilute ore pulps, whether they are to be leached or not. The countercurrent system of leaching makes use of these thickeners in series and has proved to be a most effective and economical way of leaching fines.

About the time this device came out, there were in process of development numerous types of ore filters. Aside from the filter presses that had been in common use in the chemical industry for many years, the first ore filters were of the leaf type. These consisted of a multiplicity of parallel canvas-covered frames suspended at 4-inch intervals from a rack and connected with a manifold leading to a suction pump. The solution was drawn through the canvas and a cake of ore about an inch thick built up on the outer surface. In the Moore type of filter, the rack of leaves was lifted out of the ore pulp by means of a crane when a cake of appropriate thickness had accumulated, and the cake was discharged by shutting off the suction and applying a blast of compressed air. In the Butters type of leaf filter, the leaves remained in situ but the ore pulp was withdrawn, and, after washing with water, the cakes were blown off and sluiced away. Subsequently the drum type, or Oliver filter, came into use and was followed by the modification known as the disk filter. Both of these are continuous and are much used not only in leaching plants but for the collection of flotation concentrates. All these filters are in use today.

In conjunction with the Dorr thickener, they have solved the slimes problem of the cyaniding plants to such an extent that modern mills frequently are designed to fine-grind and slime all of the ore, thus doing away with the percolation tanks. It is hardly necessary to say that numerous improvements have been made in other parts of the process; for example, in the precipitation, which frequently is done by means of zinc dust instead of shavings, the precipitate being collected in filter presses. Electrolytic precipitation of the gold has also been employed but does not seem to have come into general use. Automatic devices for the regulation of the flow of solutions and ore pulps have been devised. Grinding in cyanide solutions has been carried on for many years. Methods for the protection of cyanide from fixation or destruction by base-metal compounds occurring in the ores have been investigated. The Merrill sluicing filter press is employed at Homestake and elsewhere for the collection and leaching of slimes.

The technique of leaching gold ore is important for what follows because it preceded and, to a considerable extent, laid the foundations of and furnished the equipment for, the base-metal leaching processes that have assumed so much prominence in recent years.

Copper Leaching

The first of these was copper leaching, but it should not be assumed from this statement that this method is of recent origin. Not only is this not so, but on the contrary, the leaching of copper ores was the first wet metallurgical process ever practiced. A copper sulphate solution is so readily formed, and metallic copper is so easily precipitated therefrom by means of scrap iron, that this is not surprising. One of the early methods for recovering silver from copper matte was the so-called Ziervogel process, by which the matte was roasted at a carefully controlled temperature so that much of the copper was converted into sulphate. The sulphated matte was then leached with water, which dissolved both copper and silver sulphates. The silver was precipitated from the solution by means of copper and the copper from the silver-free solution by means of iron. Spanish pyrites, which were much used for the making of sulphuric acid in Europe and England, generally contained from 1 to 2 per cent of copper. The calcine from the acid-plant roasters was mixed with salt and subjected to a chloridizing roast. This rendered the copper soluble and the leaching was done in small rectangular brick-lined tanks. Cement copper was precipitated from solution by iron. The process was efficient chemically but the equipment was small and much hand labor was required. The recovery of copper was incidental to the main job of making acid, but at Rio Tinto cuprous pyrites were leached in great heaps with solutions containing ferric salts. Weathering helped to render the copper soluble.

Where sulphuric acid could be obtained cheaply and where oxidized ores were available, attempts were made from time to time to leach these commercially. Such attempts were made in the eastern states on sandstone ores that occurred here and there. In fact, in one such plant an attempt was made to employ electrolytic precipitation. In Arizona, at the Black Warrior mine, oxidized ores were leached with sulphuric acid made locally. The solutions were precipitated with scrap iron. At the Butte and Duluth mine, a small plant was built where the finely crushed ore was leached in a series of Dorr classifiers operated countercurrent to the flow of the solutions and wash water. The solution was clarified in settling tanks and then was passed through electrolyzing cells equipped with lead anodes. The copper deposited on starting sheets in refined form. In 1913, the first large-scale leaching plant to operate on low-grade material was constructed at Anaconda for the treatment of semioxidized coarse tailings containing about 0.75 per cent copper. Since the tailings were only partially oxidized, they were first roasted in McDougall furnaces and then charged into wooden, lead-lined, leaching tanks, similar to those used in cyaniding. The leached tailings were sluiced away through openings in the bottoms of the tanks. The copper was precipitated from the solution by means of scrap iron and the cement copper sent to the smelter. The plant treated 2500 tons per day, and remained in successful operation for a number of years.

However, the real need for a satisfactory copper-leaching process became apparent when the porphyry mines suddenly came into prominence. While most of these deposits consisted of only slightly oxidized sulphides, in a few of them the sulphide ores were overlain by large tonnages of oxidized ore; for instance, Ajo, Chuquicamata and Potrerillos.

AJO, ARIZONA

A pilot plant was constructed at the mines in Arizona at the direction of Dr. L. D. Ricketts, where it was demonstrated that the oxidized ores at Ajo could be satisfactorily leached when crushed to a size of about ⅜ inches. Extractions of 90 per cent of the copper were obtainable and a portion of the extracted copper could be precipitated electrolytically. The ore contained considerable iron, some of which dissolved, thus consuming acid and fouling the electrolyte. No means were available for removing the iron, so it was permitted to accumulate in the solution and held within bounds by systematically discarding a portion over scrap iron. An amount of acid equivalent to the copper plated out was regenerated but at least an equal amount had to be added as fresh acid. Nevertheless, the process appeared to be sound and a plant capable of treating 5000 tons per day was erected at the mine. The make-up acid was manufactured at one of the smelters near Douglas and shipped to Ajo.

This plant was very successful and represented a departure from cyaniding practice in that very large, rectangular, concrete, lead-lined leaching tanks, holding 5000 tons at a charge, were employed, and these tanks were arranged in a group of 10, so that the solution could flow through in countercurrent, proceeding from the oldest ore to the freshest. The purpose of this was to economize on wash waters and to build up the solution strength. The ore was excavated from the tanks by a so-called stiff-leg excavator like those used in the Lake region for unloading ore boats. The tailings were hauled away in trains of dump cars. The ore was reduced to the proper size in gyratory crushers and in the recently developed Symons disk crusher. The electrolytic plant closely followed the design of the standard copper refinery except that insoluble lead anodes were used instead of copper anodes. The voltage between electrodes was much higher than in a refinery, and the rather large amount of power required was generated in an efficient steam-turbine plant at the property. The copper was fully up to electrolytic standard and was shipped east for casting into the shapes required by the market. The enterprise was an outstanding technical and commercial success. The only drawback to it was the necessity for discarding about one third of the dissolved copper through the scrap-iron tanks. The cement copper had to be put through the usual smelting and refining process and the iron consumption was high because of the presence of ferric iron and acid in the partially spent electrolyte.

CHUQUICAMATA, CHILE

About this time, there was formed the Chile Exploration Co., for the purpose of developing the enormous copper-ore deposits at Chuquicamata, Chile. There were found hundreds of millions of tons of oxidized copper ores, which, like the ore at Ajo, could be mined by power shovels. The pilot plant for experimenting with these ores was constructed in New Jersey and the development of a suitable process was carried on under the direction of E. A. Cappelen-Smith. The ore was most suitable for leaching in some respects and very difficult in others. The copper minerals were readily soluble and, because there was a good deal of antlerite or basic copper sulphate present and but little iron, the acid regenerated in the electrolytic cells was more than sufficient for the leaching of the ore. On the other hand, the ore contained considerable quantities of atacamite, a basic chloride of copper, as well as sodium nitrate and some sodium chloride.

The nitrates and chlorides that accumulated in the solution made it impossible to use lead anodes in the cells and after the solution had circulated a few times it became so strong in nitric acid that even lead pipe lines and lead linings were rapidly corroded. A substitute for lead had to be found for nearly every place at which this metal had been used at Ajo. A reinforced asphalt mastic was decided on for tank and cell linings and pipe lines but the anode problem was more serious. At first anodes made of magnetite by a German process were employed. They were never satisfactory and later became unobtainable, so duriron was substituted. These had the disadvantage that they corroded rather rapidly and caused iron to enter the solutions, thus reducing current efficiency and threatening a shortage of acid. Finally, a copper-silicon anode containing small amounts of lead and tin was devised and this, under the name of Chilex anode, gave satisfactory results until, as the mine became deeper, the nitrate content of the ore became low enough so that anodes consisting of an alloy of lead and antimony could be used.

The plant at Chuquicamata followed the general lines of the Ajo plant but the leaching tanks held 10,000 tons of ore at a charge and were not arranged in countercurrent. They were leached individually, following the practice in cyanide plants and at Anaconda. Solutions of different strengths followed by wash waters were put through the ore one after another. Pregnant solution was sent to storage tanks. The ore was excavated from the tanks by clamshell buckets operated from a movable bridge, which spanned the row of tanks. Tailings were hauled away in dumpcars. At first, rolls had been installed for crushing the ore but these proved unsatisfactory and were replaced by vertical disk crushers like those at Ajo. The pregnant solution had to be freed of its chlorides before it could be electrolyzed satisfactorily. At first this was done by passing it through slowly revolving cylinders filled with copper shot. These required a considerable amount of power and had a rather small capacity, and not long after the plant commenced operating they were replaced by dechloridizing tanks, in which the solution was violently agitated with fine cement copper. This proved a very effective way of dechloridizing and is the method now in use. The precipitated cuprous chloride is decomposed in revolving drums filled with scrap iron. More cement copper is made than is required in the process. It is separated into coarse and fine, the former being smelted and the latter being returned to the dechloridizing plant. This process is so effective that it is used also for stripping solution that has to be discarded. Because of the very small percentage of soluble iron in the solution, the current efficiency is high. Nearly all the copper is produced as electrolytic cathodes, which are melted and cast into shapes required by the market at a furnace refinery of the usual design situated near the tankhouse.

POTRERILLOS, CHILE

The oxidized ores at Potrerillos were similar to those at Ajo in that they contained a considerable percentage of soluble iron, but they also contained unusually large amounts of arsenic. They could be leached like the Ajo ores, by using the countercurrent system, but the cathodes resulting from electrolysis of the solution contained too much arsenic to be marketable. It was apparent that it would either be necessary to precipitate the copper in some other way or the solutions would have to be purified before electrolysis. After some experimentation with the Van Arsdale process of precipitating metallic copper by means of sulphur dioxide, it was decided that purification was preferable. It was known that ferric iron could be precipitated from a cuprous solution by means of calcium carbonate provided that this was added in a carefully regulated amount and not in excess. Upon this fact depends the purification process that was built into the Potrerillos plant about 20 years ago and is still used. Finely ground limestone serves as the precipitating agent for both iron and arsenic. The slimy precipiate is separated from the purified copper solution by filtration through a battery of Moore filters. The purified solution can be electrolyzed at a very high efficiency to produce an excellent grade of copper. In addition to purifying the solutions, the process provides an excellent means for stripping the copper from dilute wash waters. This may be done without increasing the requirement of limestone, all of which is first passed through agitators with the wash waters. The precipitate of copper carbonate and excess limestone so formed settles and filters very rapidly and is just as effective as the limestone itself as a purifying agent for the pregnant solution. The copper carbonate redissolves; thus no cement-copper precipitation of wash waters or spent electrolyte is required, and substantially all the copper is recovered from these highly impure and ferruginous ores as electrolytic.

INSPIRATION, ARIZONA

The copper mineral at Inspiration happens to be chalcocite, which is the reason that it can be extracted along with the copper oxide by leaching with an acid solution containing ferric sulphate. The plant has been in successful operation for about 20 years. Rolls in closed circuit are employed for crushing, as it is desirable to have the ore a little finer than at the other properties. The leaching plant does not differ fundamentally from the other plants using the countercurrent system, nor is there any fundamental difference in the electrolytic plant, but there is a considerable difference in the mode of operation. This difference is necessitated by the fact that the solutions must perforce contain a considerable percentage of ferric iron and this must be restored as rapidly as it is depleted by the oxidation and dissolution of the chalcocite. Only a very small percentage of the copper contained in the solution can be plated out at one pass through the electrolytic cells and, at the same time, there must be maintained a high oxidizing efficiency at the anodes in order that the ferrous iron may be reoxidized to ferric iron. In order to establish these conditions, it is necessary to maintain an unusually high rate of circulation through both leaching tanks and electrolytic cells, and it is also necessary, from time to time, to recondition the anodes in order to restore their oxidizing efficiency, which falls off after a while. The process has been highly successful at Inspiration and extracts close to 90 per cent of the total copper but its application is limited because most ores contain considerable quantities of other copper minerals such as chalcopyrite or energite, and these are not attacked by ferric sulphate.

VARIOUS LEACHING PROCESSES

In addition to the acid processes described, there is a process that employs ammonia as the solvent. It is being used for the leaching of low-grade native copper tailings dredged from the bottom of a lake in the copper country. The process is carried out in circular steel leaching tanks, which are covered so as to avoid losses of ammonia. In order to reduce these still further, the tailings are given a final treatment with steam before being discarded. The copper is precipitated as oxide by boiling the pregnant solution. The copper oxide is readily reducible to metallic copper of high purity. The ammonia is recovered for re-use, and reagent losses are extremely small. The process has a rather limited application, as ammonia is not nearly as powerful a leaching agent as sulphuric acid. It is, however, excellently adapted to the purpose for which it is used, as is indicated by the fact that tailings containing only 12 pounds of copper per ton are being treated and an excellent recovery is obtained therefrom. For some years, the ores of the Kennecott mine, Alaska, were treated by ammonia leaching. The process has recently been applied to the treatment of low-grade nickel ores, and it is possible that for this purpose its use will spread.

ELECTROLYTIC ZINC PROCESS

A process for the recovery of zinc from its ores by leaching and electrolysis was patented many years ago but never got beyond the laboratory stage. During the '90s, some experimental work was done with such a process on a pilot-plant scale in Australia but did not get beyond that stage. Nothing of much importance was done with the process until it was taken up in Canada and the United States.

In 1914, experiments were started in Anaconda, which culminated in the construction of a plant that produced about one million pounds per month of electrolytic zinc. This was followed in 1916 by a plant at Great Falls, which produced 6,000,000 pounds per month and was subsequently enlarged from time to time so that it now produces 28,000,000 pounds per month. Some years later, a plant of half the size was constructed at Anaconda. It was enlarged a few years ago and the two plants together now have a producing capacity of over 40,000,000 pounds per month, or almost one quarter of a billion pounds per year. About the time that the work of developing this process started at Anaconda, similar work was undertaken at Trail, following pretty much the same pattern. Subsequently a plant was built in Australia and later was followed by several plants in Europe and in the United States.

Fundamentally the process is simple. It consists of leaching calcined zinc concentrates with dilute sulphuric acid, purifying the solution by treatment with zinc dust and electrolyzing it in cells with lead anodes and aluminum cathodes, from which the thin deposit of zinc is stripped from time to time.

This sounds easy enough but, like so many other technical processes, many difficulties had to be overcome before success was achieved. One of these was the tendency of zinc and iron to combine in the course of calcination into an insoluble ferrate. Selective flotation, fortunately, has made it possible to separate iron and zinc in most ores even when the two minerals are intimately associated. Since the material to be leached was very fine, the slime-treatment methods developed by the gold metallurgists were employed; that is to say, the calcine was agitated with dilute acid and the residue was separated by settlement in Dorr thickeners followed by filtration of the thickened pulp. Iron, arsenic and antimony were precipitated from the solution by oxidizing it with manganese dioxide and adding an excess of zinc oxide in the form of calcine. After this it was agitated with zinc dust to precipitate cadmium, copper and other impurities. Finally it was electrolyzed and the spent electrolyte was returned to the leaching plant.

In outline this is the process employed today but numerous variations have been made in the way in which it is carried out. At some plants the calcine is leached in batches and the solution is neutralized at once. This simple method may be used where the calcine is very high grade and where the loss of a small amount of zinc is not important. Otherwise, it is necessary to leach in two stages, the first stage producing a slightly acid solution and a clean residue and the second stage producing a neutral solution and a residue containing soluble zinc, which is returned to the first stage. There is also a wide variation in the current density employed at the various plants. This ranges from about 30 to 100 amperes per square foot. In the high-density process so much heat is developed that the solutions are circulated through cooling coils outside the electrolyzing cells whereas in the low-density system the cooling coils are in the cells themselves. The multiple system is used in all the tank houses. In the high-density system, it is customary to clamp the electrodes to the bus bars, but this is not necessary in the low-density system. In the construction of the plant, chemical lead must be used throughout because antimonial lead interferes seriously with the plating out of the zinc.

Purification by a simple treatment with zinc dust sufficed at first but proved inadequate for the treatment of ores containing cobalt. This element is removed by treatment with nitroso-beta-napthol and other refinements have made it possible to treat almost any kind of ore. The effect of impurities in the solutions, even when present in minute amounts, is very marked, and certain rare metals, notably germanium, particularly in conjunction with cobalt, interfere so seriously with the electrolysis of the solution that as little as 10 parts per million virtually inhibit the plating out of zinc. The purity of the zinc cathodes is affected also by the presence of trace elements in the electrolyte, but, strange to say, a minute percentage of cobalt aids in the production of special high-grade zinc. The surface condition of the anodes is also very important in this respect.

When electrolytic zinc first came onto the market, the only other source of high-grade zinc was the so-called Horsehead brand produced in New Jersey by distillation of ores free from lead. The common grade of zinc contained about one per cent of lead but sometimes was refined by redistillation to produce Intermediate and Brass Special. From the first, the electrolytic process produced a grade of zinc that equaled the New Jersey brand and complied with the specifications for High Grade, which permitted the presence of 0.07 per cent lead. With the establishment of the die-casting industry there came a demand for zinc containing still less lead, and now the maximum percentage of lead allowable in so-called Special High Grade zinc is less than 0.004 per cent. This demand has been met successfully and at one plant zinc containing only 0.002 per cent lead is regularly turned out, and selected lots may run as low as 0.001 per cent. Such zinc is now also being produced by fractional distillation so successfully that the electrolytic plants are hard pressed to hold their own in this field.

THE LIGHT METALS

The limitations of this paper permit only the barest outline of progress in the reduction of aluminum and magnesium, in no way commensurate with the importance these metals have attained. For all practical purposes these are new metals. Aluminum was first produced in quantity when the Hall process was discovered about 1886. From the modest start made then the industry has grown until in a recent year production exceeded 1,500,000 tons. Large-scale production of magnesium started much later but in the same year was not far from 150,000 tons. While most of this sudden expansion was due to the recent conflict, it is probable that both of these metals will retain a considerable part of the gains made during the war.

Aluminum

Bauxite is the raw material from which aluminum is produced. In the Bayer process, alumina is extracted from it by leaching with caustic soda. A supersaturated solution is made from which pure aluminum hydroxide is precipitated by "seeding." The precipitate is collected by filtration, dried and ignited to aluminum oxide. This worked well on high-grade bauxite low in silica but gave a poor recovery on low-grade ore high in silica. Recently it has been supplemented by the so-called "lime-sinter process," which enables relatively low-grade ore to be treated. The Hall process starts with the pure aluminum oxide, which is dissolved in a bath of molten cryolite and electrolyzed. The bath is contained in a rectangular steel box lined with refractory material. The current enters the cell from a row of carbon electrodes, which project into the bath, and leaves through the reduced metal that accumulates on the bottom. A row of cells, called a "pot-line," is connected in series and supplied with direct current from a converter or rectifier. The electrodes require frequent renewal, as they are consumed by the oxygen of the alumina. The process itself has undergone no radical change but many technical improvements have been made and the scale of the operation has grown tremendously.

Magnesium

Magnesium has been recovered from magnesite, dolomite, salt brines, and sea water, by direct reduction and by electrolysis of the molten chloride. Magnesium oxide may be reduced directly to metal by carbon in an electric furnace. The vaporized metal must be "shock-cooled" by contact with a large volume of natural gas or it will reoxidize. It is collected as a fine powder, which may be reprocessed or used as produced. The magnesia in burnt dolomite may be reduced to metal by being mixed with ferrosilicon and heated in a chrome-nickel-steel retort in which a high vacuum is maintained. The metal vapor condenses in ring form in a vessel attached to the retort.

The bulk of the magnesium produced during the war was made by the electrolysis of fused magnesium chloride. There are two processes, which differ in the mode of making the chloride, in its freedom from water and in electrolyzing technique. In the Dow plants crystalline magnesium chloride is first obtained directly by evaporation of brines or indirectly from sea water, by precipitation as hydroxide, which is dissolved in dilute hydrochloric acid to form a solution of magnesium chloride, which is then evaporated to crystals containing six molecules of water. In either case, these are dried to two molecules, which is as far as it is possible to go without decomposition of the chloride. This hydrous chloride is then fed into the anode compartment of an electrolyzing cell, in which it melts and in which dehydration is completed in an atmosphere of chlorine and hydrochloric acid. The metal that is liberated at the cathode floats on the surface of the molten electrolyte and is skimmed off and cast into bars. The carbon anodes are corroded by the oxygen of the water and the chlorine evolved combines in part with the hydrogen. The anodes and the cells are of steel and the bath is kept molten partly by the electric current and partly by extraneous heating.

In the plant at Las Vegas, the raw material was a calcine produced from a magnesite concentrate containing only small percentages of lime and iron. The calcine was mixed with powdered coal and made into a thick slurry with magnesium chloride solution. The slurry was discharged from the mixer onto a slowly moving belt, where it "set" into a hard mass, which was partially dried in rotary kilns. The hard lumps and granules, called "pellets," were charged into the "chlorinators," which were brick-lined cylinders with electrical resistance heaters in the bottom. Chlorine from the cells plus some make-up entered near the bottom and reacted with the magnesium oxide and the carbon to form anhydrous magnesium chloride and carbon monoxide. Because the pellets contained moisture, some hydrochloric acid also was produced and was condensed in towers to be used for making pellets. The molten anhydrous chloride was tapped at intervals and poured into brick-lined electrolyzing cells, which were not heated extraneously and gave off only chlorine at the anodes. The fused bath was a mixture of magnesium chloride with the chlorides of calcium, potassium and sodium. During the war this plant produced metallic magnesium at the rate of 10,000,000 pounds per month, and was the largest in the world.

ACCOMPLISHMENT

Thus ends our survey. Certainly no similar period in the history of metallurgy can show such progress as that recorded here. Not only have old methods been improved and expanded to meet the enormous increase in demand for metals that were in common use 75 years ago, but new methods have been devised, and metals that in 1871 were merely laboratory curiosities are being reduced from their ores by the tens of millions of pounds, and form the basis for alloys and structural materials the like of which have never been seen on this earth.

The substitution of scientific methods of control for "rule of thumb" and the application of mechanical appliances throughout the industry have enormously reduced the human effort required to produce the metals so vital to our modern way of life. It is an impressive record of accomplishment, of which this survey conveys but a sketchy and incomplete account. Nevertheless, enough has been said to demonstrate that the metallurgical profession has not been idle, but has contributed in full measure its quota toward making possible the modern world in which we live.

Seventy-five Years of Progress in Iron and Steel

Coke, Pig Iron and Ingot Manufacture

By C. D. King

CLARENCE D. KING

The "operating" committees of the United States Steel Corporation have as their function the formulation and direction of operating procedure in the coke oven, blast-furnace, open-hearth and other major departments. As chairman of all committees since 1933, Mr. King has an intimate knowledge of every phase of the industry. He has been active in the Iron and Steel Division, A.I.M.E., and in 1944 was awarded the Robert W. Hunt gold medal of the Institute.

This year the American Institute of Mining and Metallurgical Engineers celebrates its seventy-fifth anniversary as well as the same anniversary of iron and steel in this country as we now know it. The society's span of life comprehends the very beginning and gradual development of the present-day iron and steel industry and its Transactions are rich with the trials and achievements of the pioneers in this field.

It is difficult to believe that in the first year of the Institute's existence there was produced in this country only 84,000 net tons of ingots, of which only 2000 tons was made by the open-hearth process; that the bessemer process was just barely beginning; that charcoal and anthracite were virtually the only blast-furnace fuels; that Mesabi ores had not been used in blast furnaces, and such pig iron as was then made was produced at a number of small units, each adjacent to its ore and fuel supply. The growth from 84,000 net tons production of steel ingots to 95,500,000 tons in 1945 eloquently tells the story of America's industrial growth.

This article is a condensation of a comprehensive paper prepared by Mr. King at the invitation of the Anniversary Volume Committee. The full text will be published in a separate bound volume, as one of the A.I.M.E. Series, sponsored by the Seeley W. Mudd Memorial Fund.

Coal and Coke

In the past 75 years there have been various changes in the type of fuel used for the smelting and refining of iron and steel products. Wood charcoal, anthracite and bituminous coal, beehive and by-product coke, all enjoyed widespread use in the industry during this period. It is of interest to note that the life of the Institute has encompassed the successive periods of supremacy attained by each of these fuels; moreover, each of these periods has been marked by an output of pig iron greater than the one it followed, as shown in Fig. 1.

CHARCOAL

Until about 1840, almost all the pig iron manufactured in the United States was made with charcoal, which continued to be the principal smelting fuel until 1855.[1] After 1910, the greatest production of pig iron with charcoal occurred in 1917, when a total of about 421,700 net tons was made. During the latter part of that year, of the 407 blast furnaces then operating, 22 used charcoal.[2]

ANTHRACITE

Early use of anthracite as a fuel for the production of pig iron was another phase in the progress and development of the industry secondary only to that of charcoal. The successful use of anthracite did not occur until after the first practical application in the United States of the hot blast to pig-iron smelting in 1834.[3] On Oct. 19, 1839, the Pioneer furnace, at Pottsville, Pa., was successfully blown in using anthracite exclusively as fuel. Thereafter, for a period of approximately 80 years, anthracite was used either exclusively or in combination with coke made from bituminous coal. Statistics[4] show that 1914 was the last year in which pig iron was produced with anthracite exclusively and that the combination fuel was last used several years later.

BITUMINOUS COAL

Throughout the history of the iron industry, uncoked bituminous coal has been the least popular of the various blast-furnace fuels. Information as to the earliest successful use of coal as a blast-furnace fuel is not immediately obtainable, but "in 1845[5] a furnace in Mercer County, Pennsylvania, began the successful use of block bituminous coal to reduce iron ore." In the year the Institute was formed, five of the six furnaces in Clay County, Indiana, were operating with uncoked block coal.

Use of uncoked bituminous coal exclusively has long since been discontinued.

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[1] References are on page 197.

COKE

The early commercial exploitation of the use of coke as a fuel for the production of iron is perhaps the most significant factor in the development and expansion of the iron industry. The first successful use of coke occurred in 1835.[6]

Progress in conversion to the use of coke was rather slow. During the year 1871 about 30 per cent of the iron then produced was made with coke, and in 1875 the production of iron with coke exceeded that from either anthracite or charcoal.

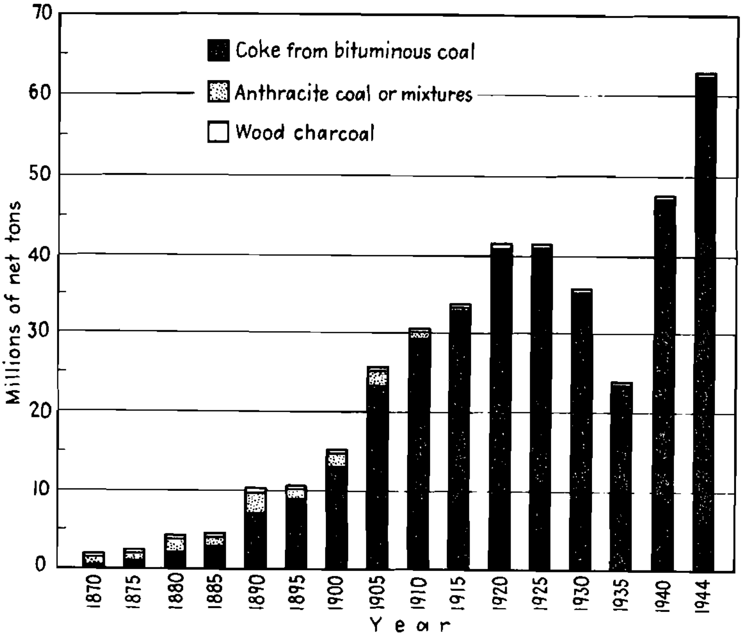

Fig. 1—*Production of pig iron and ferroalloys, according to fuels, 1870–1944. Source: American Iron and Steel Institute.*

After 1919, the priority of beehive coke as a major fuel source was lost; by-product ovens in that year produced 57 per cent of the total compared with 43 per cent from the beehive plants. The output of beehive coke steadily declined after that year. In 1859, Connellsville coke was first used at the Clinton furnace, built by Graff, Bennett and Co. in a plant on West Carson Street, Pittsburgh. The Clinton furnace was the first to be built in Allegheny County after the abandonment, for the lack of ore, of George Anshutz's furnace at Shadyside in 1794.[6]

The most significant phases in the history of by-product coking occurred in Europe in 1856 and 1883, respectively. In 1856 a battery of ovens was built by Knab with apparatus for the recovery of tar, ammonia, and gas, the gas being returned and burned in flues under the ovens. In 1883, Gustav Hoffman added to the Otto-Coppee oven a regenerator. In 1892, Louis Semet built 12 Semet-Solvay ovens at Syracuse, N. Y.[7] That was the first plant erected in the United States for making by-product coke. The coke was used for making soda.

By 1894, the by-product coke industry was well established in Europe. Also in that year, the Cambria Steel Co., at Johnstown, Pa., built a battery containing 60 Otto-Hoffman ovens, forming the first by-product coke-oven plant built in the United States[6] to supply coke for blast furnaces.

THE MODERN BY-PRODUCT OVEN

From its beginning in 1894 up to about 1910, adoption of the by-product oven was rather slow, but the impetus provided by World War I accelerated conversion of the steel industry to this process. Improved utilization of fuel made possible by the modern by-product coke oven, as shown in Fig. 2, is a fitting tribute to the early pioneers in this field.

Change from the beehive to the by-product method for coke production has brought the steel industry into intimate relationship with the chemical industry, particularly those branches associated with ammonia, coal tar, and benzol products. The availability of coal chemicals had a profound influence on the outcome of World War I. By-product coking capacity in the United States increased about 268 per cent from 1919 to 1944, but even this increase was insufficient to provide the demands for coal chemicals required in the second World War.

The use of mechanical cleaning, or coal washing as it is often called, originated in the iron industry, and has been used for the improvement of coal quality since the formation of the Institute. Thirteen washing plants were operating in Allegheny, Fayette and Westmoreland Counties of Pennsylvania in 1880, and an additional plant was erected at Latrobe in 1881. Use of these plants was later discontinued and there was little change in the extent to which coal washing was employed by the steel industry until well after the turn of the century.

Production of Iron

No phase of the steel industry is more typical of its remarkable progress than is the evolution and development of the modern American blast furnace. The founding of the Institute in 1871 also marked the beginning of a new era in the pig-iron industry.

Prior to this period, the iron industry, largely concentrated in the East, was based upon the consumption of local iron ores and local fuels, the latter predominately charcoal and anthracite. In about 1860, exploitation of the newly discovered rich ore deposits in Michigan and the successful adaptation of blast furnaces to coke produced from coal of the great Pittsburgh seam in western Pennsylvania proved to be major factors in firmly establishing the general westward shift of the industry. But these were largely economic in character, and it was not until about 1870 that the aggressive, individualistic nature of the ironmaster asserted itself in no uncertain manner. It is not surprising that Pittsburgh was the center of this new activity.

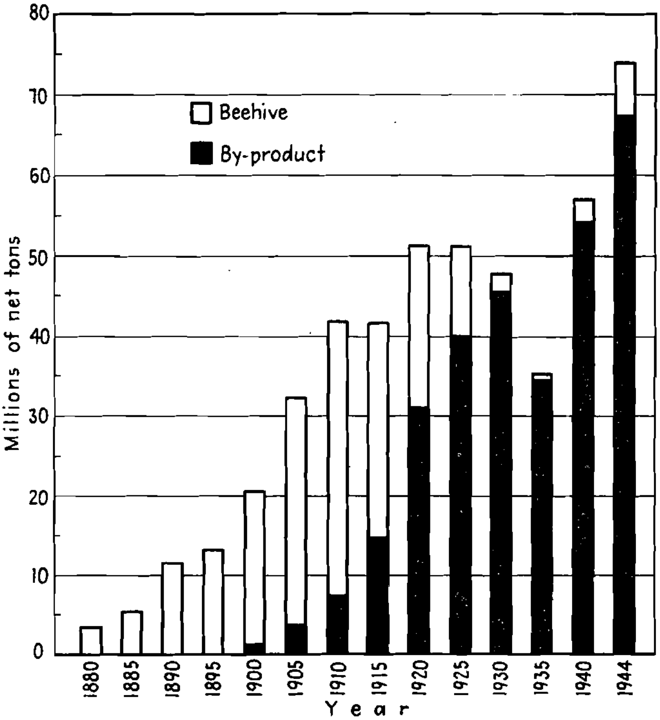

FIG. 2—*Production of beehive and by-product coke in the United States, 1880–1944. Source: Mineral Resources of the U.S.A.*

THE EARLY FURNACE PLANT

Those familiar with the blast-furnace process are impressed by the many similarities between modern and early furnaces. The process itself is unchanged; ore, coke and limestone are still charged in layer fashion by a bell

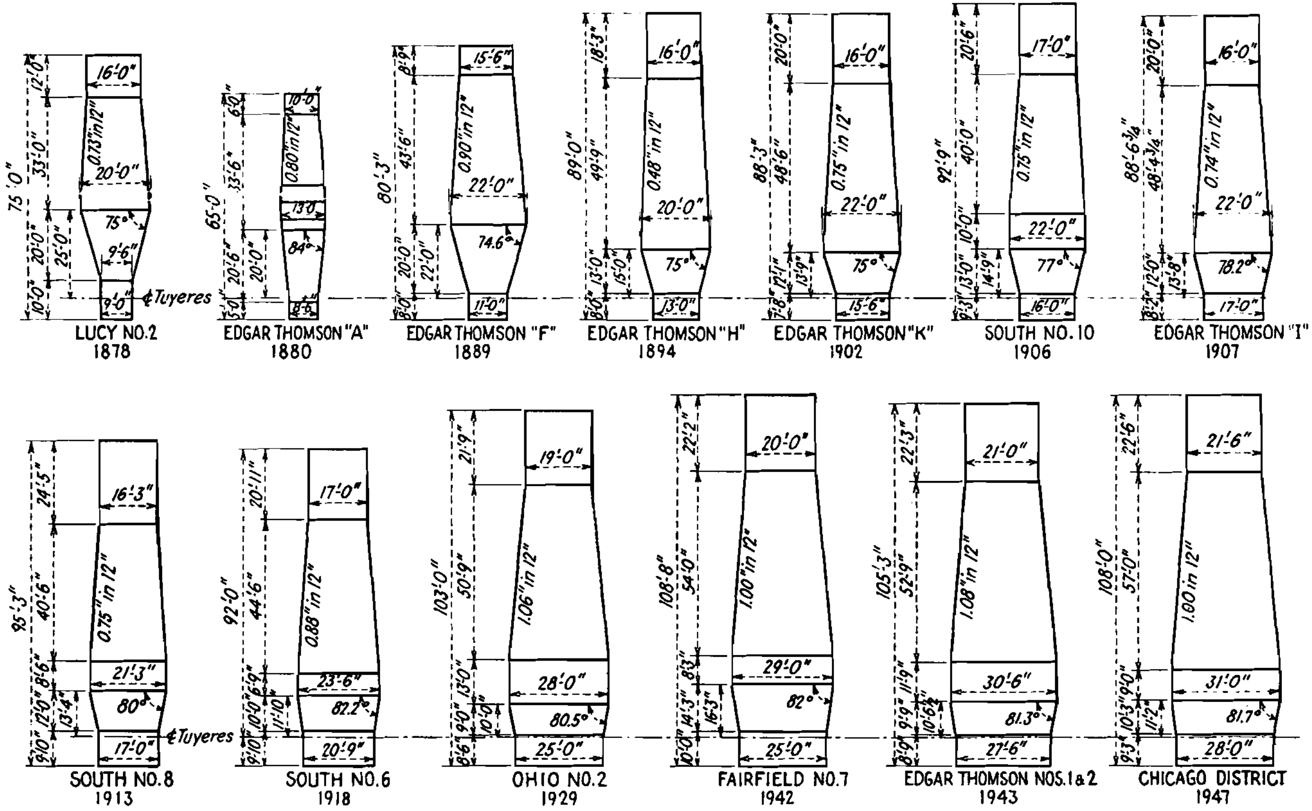

FIG. 3—*Development of blast-furnace lines.*

at the furnace top, preheated air is blown through tuyeres in the crucible, and molten slag and iron are drawn from separate openings in the hearth—all in almost exactly the same manner as practiced in the 1870s.

The following description[9] of the first Lucy furnace in 1873 serves to illustrate a typical plant of this period:

> The furnace is neater and more attractive than the stone stacks of the East, and in many respects more convenient.
>
> The Machinery of the works is of the best quality, though of a very different character from that usually seen in the East. There are three excellent blowing engines by Messrs. Mcintosh, Hemphill & Co. of Pittsburgh. Steam is raised by a Battery of eight boilers, each sixty feet long by forty-three inches in diameter.
>
> The capacity of the furnace is about 550 tons a week, taking the average of the seasons. The ores used are mostly Lake Superior Specular and Hematite. The Fuel is a coke made from he slack of the bituminous mine near Pittsburgh—at ovens located at Carpenter's Station. The fuel costs but $3.60 per ton at the furnace, and we are informed that the consumption in the stack is only about one and half tons to the ton of pig iron made.

Firebrick stoves were not introduced in this country until installed at Rising Fawn furnace in Georgia and at the Cedar Point No. 1 furnace, Port Henry, N. Y., in 1875.[10] The first record of their use in the Pittsburgh district appears[11] at Dunbar furnace, Fayette County, in 1876.

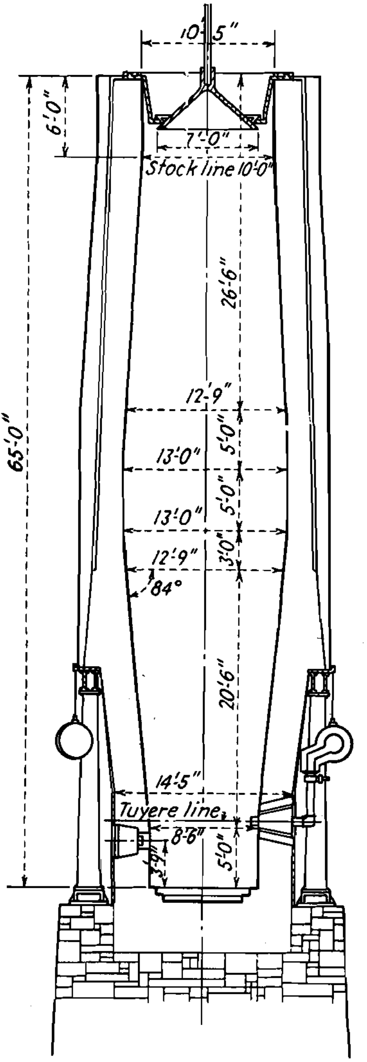

FIG. 4—*Blast furnace A at Edgar Thomson Works, 1880.*

DEVELOPMENT OF FURNACE LINES

Lines of early furnaces were characterized by small hearths, high and relatively wide boshes, and diameters at the stockline or "tunnel-head" usually greater than the diameter at the hearth. Lucy No. 2 furnace (Fig. 3), built in 1877, is typical of this design. A slightly different design is found in Edgar Thomson

"A" furnace (Fig. 4); originally a charcoal furnace at Escanaba, Mich., but in 1879 moved and re-erected at Braddock, Pennsylvania. This successful furnace employed a blast rate higher than other furnaces designed with twice the volumetric capacity, which established a precedent followed almost at once by the industry in general.

Unfortunately, although much higher blast rates were generally achieved, most furnaces responded with prohibitive coke rates associated with excessive blowing. The literature implies that the higher blast rates seriously affected the life of the brick lining. Attention then turned to lowering of blast rates to obtain better fuel consumption, and to the problems involved in preserving the lining by means of water-cooled plates. As a result of these efforts, the use of horizontal bronze plates embedded in the bosh brickwork was developed.

During the next 15 years adaptation of blast furnaces to fine Mesabi ores resulted in a number of significant changes in blast-furnace lines. The first shipment of Mesabi ores was made in 1892. In 1894, blowing in of Edgar Thomson "H" furnace with its 13-ft. 0-in. hearth diameter and 13-ft. 0-in. height of bosh, ushered in a new phase in blast-furnace design, its distinctly lower bosh pioneering a trend that has persisted up to the present time.

While the fine Mesabi ores had enabled faster driving rates because of their higher reducibility, their initial use led to difficulties due to an extreme tendency toward channeling of gases within the stock column, with subsequent slipping, hanging, and general irregular working. This irregularity inevitably caused a gradual increase in coke consumption as the percentage of Mesabi ores was increased in the burden. This is indicated in Table 1, which shows average data representing a large number of furnace plants.[12]

TABLE 1—*Effect of Mesabi Ore on Coke Consumption Rate at Blast Furnace*

Year	Percentage Mesabi Ore in Burden	Coke Rate, Lb. per Net Ton Iron
1902	43.8	1924
1903	50.3	1956
1904	55.0	1999
1905	61.0	2031
1906	65.2	2003
1907	68.7	2109

The next major development in blast-furnace lines was the hearth 25 feet in diameter and other dimensions of the furnace commensurate with this diameter. One of the first furnaces[13] of this type was No. 2 furnace at Ohio works, which was blown in in 1929.

The most recent step in the development of large blast furnaces is embodied in the design of the 27-ft. 6-in. hearth diameter of Nos. 1 and 2 furnaces at the Edgar Thomson works, and in the design of three furnaces now under construction at South and Gary works in the Chicago district (Fig. 5).

PRESERVATION OF LINING

Blast-furnace construction in the 1870s was characterized by a relatively great thickness of lining, a feature no doubt carried over from the early stone stacks. The first type of horizontal plates embedded in the brickwork, which consisted of iron castings containing a double coil of pipe, was used at Dunbar furnace, Pennsylvania, in 1876. One of the first uses of a bronze bosh plate is believed to be an installation made by Julian Kennedy at one of the Lucy furnaces, probably in 1883. Shortly thereafter, James Scott, at Lucy furnaces, and James Gayley, at Edgar Thomson works, developed bosh plates that combined the removable feature with the high-pressure water feed of the completely enclosed bronze plate. The latter type, developed about 1890, is practically identical with those used today.

The protection of the stockline by means of iron or steel armor built into the brickwork was practiced[15] as early as 1872 at the Glendon Iron Works, Easton, Pennsylvania.

The importance of refractories of high physical and chemical quality has long been recognized in this country. The use of various types of brick[16] to withstand the different service conditions in various parts of the furnace was practiced as early as 1870. More important developments in this field since that time include the introduction of machine-made brick about 1917. and vacuum-pressed brick in 1935.

STOCKING AND CHARGING EQUIPMENT

In tracing the development of modern facilities for stocking and charging raw materials at blast furnaces, one is impressed with the fact that here is an excellent example of the manner in which technologic progress in one phase of an operation forces development in a related but lagging auxiliary component. The vertical hoist was used at blast furnaces in the 1870s for raising charge barrows to a point from which they could be wheeled to the furnace and manually dumped over the large bell. It is not surprising to note that the high production records achieved at Lucy furnaces led to the first installation of an inclined skip hoist at that plant in 1883. This installation, with which was incorporated a double hopper at the furnace top, did away with the necessity for employing top fillers.

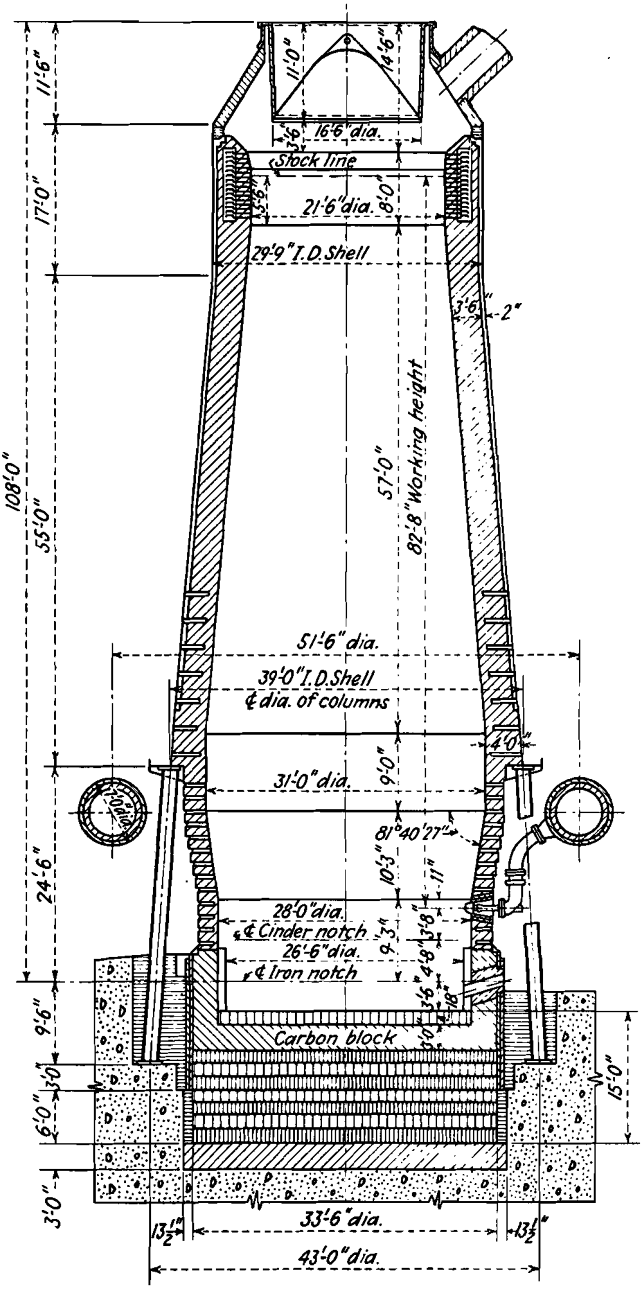

FIG. 5—*New blast furnaces at South and Gary Works, 1947.*

Increased production rates at blast furnaces during the decade beginning with 1890 also forced the development of mechanical methods of handling and stocking raw materials before charging into the furnace skip car or bucket. Prior to this time, raw materials were handled largely by hand after initial dumping from railroad cars from an elevated trestle. In 1895, construction of the Duquesne blast-furnace plant was begun, and the inclusion at this plant of an ore yard with a stocking bridge system invented by Alexander E. Brown, and of stockhouse bins designed to permit gravity charging of the Neeland buckets, was so radical a departure that it is referred to in the literature[14] as the "Duquesne revolution."

GAS CLEANING

The rather coarse nature of iron ores used in the northern district and the low blowing rates generally employed prior to 1880 presented no major problems brought about by excessive dust in blast-furnace top gas. As late as 1890, dust catchers were sometimes omitted in blast furnaces in the northern district.

Following the introduction of Mesabi ores in 1892, it was apparent that the dry-type dust catcher alone did not adequately fulfill gas-cleaning requirements. It is probably not mere coincidence that one of the early references in the literature[18] to a specific wet-cleaning unit concerns the installation of a Jarrell gas washer at a plant in Buffalo in 1893.

In 1903, B. F. Mullen developed[19] and installed at the Leetonia, Ohio, plant of the Cherry Valley Iron Co., a gas washer designed to remove dust by impingement of the gas on a water surface; this washer was the most successful of its type and was used in many plants.

The Brassert-Bacon tower washer, installed at the South works of the Carnegie Illinois Steel Co. in 1914, included wooden hurdles, as in the Zschocke system, but was novel for its multiple banks of water sprays together with the offsetting of the hurdles to prevent channeling. More effective results have been achieved by various methods, such as the replacement of the lower banks of wooden hurdles with ceramic tile; use of wooden hurdles with a cross section in the shape of a tear drop and design of a spiral-vaned moisture eliminator; use of mechanical cascading rotors in combination with banks of hurdles. These improvements have rendered modern washers capable of consistently cleaning blast-furnace gas from inlet conditions of approximately 5 grains per cubic foot to less than 0.15 grains per cubic foot.

With the advent in 1903 of blowing engines driven by blast-furnace gas, it became necessary to clean gas to a greater degree than could be provided by washers of the primary type. The first unit was the Theisen drum-type washer, developed in Germany and first installed at South works in 1907.

The Theisen disintegrator has been widely applied to final cleaning, with good results.

The second type of secondary or final gas-cleaning equipment is the electrostatic system, originally developed by Dr. Frederick G. Cottrell, of the United States Bureau of Mines. The first full-scale installation[20] of this system on blast-furnace gas was made in 1919 at the Dunbar, Pa., plant of the American Manganese Manufacturing Co. The success of the Cottrell system, as presently developed, is well established, as evidenced by the large number of installations at the present time.

STOVES

The advantages of heating the air blast prior to its delivery to the furnace tuyeres were well established in American ironmaking circles before 1870. Neilson's invention of the hot-blast stove in 1824 and the phenomenal results[21] obtained had far-reaching effects.

In Neilson's early iron pipe stove, the maximum temperature possible for the preheated blast was 600°F. Later modification and improvements made possible the delivery of blast preheated to 1100°F. in a pipe stove[22] of American design, such as shown in Fig. 6.

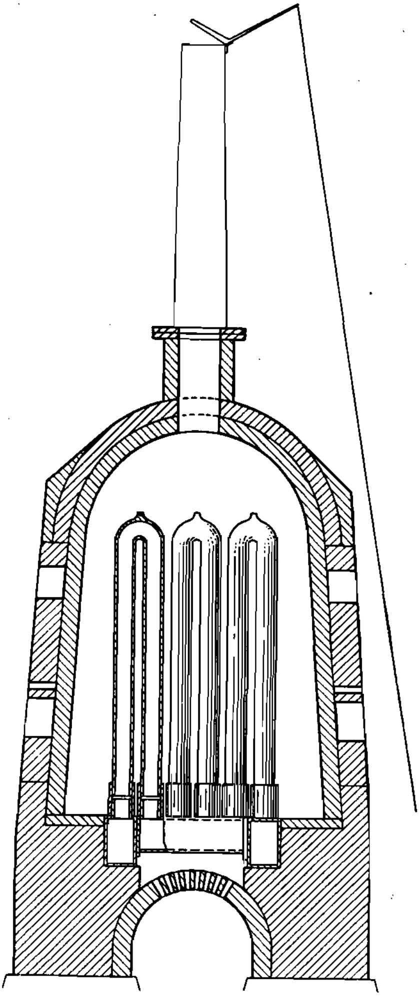

FIG. 6—*Iron pipe stove.* (*Courtesy of Iron and Steel Engineer.*)

Development of the firebrick stove was extremely rapid in America during the period 1875 to 1890, as indicated by Fig. 7, which shows a two-pass stove designed by Julian Kennedy and used at the Edgar Thomson works in 1890.

With the introduction of fine Mesabi ores in 1892, blast-furnace operators were confronted with problems brought about by the plugging of stove checker openings by excessive dust in blast-furnace gas. This required the construction of stoves with larger checker openings. In the early period of the use of Mesabi ores, high blast temperatures could not be carried on the furnace. In retrospect, it can be observed that the attention paid to gas cleaning in the period 1905 to 1920 was influenced in large part by the desire of

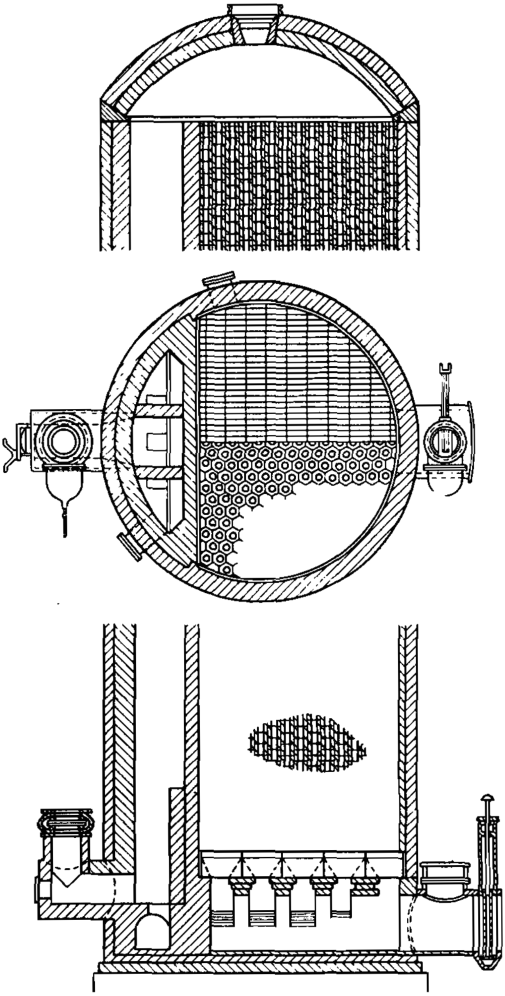

FIG. 7—*Hot-blast stove at Edgar Thomson Works, 1890.*

the operator to apply smaller checker openings in stoves in order to facilitate the use of higher blast temperatures.

The successful solution of the gas-cleaning problem largely removed the limitation formerly placed by this factor on stove design. From about 1915 to the present time a large variety of stove checkers of special shapes and small openings have been applied as a consequence, with the result that a stove shell that formerly was capable of providing only approximately 80,000 square feet of heating surface with checkers of large openings can be relined with modern checkers of smaller openings to yield a heating surface in excess of 250,000 square feet.

HANDLING OF IRON AND SLAG

Developments in the handling of iron and slag from the blast furnace have been characterized largely by the elimination of the arduous task of manual disposal of the furnace products through the application of mechanical devices.

Invention of the hot-metal mixer, by Capt. William Jones in 1889, brought about a drastic change in handling iron at the blast furnace, through the introduction of ladles in which hot metal was transferred directly from the furnace to the mixer. In 1896, installation at Lucy furnaces[23] of a pig-casting machine invented by E. A. Uehling finally brought about the complete elimination of pig bed in the cast house.

As the productive capacities of blast furnaces were increased, hot-metal ladles were increased in size. The early open-top units of 10 tons capacity were gradually increased to capacities as high as 75 tons. The first mixer-type ladles, installed in 1915, were of 75 tons capacity. Their size was increased in 1922 to 125 tons and in 1925 to 150 tons.

The procedure of opening and closing the tapping hole has undergone changes that are considered by those directly involved in the operation of the furnace as important as any in the recent history of blast furnaces. The application of the pneumatic rock drill[24] in tapping-hole practice at the Sparrows Point plant of the Maryland Steel Co. in 1890 was the first of several significant developments. The clay gun used for stopping the tapping hole was invented by Samuel W. Vaughen and first[25] applied by the Cambria Iron Co., Johnstown, Pa., in 1896. In 1906 the use of oxygen was first applied[26] to the melting of iron skulls in tapping holes; this development, which has since become universal, proved to be one of the most useful as well as most appreciated labor-saving methods applied in the past 50 years. Other improvements that have contributed to the efficient handling of hot metal at the blast furnace include the invention of a device for skimming slag from hot metal in the iron trough, by Michael Killeen, at Edgar Thomson works in 1909.

The method of handling slag prior to 1883 involved the flow of slag into molds on what formerly was called the "cinder wharf." Later, the slag was broken before it cooled completely and loaded into cars by manual labor,[17] and still later molten slag was poured directly into flat-bottom cars. Before 1890, a cinder ladle car with a mechanical dump feature was used at several plants. After 1890, the only significant changes in slag-disposal methods were the development of the mechanical cinder bott operated by remote control, and the application at some plants of water granulation of molten slag at the furnace.

BLOWING

Progress in the development of equipment for the generation of the air blast is largely one of progress in mechanical engineering.

The development of the reciprocating steam-driven blowing engine was extremely rapid in this country from the period marking the beginning of high blast-volume rates from about 1880 until 1905. In 1903, the first gas-driven blowing engines used in this country were installed at the Lackawanna plant at what was then the Lackawanna Steel Co. The most recent development in generation of the air blast is the turboblower, first applied[27] to the blowing of blast furnaces at the furnace of the Empire Steel Co., Oxford, N. J., in 1910. The reliability of the turboblower has increased with knowledge and experience, until today it commands an unchallenged position in the field of generation of the air blast. At present some turboblowers deliver 125,000 cubic feet per minute of air at a pressure of 30 pounds per square inch, and units under construction will have a capacity of 140,000 cubic feet per minute at a pressure of 40 pounds per square inch.

RAW MATERIALS

Today blast furnaces are being operated in various sections of this country on raw materials that from the technologic standpoint have little in common either physically or chemically. The iron industry in the Birmingham district of Alabama is based upon ores containing only 36 per cent iron; the northern ironmaking district, which contains the bulk of the nation's producing capacity, is supported largely by ores from the famous Mesabi Range, a typical ore from this region being so fine that more than one third of it will pass through a screen having openings of less than 0.02 inch. In Utah, blast-furnace operations have been conducted successfully for a number of years on coke so friable that it can be crushed to powder under the pressure of one's heel.

The transition from beehive to by-product coke was as troublesome to the furnaceman as was the initial adaptation of beehive coke, and for many years Connellsville beehive coke was considered the premium blast-furnace fuel, even after the by-product oven had been firmly established as a component of the integrated steelworks.

The successful solution of the by-product coke problem in the Pittsburgh district as well as other iron-producing districts demonstrated that the integrated steel-producing company and the integrated plant possessed advantages beyond the scope of their obvious initial economic merits.

The transition in the northern iron-producing district from local iron ores to the coarse, rich ores found in the Upper Peninsula of Michigan was well under way prior to 1870. The first shipment of Mesabi ores in 1892, and the rapid increase in the use of this extremely fine ore, mined by relatively inexpensive open-pit methods, confronted the blast-furnace operator with problems so serious that fully 20 years was required for their satisfactory solution, as indicated in the foregoing sections of this paper. It was during this period that furnacemen came to a full realization of the importance of physical as well as chemical quality of raw materials.

As the result of renewed activity in ore preparation, equipment for the agglomeration of iron-ore fines has assumed new importance. Agglomeration of flue dust was practiced as early as 1896 at the South works[28] of the Illinois Steel Co., where a plant was erected for briquetting this material with an admixture of flux. In the period 1910 to 1920, many installations were made for the sintering of flue dust by the downdraft process, using the Dwight-Lloyd continuous traveling-grate system or the Greenawalt stationary-pan type. Recent activity in the agglomerating field has brought about the deserved, if belated, attention this important auxiliary requires; considerable pains are now taken in the design and operation of sintering plants in order to provide proper mixing and blending arrangements so essential to quality control.

TECHNOLOGIC DEVELOPMENT

Blast-furnace progress before 1900 revolved around the development of large units of increased productive capacity, and the accommodation of these units to changing conditions in raw materials by changes in furnace design. In the meantime, increased knowledge of the physical metallurgy of steel had opened enormous new fields in the application of steels of various analyses. The production of these steels placed a burden on the open-hearth and bessemer operator that often he was not able to sustain under the then prevailing qualities of iron produced.

The same criticisms directed toward furnacemen by the steelmaker were voiced by foundrymen. In 1904 a subcommittee of the American Society for Testing Materials prepared standard specifications[29] for pig iron based upon chemical analyses. Prior to this time, pig iron had been graded[30] and sold on the basis of the appearance of its fracture, but the action of the subcommittee sounded the death knell of this haphazard system.

Many branches of the industry have cooperated in efforts to solve the problem of process control. Attention turned first to the identification and grading of northern iron ores. Shortly thereafter, Mesabi ores were blended to yield standard grades of specified chemical analyses. At about the same time, a complex system was evolved for the handling of ore at Upper Lakes docks and vessels, with such improved results in uniformity of analyses that problems arising from former deficiencies in this respect were largely eliminated.

Developments in process control were not confined to raw materials. The invention of the stockline recorder by David Baker, and its installation[31] at South Works in 1901 gave the operator his first real knowledge of the flow of materials within the furnace.

The adaptation of refrigerating equipment for removal of moisture from the air blast[32] by James Gayley at the Isabella furnaces in 1904, and the reported beneficial results obtained, marked the end of a period in blast-furnace history noted largely for mechanical developments. From the healthy controversy that engulfed the industry after the first results at Isabella were published, there emerged a period of technologic endeavor important for its contributions to blast-furnace theory and practice.

Despite the notable technologic strides made during the last 25 years, some will decry the present state of our knowledge of the process and the general reluctance on the part of the operator to apply new and revolutionary methods or devices. On the other hand, the same aggressive spirit typical of early work in ironmaking is being manifest in new ways in two significant developments. The operation of blast furnaces under elevated top pressures, begun in 1943 and now adopted as a routine practice at the Cleveland and Youngstown plants of the Republic Steel Corporation, is a method holding considerable promise as a means of carrying high blast rates with low top-gas velocities and more favorable conditions of gas flow. Another development toward which the attention of the industry has turned is the enrichment of the blast with oxygen, a subject long academic but now sufficiently promising to warrant trial, owing to the perfection of methods for producing oxygen at expected substantially lower costs than formerly have prevailed.

At the present time, therefore, the new avenues of endeavor in the field of blast furnaces appear to be ore preparation, high top pressure, and oxygen enrichment. It is not possible at this time to predict the extent to which each of these methods will ultimately be applied. Judging from the experience of the past 75 years, it is safe to assume that these and other methods will be successfully developed and applied to maintain the supremacy of the blast furnace in the realm of pig-iron production for many years to come.

Steel Ingots

The organization of the American Institute of Mining Engineers 75 years ago parallels the beginning of present-day steel-producing methods in the United States. This early association with the industry is emphasized by the fact that the first open-hearth furnace constructed and operated in this country was then only 3 years old, and the first commercial bessemer converter was just 7 years old.

Total production of steel in the year 1871, as recorded by the American Iron and Steel Institute, was 84,000 net tons, of which 2000 tons was produced by the open-hearth process, 45,000 tons by the bessemer, and 37,000 tons by the crucible, puddled iron, and other processes. The bessemer process had thus become the major source of steel production. The development of Lake Superior ores during 1870–1890 and the exploitation of the Mesabi Range in 1893 provided the industry with great quantities of high-grade ores. The abundance of coking coals and limestone in the region adjoining western Pennsylvania and the development of cheap water transportation on the Great Lakes tended to shift the center of iron and steel manufacture to an area west of the Allegheny Mountains. The growing application of steel during this period is reflected by the proportion of bessemer steel used for manufacture of rails. During the early 1880s almost all bessemer steel was rolled into rails; by 1890, only 63 per cent; and by 1896, only one third was used for this product.

The development of reversing mills permitted bessemer to displace wrought iron, a process of historical interest only. Economies derived from this innovation forced wrought iron from the market, and by 1900 the bessemer process had reached an annual production of 7,500,000 net tons of ingots.

Coincident with these developments, the open-hearth process was growing rapidly. Steel produced by this method between 1880 and 1900 increased from 112,000 to 3,800,000 net tons annually.

Commercial application of the electric furnace in 1906 and the use of a number of duplex and triplex processes utilizing combinations of bessemer, open-hearth, and electric-furnace facilities, represent more recent developments in methods of steel production. Advantages of the electric furnace subsequently permitted it to supersede the crucible as a major steel-producing medium within a comparatively short period of time.

It seems difficult to believe that in 75 years this industry has grown from a production of 84,000 net tons of steel in 1871 to a capacity of over 95,000,000 net tons in 1945, as shown in Table 2. In retrospect, it is interesting to note that the basic principles of steel production have changed but little in this period of 75 years—but, apart from basic principles, there is nothing in common between present-day facilities or methods and those employed years ago.

TABLE 2—*Steel Ingots and Steel for Castings, 1945*

Kind of Steel	Open-hearth		Bessemer		Electric and Crucible		Total Annual Capacity, Net Tons
	Number of Furnaces	Annual Capacity, Net Tons	Number of Vessels	Annual Capacity, Net Tons	Number of Furnaces or Units	Annual Capacity, Net Tons	
Open-hearth, basic.	940	82,611,730					82,611,730
Open-hearth, acid.	50	1,559,860					1,559,860
Bessemer.........			41	5,874,000			5,874,000
Electric..........					259[a]	5,455,890	5,455,890
Crucible.........					3	3,800	3,800
Total..........	990	84,171,590	41	5,874,000	262	5,459,690	95,505,280

[a] Represents furnaces making ingots only, year of 1945.

THE BESSEMER PROCESS

Early Developments

The bessemer, or pneumatic, process was the first great advance in the manufacture of steel, and made possible the great industrial development following its invention by Henry Bessemer in England and William Kelly in America.

Two American interests began the manufacture of steel by the new process under the Kelly and Bessemer patents but after much litigation, the rival organizations decided to combine their respective interests early in 1866. This led to efforts to expand the industry, and many blast-furnace owners were prevailed upon to have their irons tested for steelmaking. While most of these were found unsuitable, it was the experience gained from this blind use of unknown irons that first indicated the possibilities of making good product from irons of specified analysis. Soon thereafter, when consignments of pig iron were purchased it was stipulated that phosphorus content should be below 0.1 per cent.

By 1871, production of bessemer steel had increased to 45,000 net tons, and comprised about 55 per cent of the total amount. Plants operating in 1871 are listed in Table 3. By 1877 other companies added converters, and production of bessemer steel was expanded to 560,000 net tons annually, which represented 88 per cent of the total. Until 1877, the maximum production of any bessemer plant was about 350 tons per day.

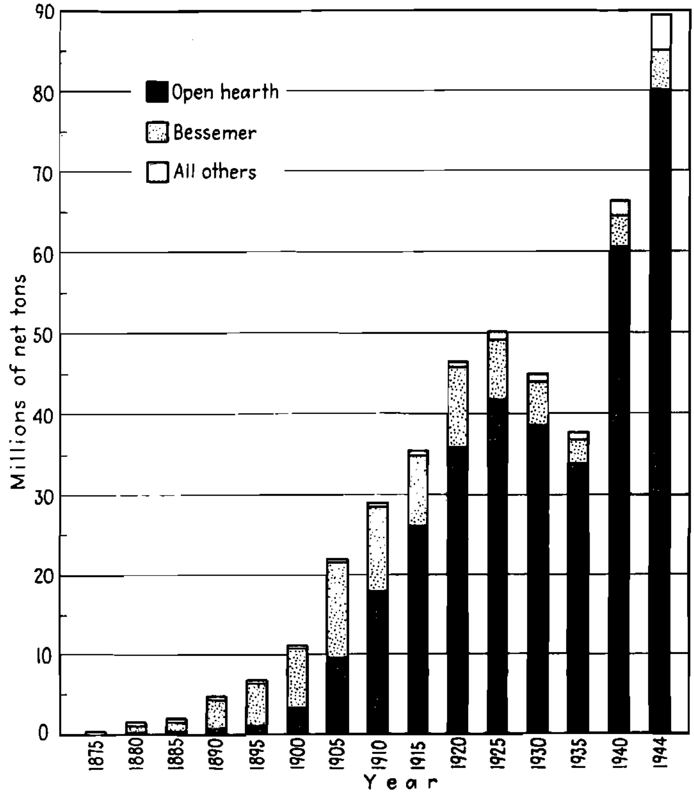

FIG. 8—*Production of ingots according to processes, 1875–1944. Source: American Iron and Steel Institute.*

Despite the progressive improvement in bessemer steel during these years, it was not until the hot-metal mixer came into general use that the bessemer became firmly established on a large scale. This important advance was made by Capt. W. R. Jones, of the Edgar Thomson plant of the Carnegie Steel Co., in 1889.[3] Perhaps no single development in steel has had such an important bearing on the industrial life of America.

As illustrated in Fig 8, annual open-hearth production exceeded that of the bessemer in 1908 for the first time in the history of this country. Since then bessemer production has shown a marked decline in relative importance to its present status of 5,500,000 net tons annual capacity. The decline in annual production from 1900 to 1946 is shown by the following figures: 7,486,042 net tons produced in 1900; 10,542,305 in 1910; 9,949,057 in 1920; 5,639,714 in 1930; 3,708,573 in 1940, and 3,327,815 in 1946.

Recent Trends

Despite the foregoing, some modern bessemer plants were built in the period 1910 to 1930, usually in conjunction with tilting basic open-hearth furnaces. This arrangement permitted the use of converters for production of bessemer ingots as well as the manufacture of basic open-hearth steel.

TABLE 3—*Bessemer Plants Operating in Year 1871*

Plant	Location	Number of Vessels	Capacity of Vessels, Gross Tons	Date of First Blow
E. B. Ward	Wyandotte, Mich.	1	2½	Fall of 1864
		1	2½	Feb. 16, 1865
Winslow, Griswold and Holley		1	5	Early in 1867
Pennsylvania Steel Works	Harrisburg, Pa.	2	5	June, 1867
Freedom Iron and Steel Co	Lewistown, Pa.	2	5	May 1, 1868
Cleveland Rolling Mill Co	Newburgh, O.	2	5	Oct. 15, 1868
Cambria Iron Co	Johnstown, Pa.	2	5	July 10, 1871
Union Iron Co	Chicago, Ill.	2	5	July 26, 1871

Recent years have adequately demonstrated the advantages of blown bessemer metal when applied to the stationary open-hearth furnace, a practice that is expected to increase in the future at plants where pig iron in excess of the normal practical limits of stationary furnaces is available. There is in operation today approximately 12,000,000 net tons of rated converter capacity with a potential capacity considerably greater. This is made up of approximately 5,500,000 net tons for bessemer ingots and the balance blown metal for use in open hearths and, to a limited extent, in electric furnaces.

Metallurgical Advances

The development of fully killed bessemer steel for manufacture of seamless pipe in recent years was an outstanding metallurgical advance, and many hundreds of thousands of tons of this product are in service.[35] This is the first important reversal in trend in the application of bessemer steel since its heyday in 1908. The improved quality of these steels holds considerable promise for the bessemer process in the production of improved steels for many applications. In addition, alloy steels have also been developed successfully by the bessemer process, and many other new and useful applications have been effected.

Dephosphorized bessemer steel has been found to possess the good welding and machining qualities of normal phosphorous bessemer steel, and some of its stiffness and reaction to cold-work. Moreover, it has improved ductility and a much lower degree of brittleness under impact stresses.

The use of the spectroscope and photronic cell[36] for more exact determination of the end point of the blow, and thereby the degree of oxidation, has contributed to a more uniform product and economies as well. Bessemer steel possesses superior machinability, favorable resistance to corrosion, and excellent weldability. In the field of free-machining steel, it is without par.

With means available for reducing the phosphorus content in bessemer steel to open-hearth levels, and the possibility of obtaining nitrogen contents equally as low, it would be foolhardy to dismiss bessemer from the future picture. These improvements in metallurgical practices of which the above represent only a few, have awakened new interest in the use of bessemer steels. Many realistic operators believe that if the same interest and studies are devoted to the bessemer process as have prevailed in open-hearth practice, the future of the bessemer process will be assured.

OPEN HEARTH

Early History

At the time of the early bessemer developments, a new and practicable method for obtaining sustained steel-melting temperatures in an "open-hearth" furnace was made possible by Siemens' invention of the gas producer, coupled with a new regenerative principle for preheating the gasified fuel and air for combustion. By 1868 open-hearth steelmaking by the pig-and-ore and pig-and-scrap processes had been successfully developed in England and France,[37] and the process was in that year introduced in America by the Cooper-Hewitt Co. at Trenton, New Jersey.

The Lakeside plant of the Otis Steel Co. in Cleveland was the first plant designed for the exclusive manufacture of open-hearth steel. It started operation in October 1874 with two 7-ton furnaces of improved design. Early in 1886, one of the 15-ton Otis furnaces was changed from an acid bottom to a basic bottom, consisting of magnesite imported from Austria, and so operated for a number of months. This is reported to be the first test of a basic open-hearth furnace in the United States. The commercial production of basic steel was achieved two years later at the Homestead works of Carnegie, Phipps and Co., and dates from March 28, 1888, when the first heat was tapped from No. 1 furnace.

The layout of the Homestead No. 1 open-hearth plant is shown in Fig. 9. Its 10 furnaces were arranged in two parallel rows with the pit-side area between. Charging tracks ran parallel to the rows of furnaces on the charging side, and the mold and ingot tracks entered between the furnaces of each pair, adjacent to the pouring pits. With heats tapping, pouring and stripping in the restricted pit area, it will be readily agreed that the pit side was aptly described as being "hotter than hell itself."

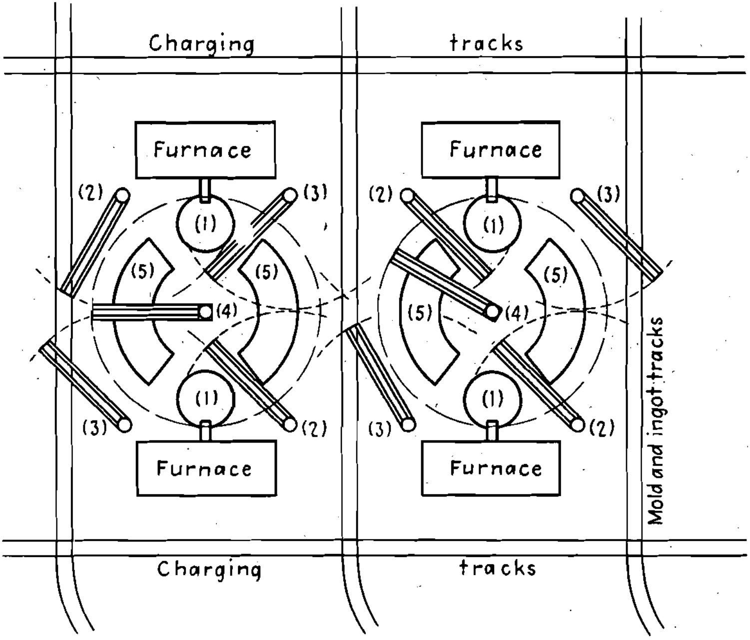

FIG. 9—*Arrangement of No. 1 open hearth, Homestead Works, 1888.*

1. Ladle pits.
2. Spout cranes.
3. Ingot cranes.
4. Ladle crane.
5. Pouring pits.

Eight of the 16 furnaces in the No. 2 shop went into operation in 1890 and were rated at 47 net tons capacity. The arrangement of this plant, which was a great improvement over the older shop, is shown in Fig. 10. The furnaces were placed in the same general arrangement and at ground level, but the ladles were placed on cars and moved to the pouring pits at the end of the plant.

Shortly after the original Homestead plant was completed, the innovation of pouring directly from the ladle into molds mounted on movable railroad trucks was developed at the Sparrows Point plant of the Bethlehem Steel Company.[38]

Following the successful operation of these furnaces, production of basic steel expanded rapidly. This was enhanced during the period from 1890 to 1900 by the availability of magnesite for open-hearth bottoms and the use of silica refractories instead of fire-clay brick.

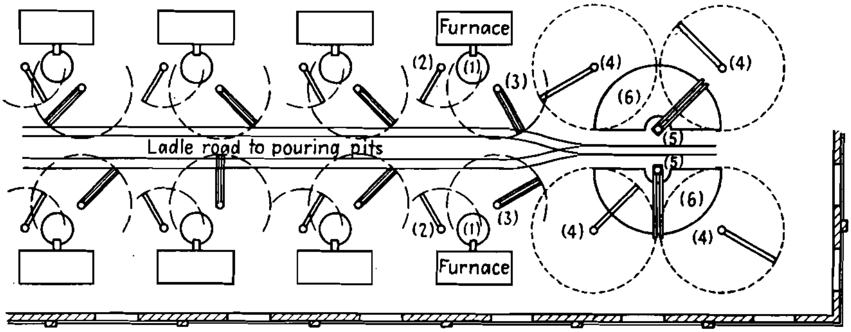

FIG. 10—*Arrangement of No. 2 open hearth, Homestead Works, 1890.*

1. Ladle pits.
2. Spout cranes.
3. Ladle cranes.
4. Ingot cranes.
5. Pouring cranes.
6. Pouring pits.

The period prior to 1900 was characterized by rapidly changing designs, equipment, and process technique. It was an era of opportunity in an obviously profitable field. It was during this period that the industry first saw the application of tilting furnaces to open-hearth steelmaking well in advance of the ability to properly utilize this principle. The original tilting open-hearth furnace, Fig. 11, was placed in operation at the Steelton plant, Pennsylvania Steel Co., in 1889, by Campbell, an outstanding figure in the industry.

The Intermediate Period

The growth in size of open-hearth furnaces from 1870 to 1900 was relatively slow and limited not by the lack of venture on the part of management or desire for larger units, but rather by the mechanical facilities and auxiliary equipment then available. The enormous increase, from 3,800,000 tons of open-hearth ingots in 1900 to 30,000,000 tons in 1920, was obtained not by enlarging the furnaces but almost entirely by the installation of additional plants and furnaces, a practice subsequently reversed to a great degree in the next 20 years. In the period from 1900 to 1920, the present modern plant layout was then in existence, the present-day type of furnace, except for size and accessories, then in operation, and many of today's metallurgical practices already firmly established.

It was during this period that the wheelhorse of metallurgical fuels, producer gas, met its first competition from tar and coke-oven gas from by-product plants, and the decline of its popularity then started.

This was an era characterized by emphasis on production, with a lack of understanding of the need for uniformity of raw materials and exacting practices to assure consistent steel quality. Hot-topping, the use of inverted molds, and strict adherence to sound metallurgical practices were rarities. Furnaces were driven at top speed with a fuel input well beyond the possibility of efficient use. Insulation was unknown and even reasonable tightness of the furnace system either not appreciated or, where recognized, seldom practiced. Accordingly, the industry paid the penalty in extravagant practices and nonuniformity of steel quality at the expense of production.

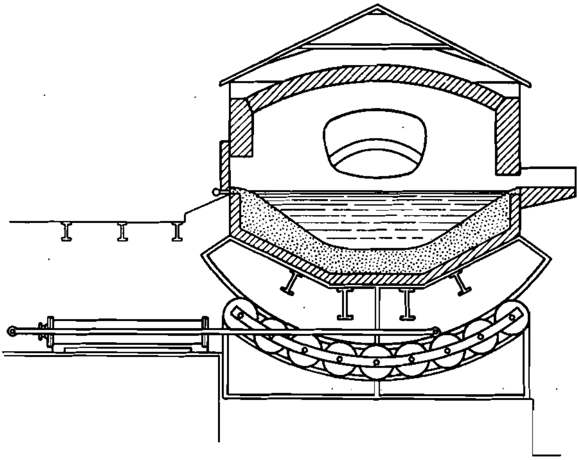

FIG. 11—*Campbell's tilting open-hearth furnace, showing hydraulic cylinder and mechanism for tilting, 1889.*

Recent Trend of Developments

From the beginning of the third decade until the present time, many important changes have been made in open-hearth design,[39] facilities, and practices. The marked increase in ingot production from 30,000,000 tons in 1920 to 61,500,000 tons in 1940, was obtained to an important degree through changes in earlier facilities. Large hot-metal mixers, up to 1500 tons capacity, replaced the small 200 to 300-ton pear-shaped units. Charging machines were enlarged; stocking facilities were expanded, and improved types of cranes, ladles, slag thimbles, and other auxiliary equipment forced by the tendency to increase size of heat.

Still other means have been developed to permit the use of high pig percentages where normal usage would involve difficulties and hazards. A striking example is furnished by the experience at the Weirton plant of the Weirton Steel Co., where, according to Clyde Bayer, General Superintendent, considerable proportions of converter blown metal have been substituted for pig iron, the remainder being owned or purchased scrap. These furnaces, of approximately 400 tons capacity, are exceptionally deep. By using blown metal up to 70 per cent of the charge, with the balance steel scrap, these furnaces have produced as much as 23,000 tons per furnace per month, with an average production of 25 to 28 tons per hour in charge to tap. When these furnaces are operated with 30 per cent hot metal and 62 per cent scrap, the production rate falls to an average of 16 tons per hour in charge to tap.

Present-day Processes

Present-day open-hearth steelmaking processes can be divided into three main groups: cold-iron plants, hot-metal plants, and duplex units.[40]

Cold-iron plants are those using mixtures of pig iron and steel scrap in cold form, and usually are represented by small producing units situated at centers where steel scrap is relatively cheap compared with pig iron.

The vast majority of steelmaking plants in this country operate with hot metal and invariably are associated with integrated units. The furnaces range from as little as 60 tons up to 400 tons. The pig-iron charge normally employed ranges approximately from 40 per cent to 70 per cent.

The duplex process is made up of two components, one being the oxidation of carbon, silicon, and manganese of the molten iron by bessemerizing, and the other consisting of the dephosphorization and refining of the blown metal in the basic open-hearth tilting furnace. It is an extremely rapid process. In addition, duplex plants possess amazing versatility in application to all grades of steel.

Melting Fuels

In the early years of open-hearth operation, and as late as 1910, three fuels constituted the source of thermal energy; namely, fuel oil, natural gas, and producer gas. The use of atomized fuel oil started with the introduction of the basic process in this country. Some modern plants operate with as little as 20 gallons per net ton of ingots, or 3,000,000 British thermal units.

Natural gas has long been used in districts where it is economically available. Furnaces operating with natural gas do not produce as much steel per hour as those fired with oil or tar. However, fuel consumption as low as

3200 cubic feet, or 3,200,000 B.t.u. per ton of ingots has been obtained over extended periods at modern plants.

A fuel widely used in earlier days but rarely seen in large modern plants is producer gas, obtained by the gasification of selected coals and regenerated in checker chambers. It possesses a high luminosity. Very high production rates have been and continue to be obtained with this fuel under proper conditions, and fuel consumption as low as 350 pounds of coal per net ton of ingots has been obtained over long periods. Burning out accumulated carbon in checkers, the extra investment for gas producers, and the depletion of available high-volatile, low-ash and low-sulphur coals are a few of the reasons for its almost complete replacement by superior and more readily available fuels.

During World War I, the lack of other fuels forced some plants to use powdered coal but this fuel requires carefully selected coals of low sulphur and low ash content, therefore its use was abandoned as promptly as other fuels became available.

With the introduction of by-product coke plants in 1910, and their subsequent rapid installation during World War I, the use of coke-oven gas and tar became prevalent. The Clairton works, Carnegie-Illinois Steel Corporation, is an outstanding example of the successful use of coke-oven gas alone, as little as 7700 cubic feet, or 3,850,000 B.t.u., being consumed per net ton of ingots over a year's period. When coke-oven gas alone is used, production rates are lower than when mixtures of liquid fuel and coke-oven gas are employed.

Where fuel economy of the plant dictates the use of blast-furnace gas in open hearths, it is necessary to clean the gas. A few American plants have used blast-furnace gas in conjunction with other fuels.

Fuel consumption in 40 years has been reduced 50 per cent or more and many stationary furnaces today are operating with 3,000,000 to 4,000,000 B.t.u. per ton of ingots.

Furnace Controls

Furnace controls as used today were entirely lacking in 1910, and for many years thereafter the only so-called controls in existence were in the nature of meters, most of them inaccurate if not entirely useless.

Control of seemingly minor differences in fuel input, air infiltration, and draft regulation has been the major factor in reducing fuel consumption from 6,000,000 B.t.u. or more per ton of ingots in earlier years to the 3,000,000 to 4,000,000 B.t.u. characteristic of present practice. The Isley system of draft control is novel in that two Venturi stacks are employed instead of the customary single one, each stack being at the end of the opposite flue system.

Refractories

All early American furnaces were operated with an acid hearth until 1886, when magnesite was introduced for hearth construction by the Otis Steel Co. Silica brick originally were produced in Akron, Ohio, about 1866 from quartz pebbles and Sharon conglomerate with a lime bond.[41] It is interesting to note that after 80 years of production, and considerable research, lime is still considered the most satisfactory bonding agent.

The first magnesite brick made in this country were produced by the Fayette Manufacturing Co. at Layton, Pa., in 1895.[42] In 1913, N. E. MacCallum, of the Phoenix Iron Works, Phoenixville, Pa., found that magnesite brick could be bonded and sustained in a wall by the use of steel plates between the brick joints.[43]

Technologic Developments

Invariably it has been the history of the iron and steel industry that technologic developments have lagged behind mechanical and operating progress. Manufacture of steel ingots is no exception.

The development of improved blast-furnace control, assuring more uniform pig iron, combined with the installation of larger metal mixers, helped to counteract variation in one important phase of the charge, and this step alone made possible the assurance of more regular melting in the open hearth, with concurrent improvement in steelmaking practice.

In the transformation of the metallurgical control of the process, technologists and metallurgists have played a most important role. Among the earliest forward steps taken in the better understanding of the process was the work of McQuaid and Ehn on the deoxidation of killed steel and the relative response to heat-treatment in the finished product; the work of Herty on the physical chemistry of steelmaking, and others.

The development of rapid methods of chemical analysis has been attended by widespread application in the steel industry. The Carbometer,[44] Carbanalyzer,[45] and the Carbonmeter[46] have been developed for rapid carbon determination.

The application of the spectrograph for rapid determination of residual alloy contents of the bath is currently employed at many steel-producing plants.

In the field of temperature measurement of liquid steel, one of the most promising inventions is the Sosman-Sordahl[47] modification of the Collins-Oseland tube equipped with a photronic cell and necessary amplifying and recording instruments.

The basic open-hearth process today is by far the major steel-producing method in the United States, and represents a capacity in excess of 82,000,000 net tons. The acid process represents a little more than 1,500,000 net tons of capacity.

The use of oxygen to provide higher flame temperatures, combined with the all-basic type of furnace construction, is a development possessing important implications on future construction, design and operation of open-hearth furnaces. Developments in the field of special carbon and alloy steels permitted a vastly greater application of steel than formerly was possible.

While these represent but a few of the developments, they are indicative of the progress that has been made. The ability of the process to produce more than 8,500,000 net tons of alloy steel, or 65 per cent of the total alloy steel produced in the year 1943, is clear evidence of the great progress made in process metallurgy.

Nor can one overlook the great contributions made by technical societies over the many years where free discussion of mutual problems has contributed to the common welfare. Assuredly, the activities of the American Institute of Mining and Metallurgical Engineers have been important factors in this development, and one need look no further than the recent publication of the Institute's "Basic Open Hearth Steelmaking," by the Physical Chemistry of Steelmaking Committee, to realize the ever growing knowledge of the industry and visualize the form it will undoubtedly take in the future.

ELECTRIC FURNACE PROCESS

Electrometallurgical developments in steelmaking received early impetus from the first successful dynamos (1860–1870), which made possible a vastly greater source of power than formerly was available. Following the development of power sources, great effort was expended in developing the electric furnace, and in this effort all known basic principles of electric heating have been employed. These principles have been classified[48] as shown in Table 4.

From among the many types of electric furnaces developed, only two have found widespread commercial application in the United States. These are the direct-arc furnaces of the Héroult type, and the coreless induction furnace.

The Héroult furnace originally was used in the production of ferroalloys and subsequently was applied to steelmaking on a commercial scale in 1899, at the Héroult plant, La Praz, France.[49]

The high-frequency furnace was of American origin. It first appeared in 1917 in small units, for melting precious metals. Lack of carbon pickup and low melting loss of oxidizable alloys make it useful in the manufacture of low-carbon stainless ingots with high percentages of stainless scrap in the charge.

The first Héroult direct-arc furnace in this country[50] was installed in

TABLE 4—*Classification of Electric Furnaces for Making Steel According to Principles of Heating Employed*

- Resistance Furnaces
  - *Indirect*—The current is passed through a special resistor to generate heat, which is used to heat the charge by radiation and conduction. Such furnaces are used for heat-treating but not for melting steel.
  - *Direct*—The current passes through the material to be heated.
    - Using current from low-voltage transformers. Not successful for melting steel.
    - *Induction*
      - *Low-frequency*—using a core transformer with the bath forming the secondary circuit.
      - *High-frequency coreless induction*—Current of high frequency is passed through a coil surrounding a crucible containing the charge.
- Arc Furnaces
  - *Indirect or independent arc*—The bath is heated by an arc or arcs above it.
    - *Direct-current Arc*—not used.
    - *Alternating Current*
      - Single-phase—rolling furnace with horizontal electrodes.
      - Two-phase
        - straight arcs.
        - deflected arc.
      - Three-phase
        - straight arcs.
        - repel-arc.
      - Furnaces may be stationary, oscillating, or rolling.
  - *Direct arc*—The current arcs from electrode to bath.
    - *Series Arc.* Current arcs from one electrode to the bath, passes through the bath, and arcs to another electrode.
      - Single-phase.
      - Two-phase.
      - Three-phase.
    - *Single Arc* Current arcs from one electrode to the bath, passes through the bath, and out through an electrode in the bottom of the furnace.
      - Single-phase.
      - Two-phase.
      - Three-phase.
  - *Combination arc and resistance*—These furnaces make use of the arc and the resistance of refractory bottom material for heating the charge, and are wired to operate with the top electrodes only until the bottom is hot enough to become conducting.
    - Two-phase
    - Three-phase

1906 by the Holcomb Steel Co., Syracuse, N. Y. It was a single-phase, two-electrode, rectangular furnace of 4 tons capacity.

The first large-scale installation of electric-furnace facilities was made at South Works of the Illinois Steel Co. in 1909–1910. These furnaces were of 15 tons capacity, then the largest in the world. The number of furnaces operating in the United States increased to 19 in 1913, 41 in 1915, and 136 in 1917. The demand for alloy-steel ingots and castings during the first World War greatly accelerated expansion, and by 1918 there were 282 furnaces operating, with an annual capacity of 510,000 tons.[51] The electric furnace superseded the crucible as a major producing process within a period of about 15 years. Table 5 shows the progressive decline of crucible steel and the increase of electric-furnace steel from 1915 to 1930.

TABLE 5—*Comparison of Crucible and Electric Steel Production, 1915–1930*

Year	Production of Crucible Steel, Net Tons	Production of Electric-furnace Steel, Net Tons
1915	127,436	79,452
1920	80,937	566,370
1925	21,910	689,373
1930	2,523	686,111

Between World Wars I and II, there was slow but continuous growth in capacity, and the arc furnace was brought to its present state of development. Among the many advances made during this period was the rapid growth of furnace size coupled with mechanical and electrical improvements, which permitted faster charging, better regulation of the power input, and improved melting technique.

In 1918, electric-arc furnaces larger than 6 tons capacity were exceptional. As shown by Arnold,[52] these were equipped with a shell 11 feet 0 inches in diameter, tilted forward only, and were arranged for hand charging. Power was supplied by a 1500-kilovolt-ampere transformer with only a single secondary voltage lead. Today the standard type-70, three-phase, three-electrode Héroult furnace has a holding capacity of 90 tons, is arranged for mechanical charging, and tilts either forward or backward. It is equipped with a 15,000-kilovolt-ampere transformer providing wide range of secondary voltages, important to efficient melting and refining operations. The production rate of this furnace is 6000 to 7000 tons of alloy ingots per month, or as much as many 100-ton open-hearth furnaces. These and similar units today represent approximately 70 per cent of the total electric-furnace ingotmaking capacity of the United States. Fig 12 shows the design of a type 70 Héroult electric furnace installed at a Pittsburgh plant during 1943. The largest Héroult

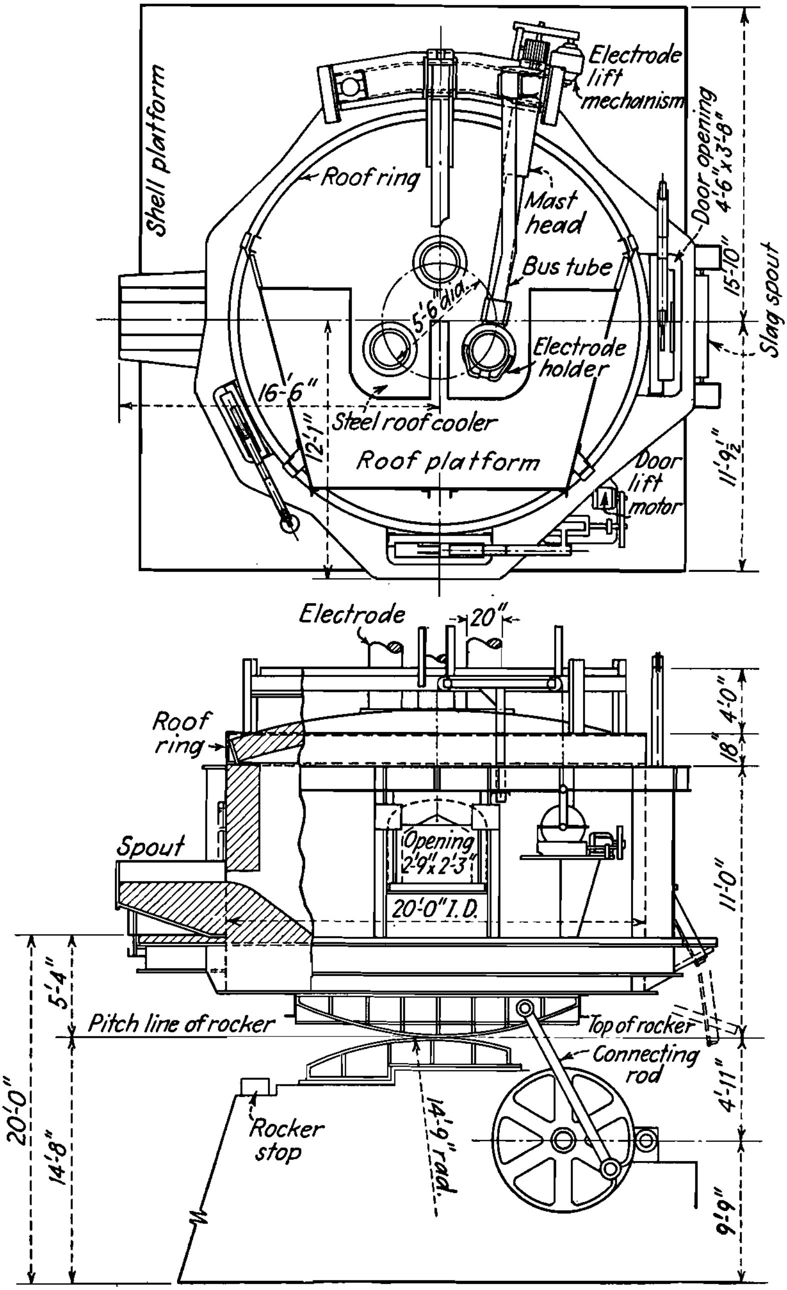

FIG. 12—*Standard type 70 Héroult furnace.*

electric furnace in the world is a 125-ton unit built by the American Bridge Co., first installed in this country in 1927.

To further expedite charging and to effect reductions in heat time and power consumption, the duplex practice is used at a number of large plants employing open-hearth or bessemer facilities. The duplex practice promises to enhance the competitive position of the electric furnace for many types of product.

Reagan[63] has shown that the top-charged electric furnaces, with swinging roof, of the Copperweld Steel Co., with a shell diameter of 16 to 17 feet and charging capacities of 85,000 to 110,000 pounds, normally produce 8 to 12 tons per hour on a cold charge. This rate was increased to 20 or 25 tons per hour by employing a triplex process involving the use of cupolas for remelting cold materials, acid bessemer converters, and electric furnaces. Coincident with the increased production rates obtainable with the liquid process, power consumption was reduced from about 520 kilowatt-hours per ton with the cold charge to 195 kilowatt-hours per ton. Various types of steels, including aircraft grades, were made by the triplex process, with uniformly good results.

Another example of liquid metal charges, described by Ess[64] is a tilting open-hearth furnace and electric-furnace combination employed by Republic Steel Corporation at South Chicago. This plant operates four tilting open-hearth furnaces with high pig-iron charges, and is capable of supplying about 1600 tons of molten steel per day to nine large electric furnaces. The charging capacity of the latter varies from 80 to 90 tons each, with a total rated annual capacity of 750,000 tons of electric-furnace ingots.

The many electric furnaces built during the war period enabled capacity to reach its all-time high. In April 1940, there were 430 electric furnaces engaged in melting iron and steel with a capacity of 1,882,630 net tons;* by January 1946, this number had increased to 784, with a capacity of 5,500,290 net tons.*

The quality of the product of 70 to 90-ton furnaces has been found as high as that obtained from 10 to 25-ton units in general use before the war.

The combination of larger furnaces, faster melting practices and the use of molten metal in the charge promises to increase the productive capacity of electric furnaces per unit to an extent that offers some interesting competitive possibilities with open-hearth steel in the large field of steels for which both are well suited.

Industrial Welfare

Modern training programs in prevention of accidents, and the widespread application of safety devices, together with the elimination of hazards through

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* The figures shown include only that portion of the steel casting production that was produced in foundries operated by companies producing steel ingots.

improved equipment, design, and operating techniques, have placed steel among the industries whose plants are safer than the street and the home, and the United States Steel Corporation's experience along these lines may prove interesting.

One of the first safety campaigns in this country was undertaken by the H. C. Frick Coke Co., now a subsidiary of United States Steel, as early as June 1890. The application of organized safety in the industry is believed to have originated at the South and Joliet Works, Illinois Steel Co., which as early as 1905 posted bulletin boards in all conspicuous working areas with the now universal slogan "Safety First." To prevent accidents, a coordinated program was initiated, involving the casualty managers of all U. S. Steel Corporation subsidiaries. The first meeting was held in 1906.

From these beginnings a permanent Corporation Safety Committee was developed, now known as the Safety Advisory Committee, and the early years of this group were devoted to the installation of safety equipment to protect the workmen. Further analysis of accident cases revealed that unsafe practices accounted for approximately 90 per cent of the accidents then occurring. With emphasis on this and with increased education of workmen, accident frequencies moved steadily downward.

The greatly improved working conditions in the industry have helped materially; for instance, the present 8-hour day, replacing the arduous and much longer shifts, and the even more onerous 24-hour shifts on alternate weeks, characteristic of the early years of the industry. Greatly improved facilities for the convenience of the workmen are now provided, and are taken as a matter of course, and adequate hospitalization and medical care is furnished with only one consideration in mind, the welfare of the employee.

Conclusion

The exceptionally high living standard of this nation, the envy of the world, is due in no small part to our iron and steel industry.

The growth of transportation, with its need for rails, railroad cars, locomotives, ships, bridges, trucks, highways, all in turn created new outlets and were followed by further demands by growing America for more and more steel, with each new industrial activity leaving its indelible mark on steel. The development of the automobile and its subsequent growth forced upon the steel world the need for improved uniformity of its products and applicability to the multitudinous requirements of the automotive industry. The canning and container industries have similarly forced the development of metallurgical practices and rolling facilities to meet their ever increasing and exacting needs. In like manner, conveyance of gas and oil through endless pipe lines caused a revolution in steelmaking practices and mill design, the gigantic present-day seamless and electric welding pipe units owing their very existence to this development.

Perhaps in no other activity of iron and steel is the mechanical genius, the metallurgical knowledge, and the ingenuity of management so clearly evidenced as in the rolling processes from ingot to finished products. The growth of mills for making continuous strip and cold-reduced sheet originates from the insistent demands for products in quantity and quality satisfactory to the consumer. The impact of new industries, the growth of cities, America itself, is clearly reflected in the rolling mills of today devoted to the manufacture of structural shapes, bars, wire and wire products, plates, rails, sheets and pipe—a list almost without end. Modern mills are eloquent testimonials to the qualities that have made industrial America great.

Young men in the industry may complain about its apparent lethargy to process and other changes, but an industrial activity that twice has saved the world from disaster, and in 1945 involved an investment of approximately $4,500,000,000, with employees numbering almost 800,000, requires no apology. Management today is no less aware of the need for progressive methods and equipment, but the infinitely higher cost of replacement and the meager financial returns do not allow for the gambling spirit bordering on recklessness that always accompanies lush rewards in a new industry. The law of diminishing returns grinds remorselessly in a fully matured and stabilized business, and the fantastic rewards that deservedly belong to the pioneers are inevitably replaced by a mere and sometimes precarious living for their followers.

Acknowledgments

When the Secretary of the Institute, Mr. A. B. Parsons, asked me to prepare a paper on iron and steel, whose history parallels that of this distinguished society, I was greatly honored. Nevertheless, my own business activities made it difficult if not impossible to accede to the request and I advised him accordingly. However, his persuasion would not be denied and finally I was prevailed upon to undertake the task, a concession I made with some misgivings. My only possible recourse was to impose inordinately upon my associates, and in that respect no author has been more fortunate. By their painstaking researches, and their cooperation, they alone have made this presentation possible. To them I gladly acknowledge my indebtedness—to Francis M. Becker for his work on coal and coke; to Carl G. Hogberg, on the production of iron; and to Charles E. Williams, on steelmaking processes. I also take this opportunity to convey my appreciation to my friends in the industry for their invaluable assistance.

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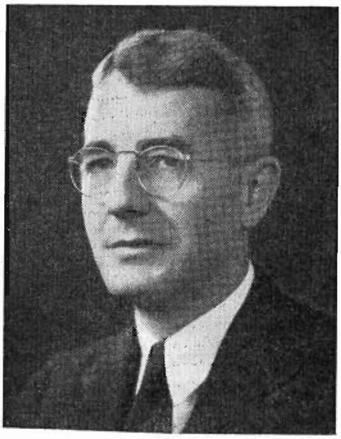
Seventy-five Years of Progress in Nonferrous Metallurgy

By W. M. Peirce

On May 16, 1871, twenty-two men met in Wilkes-Barre, Pennsylvania, and founded the American Institute of Mining Engineers.* If we could transport ourselves back to that year and survey the state of science and technology in general, and, in particular, the field of our immediate interest—nonferrous metals—we would feel a justifiable pride in what had been accomplished up to that time.

These accomplishments in the metal field were at the moment in the process of documentation by an Englishman, J. A. Phillips, in a new 700-page edition of his book to be published in 1874 under the title of "Elements of Metallurgy." True, looking over his shoulder, we would smile to read that "all metals are capable of assuming a crystalline form under favorable conditions," and that tensile testing is done "by adding weights to a firmly suspended wire until it fractures," and we would find only three pages on aluminum and none on magnesium. We would, however, find an astonishing wealth of detailed knowledge on iron and steel and the then common nonferrous metals and alloys such as brass and bronze.



W. M. PEIRCE

Outstanding among administrators of research in metals and metallurgy, W. M. Peirce has spent this entire professional career with the New Jersey Zinc Company at Palmerton. Starting as a research investigator in 1920, he advanced to "Chief"; and during the interval did much to build up a highly efficient research organization. He is the author of many significant papers and served two terms as Director and as Vice President of the A.I.M.E.

But if we possessed a little prophetic vision as we directed our attention to the short period that had elapsed since the close of the Civil War, we

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* In 1919 the name was changed to American Institute of Mining and Metallurgical Engineers.

would see significant stirrings of new progress in many fields. In the field of transportation, Westinghouse had invented the revolutionary air brake. Foreshadowing an as yet unheard of type of transport, the first of the major rubber companies had been founded. The petroleum industry, reaching the tenth year of its existence, had introduced a new fuel, which was to provide the motive power for both automotive and aerial travel. In the field of metal fabrication, Mushet had made the first high-speed steel; Weems had invented inverted extrusion and a new type of metal container, the collapsible tube, had been introduced into the United States.

In the field of mining, the diamond drill had been put into practical use and dynamite and smokeless powder were being commercially introduced. The stamp mill was making possible the recovery of gold from new ores in California. The Missouri lead belt had been consolidated under one control and the Tri-State lead district had been opened, bringing our production of lead to 40,000 tons out of a world total of 300,000 tons. The zinc industry, a lusty infant of 4,500 tons in a world producing 130,000 tons, had tapped the major ore reserves east of the Rockies, and in the Saucon Valley, south of Bethlehem, had built the world's largest pumping engine to dewater the Friedensville zinc mine. The Lake Superior copper mines had brought the United States production of copper to 120,000 tons, nearly 10 per cent of the world's total; yet even this tonnage was becoming insufficient for the growing needs of industry, and the shift of the center of copper production to the west was already discernible.

More significant than all of these perhaps were the stirrings of the electrical industry building on the scientific discoveries of the previous generation. In Europe the first practical electrical generator had been built and applied to arc lighting the year before the founding of the Institute; and that very winter at the Mechanics Institute Fair, Issac Adams, of Boston, had demonstrated a practical nickel-plating process. That a spirit of progress bordering on the reckless was in the air is attested by the report that a banker visiting the Fair bought a newly designed base-burning stove with mica lights and paid $100 to have it nickel-plated by Adams before installing it in his bank.

In this atmosphere, it was not surprising but inevitable that men of imagination in the field of metals should found a society to aid in keeping the art, science, and technology of mining and metallurgy in step with the accelerating pace of progress.

Metallurgical Development Interwoven with All Progress

As we turn from this brief glance at things as they were in 1871 to our examination of the ensuing 75 years, we must not lose sight of how inextricably the course of metallurgical development is interwoven with progress on every front of science and industry.

The electrical industry, which has played perhaps the most startling role of this 75 years, was, of course, destined to become not only the powerful servant of the metallurgical industry but also its greatest customer for copper and lead, and a major customer for practically all of the other metals.

Similarly, in the transportation industry, first railroad and later automotive transportation were to become the arteries of our whole industrial organism and also the principal customer for steel and for the nonferrous metals used in bearings. Later in the period, airborne transportation was to become a principal outlet for the light metals, aluminum and magnesium, and was to place new and exacting demands on other metals. As servant to metallurgy, aviation was to make one of its most vital peacetime contributions in aiding the development of remote and inaccessible mining territories.

The petroleum industry and the hydroelectric industry, as new sources of power, were likewise to become servants and customers, while the rubber and chemical industries, a little less directly but nonetheless surely, were to share this mutual relationship with the growing metallurgical industry.

Decades of Progress

Before we embark upon a discussion of the separate events in the history of nonferrous metallurgy since 1871, it may help to provide a background and perspective in which to view these industrial developments if we quickly outline decade by decade the principal milestones both in nonferrous metallurgy and in other parts of the industrial structure. In this bird's-eye survey, the writer will doubtless overlook many events that were significant, and may include some that to others seem insignificant, but it is hoped that this will not detract from the purpose of providing a broad chronological background.

The beginnings of the tide of industrial progress that had begun to appear following the Civil War gained momentum in the '70s. The arc light made its appearance in this country and Edison publicly demonstrated the first incandescent light. One of the major zinc-producing fields of the United States was opened when the first Joplin ore went to the Matthiessen and Hegeler smelter at LaSalle, Illinois. Two other events are worth noting, though they seem of lesser immediate significance. The first serious study of chromium steels was initiated; and in England Whittley was laying the groundwork for centrifugal casting.

As we move into the '80s, the first central power station was put into operation to supply electric light in New York City, marking the beginning of the rapid growth of the electrical industry. This was followed quickly by the first alternating current system and the first practical traction system.

Of equal significance were the operation of the first successful steam turbine and Siemens' invention of the open-hearth steel process.

Thompson's invention of the resistance method of arc welding brought together electrical and metallurgical technology, while in another phase of metal fabrication the Bethlehem Iron Works introduced into this country the first forging press, vastly extending the size of forgings beyond that possible with steam hammers, which were approaching their limit.

Again combining electrical and metallurgical science, we see in the '80s the beginning of a revolutionary series of changes associated with the electrolytic reduction and refining and the electric-furnace reduction and melting of metals. Practically simultaneously in this country and in France, Hall and Héroult produced aluminum by fused salt electrolysis, and in Germany the first magnesium was produced in a similar manner. Curiously enough, the electrolytic production of sodium, which greatly reduced its cost, occurred almost at the same time that the electrolytic reduction of aluminum started. The major market for sodium, which had been the reduction of aluminum ores, thus disappeared at the same time that the cost of sodium was radically reduced.

From this time on, it would be hard to say which has received the greater impetus from the other—the metallurgical industry from the demands of the electrical industry for metals to meet new and exacting conditions, or the electrical industry from the metallurgical industry by demands for electrolytic plants, electrical furnaces, electrically driven metal-working machinery, such as rolling mills, and electrical welding equipment.

We cannot leave the '80s without noting the discovery of the Frood mine in Canada, which was destined to supply this country with nickel for untold generations.

During the '90s the expansion of the electrometallurgical and electrochemical industries gained momentum, aided greatly by the development of the first major hydroelectric power sources at Niagara Falls. An old metal, antimony, was produced by electrolysis and a new metal, beryllium, was so produced for the first time, while the electric furnace yielded a new metal of commerce, molybdenum. Meanwhile, in Germany the serious development of magnesium alloys, which were to become known as the "electron alloys," had started. One of the early products of the electrochemical industry was calcium carbide, which provided the basis for acetylene welding, which was to appear 10 years later. Another event impinging strongly on industry was the exploitation by Taylor and White of the high-tungsten, high-speed cutting steels.

Important events occurred in other fields. The railroads introduced steel freight cars. The Wilfley table for concentrating ore was invented and, perhaps most significant of all, at the end of the year 1895, as the bicycle era was approaching maturity, four automobiles had been built!

The Twentieth Century

During the first decade of the twentieth century a number of notable metallurgical events occurred. The investigation of chromium steels, which had started in the '70s, came to fruition as these steels became of major commercial importance. The electrolytic refining of lead and the utilization through flotation of low-grade copper ores to tremendously augment the potential supply of copper were notable events in the history of two of the older major nonferrous metals. The flotation process was destined within another generation to effect the recovery not only of copper but of most of the nonferrous metals, and to place in the category of ore reserves many previously uneconomical mineral deposits. In the field of new metals the discovery of the Peruvian vanadium mines removed this element from the category of rare metals and added it to the family of important alloying metals for steel. Cobalt also appeared as a metal of commerce.

While sulphur is not a metal, and sulphuric acid is strictly a chemical, metallurgy would be at a loss to function without sulphuric acid, therefore the opening in 1900 of the Texas sulphur deposits, which were to make this country self-sufficient in sulphur and sulphuric acid, and the introduction in the same year of the contact sulphuric acid process in this country, were major events in our industrial and, hence, metallurgical development.

During the second decade of the twentieth century, which saw the First World War, the United States experienced its first urgent demand for magnesium and was at the same time shut off from Germany, its previous sole source of supply. The inevitable result was the birth of the magnesium industry in this country, with the development of the Michigan brines as a source of raw material. Lithium appeared in its first and one of its few commercial applications as a metal when it was used as an addition alloyage in aluminum. Steel passenger cars appeared and the fabrication of nonferrous metals by die forging became important. In the chemical field, the commercial fixation of nitrogen was an important milestone.

It was during this decade that the science of metallography, using the term in a broad sense to include X-ray diffraction and tools other than the microscope and thermal analysis, assumed major importance in the rapid development of metallurgy, and this decade saw a metallurgical milestone in the work of Merica and his associates on the theory of age-hardening. The fascinating story of progress in the field of theoretical physical metallurgy will be found in a separate paper.

During the '20s, aviation, which in the previous dozen years had passed through its early stages of development, became an established means of transportation and provided incentives for metallurgical progress in many directions, particularly in the light metals and alloy steels. In the aluminum field, a new refining process made commercially available a much purer grade of aluminum. Similarly, notable improvements in the methods for removing impurities from lead occurred, while two methods—one electrolytic and the other a distillation method—were perfected for producing zinc of a new degree of purity. These purer metals led to important advances in the alloying and fabrication of these metals. The development of the die-casting industry, the hot-rolling of brass and the continuous rolling mill for steel sheets were other important metallurgical events. A very old method of fabrication, powder metallurgy, found fields of application so new as to make it in effect a new industry. One of these was the production of cemented carbide cutting tools, which were destined shortly to have an effect as great as the introduction of high-speed steel.

During this same decade there was greater activity in the field of electrolytic protective coatings for steel. Chromium and cadmium plating were commercialized, while zinc plating or electrogalvanizing assumed new importance owing to radical process improvements.

Indium and beryllium found practical use for the first time in small but uniquely important applications.

The War Years

The last full decade of the past 75 years, the '30s, marked the beginning of the real competition between the use of light metals and of high-strength steels for the fabrication of light structures. Plastics offering even greater lightness, and needing no supplementary finish, essayed to compete with metals, succeeding here and there but for the most part supplementing metals or finding appropriate applications in new products. During the '30s, another event of considerable importance to our industrial structure occurred. The center of world platinum production shifted to Canada, thereby assuring our supply of this vital metal in the Second World War which followed.

During the '30s, in the laboratories of a handful of physicists, the secrets of the atomic nucleus were being fathomed, to provide in the closing years of our period the climax to a war in which every scrap of metallurgical skill had been exploited to the utmost. The production and utilization of the light metals, the carbides and the strong heat-resistant alloys, on a scale colossal by any previous standard, highlight these years of unprecedented achievement in all branches of technology.

The Individual Metals

Considering now the individual items of progress in the field of nonferrous metallurgy, we can perhaps do no better than shift from a chronological to an alphabetical sequence. As we proceed, the reader will encounter more detailed discussion of a number of things that have been mentioned as major events in the chronology we have just left.

ALUMINUM

Oersted first produced aluminum in 1825 by the reduction of aluminum chloride with potassium amalgam. Wöhler, in 1827 and 1845, made very small amounts of aluminum, using sodium. Later, St. Claire-Deville, using the double chloride of sodium and aluminum and metallic sodium as a reducing agent, made the first commercial production of the metal. When, however, the price had been reduced to $8.00 a pound, there were but limited applications. In 1886, Hall in this country and Héroult in France both succeeded in producing aluminum by the electrolytic reduction of aluminum oxide dissolved in molten cryolite, and in 1888 the Pittsburgh Reduction Company, now Aluminum Company of America, made the first commercial aluminum by this process.

Bauxite has proved the most economical source of the pure alumina necessary for the Hall-Héroult process. Bauxite is refined by the Bayer process by treating the ore with sodium hydroxide solution under pressure to put the alumina into solution as sodium aluminate. The red mud residue, containing the oxides of iron, silicon and titanium from the bauxite, is separated and aluminum hydroxide is precipitated from the solution by cooling and seeding. The hydroxide is calcined to produce the alumina fed to the electrolytic cells. Carbon anodes of high purity are required, almost pound for pound, in producing aluminum, and high-grade cryolite, either natural or artificial, is necessary for the operation of the process. Over the years, increases in the size of the cells and refinement of design and operating details have led to lower costs and the production of purer metal. At the present time cells taking 40,000 amperes are commercially employed.

Even at the relatively low prices made possible by the introduction of the Hall process, aluminum was not in great demand, since it was a new metal, little known to metal workers. Its history has been characterized by intensive research to develop new alloys and new fabricated products and by a commercial search for markets. Prior to World War I, the industry supplied commercially pure aluminum, and the alloy 3S in wrought form with an upper limit in tensile strength of about 30,000 pounds per square inch. The development of strong aluminum alloys was initiated by Wilm's discovery in

1909 that certain aluminum-copper alloys could be hardened by heating and quenching, and by his later discovery that the addition of magnesium conferred age-hardening properties on the alloy. The first successful alloy of this type was named duralumin. Research in this field was accelerated by Merica and his co-workers in 1919, when they advanced a working theory to explain the phenomena observed during heat-treatment. The utilization of the strong alloys was given impetus by Dix's development of cladding the strong aluminum alloys with pure aluminum to give them adequate resistance to corrosive environments. In the middle '20s, Hoopes developed a method of electrolytically refining aluminum, using a fused salt electrolyte, which for the first time made available aluminum having a purity as high as 99.99 per cent.

In the last 25 years a variety of alloys have been developed, which give a range of tensile strengths up to 80,000 pounds per square inch, and which have greatly extended the fields of application of aluminum, particularly those uses where structural strength is a necessity. During this period there have been corresponding increases in the sizes in which sheet, bar, extruded and rolled shapes can be obtained. This has been made possible by improvements in the casting of ingots for rolling, forging and extrusion. In 1920 the limit on ingots for working was several hundred pounds; now, aluminum-alloy ingots weighing up to 4000 pounds or larger are made.

Lightness, corrosion resistance, moderate volume cost, availability in a wide variety of rolled, drawn, extruded and cast forms, plus good fabricating qualities, have extended the use of aluminum into a wide variety of fields. In construction of airplanes, railway and automotive vehicles, lightness is at a premium, of course. In a quite different direction, the lightness of aluminum has been used to increase the carrying capacity of bridges by substituting aluminum deck structures for steel. Architectural trim, windows, spandrels, sheet roofing and siding are fields that are being exploited on the basis of resistance to atmospheric corrosion. The high electrical conductivity of aluminum has made it competitive with copper as an electrical conductor, particularly for power transmission lines. The combination of good drawing properties with good heat conductivity and corrosion resistance has led to extensive use in cooking utensils. Screw-machine parts and many other applications, too numerous to list, further evidence the versatility of this relatively new metal.

During this 75 years, aluminum has emerged from the laboratory to become second of the nonferrous metals in tonnage and first in volume, and its cost in ingot form has been reduced to 15 cents per pound, at which level its volume cost is lower than that of most other metals.

We will conclude this brief review of aluminum by recalling the prediction penned by Roberts-Austen in 1902: "We can readily imagine the use to which engineers will put aluminum in aerial navigation, from which so much is expected in the immediate future." We doubt whether the most sanguine imagination did justice to the reality.

ARSENIC, ANTIMONY AND BISMUTH

Arsenic, antimony, and bismuth are long-known minor metals with enough in common to warrant discussing them together. All are deficient in properties that are most useful in metals, strength, workability, and conductivity. As metals, their use is confined to small alloyage additions to other metals, while half or more of the tonnage produced appears as chemicals for various uses. As metal, arsenic finds some use in solder to replace a fraction of the tin, antimony hardens lead and improves its properties for use in storage-battery cable sheath and type metal, and bismuth, because it expands on freezing and has a very low melting point, is useful in formulating alloys for making patterns, fusible plugs, and other objects.

BARIUM, BERYLLIUM AND CADMIUM

Barium is used in metallic form for its chemical properties as a getter in vacuum tubes.

Beryllium falls next. It is among the last comers to the family of commercial nonferrous metals, a commercial method of production by electrolysis of the double fluorides not having been discovered until 1921. Beryllium unfortunately is one of the rarer metals in the earth's crust and the supply is almost certainly destined to be a small one. In spite of this, and because of the potency of a mere 2 or 3 per cent of beryllium in copper, it promises to play an important useful role. The effect of beryllium in copper is to harden and strengthen it greatly, increasing its fatigue strength in particular, and doing this without destroying the corrosion resistance that makes copper so unique and valuable for many applications. Interesting, but so far commercially obscure, alloys with other metals have been reported.

Cadmium, another of the metals apparently destined to remain scarce like beryllium, has found valuable applications where small amounts can be highly useful. Like beryllium, though to a lesser degree, cadmium hardens copper. The unique feature of the cadmium alloys is that the high electrical conductivity of copper is harmed less than by other hardening and strengthening additions. Thus, a strong wire with high conductivity, valuable for such applications as trolley wire, can be produced. Certain cadmium alloys have also proved useful in bearings but perhaps the dominant use of cadmium will continue to be as a plated coating on steel. Such coatings afford good corrosion protection in mild atmospheres and are themselves attractive and resistant to tarnishing.

CALCIUM AND RARE EARTH METALS

Calcium is a metal interesting because of its chemical rather than its metallic character. As a scavenger and in the form of the hydride as a hydrogen carrier it has found important use. Small additions to lead yield age-hardenable alloys.

Cerium and thorium and their associated rare earth metals became important in the '80s through the discovery of the Welsbach mantle for gas lamps, which owes its properties to the oxides of these metals. Later, the oxide of thorium was used by Jeffries to inhibit grain growth in tungsten and make possible ductile tungsten. An alloy of the metal cerium with related metals, known as Misch metal or cerium master alloy, was discovered to have pyrophoric properties, and its use in lighters is a household commonplace. Thorium is a vital constituent of vacuum-tube filaments to facilitate electron emission.

CHROMIUM, COBALT AND COLUMBIUM

Chromium is a nonferrous metal whose commercial history is confined to the present century and whose history is linked largely to that of steel. Chromium is unique for its resistance to corrosion and since the '20s, when methods were developed for electroplating it on other metals, it has been in great demand, to some extent as a protective but mainly as a decorative coating for steel and for nonferrous metals. It is usually applied over heavier coatings of copper and nickel, which provide the major underlying protection of the steel. Chromium is a sufficiently plentiful metal so that substantial amounts can be added to steel to give it much of the corrosion-resistant character of chromium. The well-known 18 per cent chromium, 8 per cent nickel steel is an example. Such steels do not rust readily and when polished have great resistance to tarnishing. Perhaps even more important, they combine this corrosion resistance with great strength at elevated temperatures as well as at ordinary temperatures. At these elevated temperatures, they are resistant to oxidation in many atmospheres and have notably extended the range of temperatures at which engineers designing high-temperature equipment can work.

Cobalt, which has appeared on the horizon of practical metallurgy since 1910, has some characteristics in common with chromium. There are fair supplies available and, to an even greater extent than chromium, cobalt imparts high-temperature strength and oxidation resistance to steel. Alloyed cobalt and chromium form the basis for the complex alloys known as the Stellites, which are extremely hard and highly heat-resistant. Certain of the improved magnet steels, which are important to various phases of present-day electrical engineering, owe their properties to cobalt in various combinations. One other unique use of cobalt depends on the fact that cobalt powder, itself resistant to high temperatures, provides a suitable tough binder for cementing together the tungsten carbide and other carbides that today provide industry with tools approaching the hardness of the diamond.

Columbium, a rare metal, has played an important role in the chrome-nickel steels to stabilize the austenite and make these steels stable at high temperature.

COPPER

The copper industry, as we have earlier implied, has developed hand in hand with the electrical industry. Purity, which is necessary both for easy fabrication and for good electrical properties, has been a goal of the copper industry longer perhaps than for any other metal. Fire refining methods were highly developed but today electrolytic refining, coupled with methods for producing oxygen-free, high-conductivity copper by controlled-atmosphere melting and casting, dominate the picture.

Two groups of copper alloys, the bronzes and the brasses, were the predominant nonferrous alloys in 1871, a position they had held for centuries. At that time, a bronze was specifically a copper-tin alloy and brass a copper-zinc alloy. During the past 75 years, the advent of new metals which could be alloyed with copper, and the changing technical and economic demands, have resulted in many new copper-base alloys that have come to be referred to as bronzes, even though they contain no tin. Thus, aluminum bronzes and silicon bronzes may contain no tin; beryllium copper, chromium copper, cadmium copper and tellurium copper are classified with the bronzes; phosphor bronze contains tin; and manganese copper is in reality a high-zinc brass containing manganese. By alloying nickel with copper, the cupro-nickels and nickel silvers have been developed. Each of these alloy types may embrace a considerable range of composition and today the copper-base alloys include a very large number of individual compositions tailored to meet a specific need. A familiar example of the evolution of a specific composition for a particular purpose is the development of high-ductility cartridge brass through the use of very pure metals and very careful alloying practice.

The development of modern repeating firearms has been utterly dependent upon material from which to make the cartridge case and, even under the stress of military demands, the most intensive and extensive research has found no substitute material as universally acceptable as brass. The perfection of cartridge brass, the methods of fabricating it and of protecting it against such weaknesses as stress corrosion has constituted one of the major branches of nonferrous metallurgy during the period under consideration.

Originally, the cartridge brasses, which contain in the neighborhood of 70 per cent copper, were cold-rolled with frequent annealing to avoid overworking. The brasses containing less than 60 per cent copper, known as the Muntz metals, were found amenable to hot-rolling or extrusion, and this constituted one economic factor in their favor. One of the far-reaching changes in metallurgical practice in recent years has been the discovery that the cartridge brasses, when free from lead to the degree made possible by modern metals of high purity, can also be hot-rolled. The art of hot-rolling, which was developed as a result of this discovery, has vitally affected the brass industry.

While it is difficult to single out alloys, brief attention may be called to three. First, there is the fairly recent development of copper alloys hardened with nickel silicide. Second, there is the somewhat older 80 per cent copper, 20 per cent nickel alloy, the standard of high-strength, white, corrosion-resistant nonferrous alloys, with many modifications utilizing chiefly zinc as the third alloying constituent to produce the well-known nickel silvers. Finally may be mentioned the so-called silicon bronzes, such as the Everdur-type alloy, usually containing, in addition to silicon, manganese and other metals in small amounts. These were developed for resistance to sea water and are applicable in such fields as condenser tubes.

GOLD

We come now to the oldest metal, gold. While little has been added to the technology of the utilization of gold, which is one of the oldest of the arts, the production of gold has undergone important developments. Amalgamation reaching the zenith of its development early in the period has been largely superseded by cyanidation, which has undergone a long process of development. A corollary to this has been the application of modern ore-dressing methods to remove impurities that prevent the recovery of gold by cyanidation.

INDIUM

Another of the scarce metals, indium, was discovered in 1863 and remained a laboratory curiosity until 1923. Since then, through the discovery of ores carrying higher percentages of indium as an impurity, and the more effective recovery of indium during the processing of such ores, the supply of indium has become appreciable and it has found uses of some significance in dental alloys, nontarnishing silver, and in some special automotive bearings.

LEAD

We come next to one of the oldest of the metals, lead. Easily reduced from its ore, it is soft, weak and low melting but highly resistant to corrosion by most of the troublesome corroding media with which the users of metal have to deal, and is possessed also of certain unique chemical properties. Uses based on this strange assortment of properties have made lead vital at a variety of points in our modern life, with the result that attention today is sharply focused on the inadequate supply of this metal. The electrical industry, and more particularly telephone systems, have difficulty in finding a satisfactory substitute for lead as a protective sheathing for their delicate and moisture-sensitive cables. In connection with this use, metallurgists have substantially improved the fatigue and creep strength of lead by developing dispersion-hardened alloys employing antimony or calcium as the principal alloyage. The internal-combustion engines that power our automotive and aerial transportation are lifeless without lead storage batteries. Our chemical industries handle many of their corrosive products in lead-lined equipment or through lead pipe. Lead is a major component in the solders that complete our electrical circuits at a thousand points and seal the radiators of our automobiles. Competing against these users for the available supply are the users of the chemical compounds of lead in paint, tetraethyl lead and elsewhere.

The history of the progress of lead, aside from the electrolytic and other ingenious metallurgical processes for improving its purity, is therefore accented by the search for new supplies and the improvement of ore-dressing methods to increase the recovery of lead from its ores.

LITHIUM

Lithium has been mentioned as an alloyage in aluminum. It has also found a role in metallurgy as a scavenger for other metals.

MAGNESIUM

The magnesium industry, whose kaleidoscopic career during the past dozen years has at times mixed science with politics, started in 1863 with the production of magnesium flashlight powder, using sodium as a reducing agent. A Boston plant operating this process during the period up to 1892 constituted our magnesium industry. It was in 1886 that the first electrolytic production of magnesium was undertaken near Bremen and 10 years later the intensive development of the electron alloys began also in Germany. In 1914, our supply of German magnesium, for which we had been paying $5.00 a pound, was shut off and between then and 1918 General Electric, followed by four other companies, went into the production of magnesium, producing during that period 140 tons. In 1916, Dow started the development of a magnesium process based on the Michigan brines, producing its first magnesium on July 20 of that year, using the sal ammoniac process for making anhydrous magnesium chloride and an electrolyte of magnesium chloride-sodium chloride and fluorspar. Meantime, the American Magnesium Corporation was working with a magnesium oxide-magnesium fluoride electrolyte at Niagara Falls.

Much of the progress from that time has hinged around the economical production of the anhydrous chloride, the design of suitable cells, and learning by experience the safety precautions necessary for the handling of magsium through the various stages from the production of a molten metal to the completion of the machined and finished part.

During the '20s, the price of magnesium was reduced to 69 cents a pound, but the domestic market lagged and during the early '30s the export market was a major factor to our magnesium industry. In 1935, our export sales reached 1000 tons but during the ensuing years export sales of planes stimulated our domestic market for magnesium. By 1940, the need for greater production as a national safeguard had become evident and the first sea-water plant, started in that year, went into operation in January 1941. During the war, even the tremendous expansion of sea-water capacity was deemed inadequate, and under Government subsidies other methods were commercialized, which promised either more rapid increase in productive capacity or the utilization of power at points where it would be better spared. The Hansgirg carbon reduction process was put into operation and two modifications of the ferrosilicon reduction process, one developed by Electro Metallurgical Corporation in this country and the other by Pidgeon in Canada, were put into commercial production.

Everything that is known about the metal magnesium and its uses as a structural material is a product of our 75 years. All of this has received such vast publicity during the last few years that repetition seems superfluous. Under the stimulus of wartime need for light alloys for plane construction, magnesium alloys have been fabricated into landing gear, fuel tanks, instrument panels and various engine parts. The counterparts of these applications in peacetime products are being developed and are beginning to appear on the market.

We have a tremendous capacity for producing this metal, which is one third lighter than aluminum, has a low elastic modulus but can be alloyed to give useful mechanical properties, and can be fabricated by the common methods and machines unusually well. Means of protecting it against corrosion have been developed, and only a rash prophet would venture to tell us what markets will ultimately be captured by this light, low volume-cost metal flowing from inexhaustible sources of raw material.

MANGANESE

Manganese is a nonferrous metal whose principal importance up to now has been in the steel industry. In 1917, F. H. Willcox, of the U. S. Bureau of

Mines, stated before a meeting of the Institute that "the basis of modern steelmaking lies in the several functions of manganese when added to steel as a carburizer or deoxidizer," and Hadfield adds: "steel of commerce must contain 0.4 to 1.0 per cent manganese." The common ferromanganese was known prior to 1871 but the manganese steels originated in 1878, with the Ferra Nori Co., and were further developed in 1883 by Hadfield. Today the appearance of low-carbon manganese and ferromanganese has opened up new possibilities in the direction of low-carbon steels of higher manganese content.

This is an appropriate point at which to bring out the relation between steel production and the use of the principal nonferrous alloyages used in steel. The figures for 1944 are:

	Tons
Steel production	90,000,000
Manganese required	600,000
Silicon required	200,000
Chromium required	150,000
Nickel required	125,000
Molybdenum required	30,000
Tungsten required	10,000
Vanadium required	3,000

In the nonferrous field the advent of pure manganese has stimulated development of alloys with copper and/or nickel, some of which are of particular interest for high coefficient of expansion, low electrical and thermal conductivity, and high vibration damping capacity.

MERCURY

Mercury, another ancient metal, has found a multitude of special applications centering largely around its metallic conductivity and fluidity at room temperature and the low temperature at which it forms a conducting vapor. The most spectacular use developed during this period is probably the mercury boiler, but more important are the many uses in thermometers, electrical contacts and vapor lamps, and in the amalgamation of other metals to alter the chemical character of the surface—for instance, the amalgamation of zinc in dry cells—or to provide special alloys such as dental amalgams. Its chemical uses in metallic form as a catalyst and in its compounds for germicidal and fungicidal properties vie in importance with its uses as a metal.

MOLYBDENUM

The first large molybdenum-mining operation was started in 1905. Ten years earlier, fairly pure molybdenum had been made from the then scarce ore in an electric furnace. With the greater availability of ore and modern metallurgical methods, the production of this high-melting metal (2400°C.), either as the powdered carbide by carbon reduction or as metal powder by hydrogen reduction, was developed and its use in steel as a substitute for tungsten was discovered. Small but important uses as a highly refractory resistance wire and for X-ray tube targets also exist. In vacuum-tube grids and plates, its high strength and low vapor pressure are valuable. The United States produces nearly 90 per cent of the world supply of this metal.

NICKEL

The importance of nickel in steel, nickel silver, Nichrome and for nickel plating, all developments of our 75 years, is today a metallurgical commonplace. The Canadian smelters today are said to smelt 80 to 90 per cent of the world's nickel. The Frood ore, which carries copper and substantial precious-metal values per ton, poses a difficult metallurgical problem. This has been solved by the Orford process, in which a copper-iron-sodium sulphide matte is separated from the nickel sulphide matte by gravity during freezing. The nickel matte is roasted and leached and crude nickel is produced by electrolysis of the solution.

The major use of nickel is as an alloying element in steel. From one half to two thirds of the nickel produced is so used. Nickel cast irons have also become important. The alloys of nickel with copper, of which Monel metal, made from the Canadian nickel-copper ores, is the best known example, are notable for their combination of strength and corrosion resistance. The nickel-chromium alloys are among the oldest and most versatile of the resistance alloys for electrical heating and have contributed largely to the development of this important field. The low-expansion alloy Invar and special magnetic alloys containing nickel are other important uses. Nickel plating, which is perhaps the best known use of pure nickel, was given great impetus by the invention in 1916 of the Watts bath, which permits more rapid and cheaper plating.

THE PLATINUM METALS

Platinum and palladium and the minor metals of this group, iridium, rhodium, osmium and ruthenium, have become commercially important with the need of the electrical industry for contacts, and of the chemical industry for catalysts and highly corrosion-resistant metals for small but critical parts. Other applications take advantage of their strength, hardness, and high melting point. Among these are thermocouples, pen points, vacuum-tube filaments, jewelry and dental alloys. While their consumption is measured in ounces, their importance can scarcely be measured even by their high monetary value.

SELENIUM

Selenium lacks in metallic characteristics. It is a semiconductor and an electronic conductor of electricity. It is used in rectifiers, which conduct electricity more readily in one direction than in the other, and hence may be used to convert alternating to direct current. An allied use is in photocells. Selenium is also used to improve the machinability of certain alloys.

SILVER

Silver, another of the ancient metals, has found several new and important uses during the last 75 years, in addition to its time-honored uses in coinage, jewelry and tableware. Its corrosion resistance has led to its increasing use in the chemical industry, the strength of some of its alloys has made them valuable for brazing, electrical contacts afford a use for other alloys and during the war years of 1941 to 1943 extensive use was made of silver alloys for bearings, where, presumably, the corrosion resistance imparted by the silver reduces the rate of wear. Twenty million ounces were used for this purpose as compared with 20 million for photography and 30 million for silverware. A major new use of silver which developed during our 75 years was, of course, in the photographic field, where the application of silver is scarcely a metallurgical one.

SODIUM

Sodium, which doubtless has interested chemists more than metallurgists, has been made very cheaply by the Castner electrolytic process since about 1890. Its uses, like that of silver in photography, are for the most part chemical, since it constitutes a powerful reducing agent employed in many organic reactions such as the production of tetraethyl lead. On a volume basis, sodium is perhaps one of the cheapest of the metals, and from the standpoint of volume produced, one of the major nonferrous metals. It possesses the metallic attribute of high electrical conductivity, and pipes of molten sodium have been used in some instances for conducting heavy currents.

TANTALUM

Tantalum, one of the rare metals that have come into use, finds application in vacuum tubes and in small parts requiring great resistance to acid. A most unique property of this metal, recently discovered, has opened up new possibilities in surgery. When used, for example, in the repair of bones, the tissues do not recede from it but tend rather to adhere to it.

TIN

Tin is in much the same position as lead. The uses are numerous and important but were well developed at the beginning of this period, and interest has centered mainly around the limited supply. A substantial amount of metallurgical work, including the development of electrolytic refining methods, has resulted in the utilization of new ores, but the growing demands of the steel industry for tin and terneplate coatings for roofing, and the huge tin-can industry, the demands of the electrical industry for tin coating on copper wire and solder, and of our mechanical age in general for babbitts and bronzes—to mention only the major uses—has kept the demand ahead of the supply.

TUNGSTEN

Tungsten, in point of tonnage, is a minor metal, the 1944 consumption being estimated at only 10,000 tons; yet it is one of the most important metals in our modern metals economy and its present-day metallurgy is a product of the present century. The process of reducing the chemically purified oxide with hydrogen and of sintering the resultant powder (mixed with grain-growth inhibitors) to yield ductile tungsten is one of the outstanding metallurgical achievements of this period. The best known application of ductile tungsten, of course, is the modern incandescent lamp filament, but many other applications have been found for this very high-melting, very corrosion-resistant metal. Vacuum-tube filaments and tungsten targets in X-ray tubes are examples. Tonnage-wise, the largest use, and certainly one of the most vital, is in the high-speed tool steels, in the tungsten carbide cutting tools and in the cobalt-chromium-tungsten alloys known as Stellites. Tungsten-chromium steels are also used for high-temperature, high-pressure applications.

VANADIUM

We have already mentioned the discovery of vanadium ore in Peru and the consequent reduction in price of vanadium from $500 to $3 a pound. This metal has taken its place as one of the important alloying agents in steel.

ZINC

We come finally to the last of the nonferrous metals that was commercially important at the beginning of this period; namely, zinc. The process metallurgy of zinc has been marked by the recovery of zinc from large deposits of complex ores in the West, by introduction of electrowinning methods, by the development of the continuous vertical retort method of pyrometallurgical recovery and also a method utilizing a vertical retort electrically heated by the resistance of the charge. The purity of zinc commercially available has been greatly increased by improved electrolytic methods of refining and by a continuous fractional distillation method. The electrolytic application of zinc coatings to steel has supplemented the commoner hot-dipping method prevalent during the early part of this period, and has extended the scope of this method of protecting steel from corrosion. Along with the electrical industry has grown a major use for rolled zinc, the dry cell, which remains after many years the best portable source of small amounts of electrical energy. The hot-rolling of brass made possible by the use of purer zinc has been mentioned, as well as another development dependent upon high-purity zinc, the zinc-base die-casting alloys. These were developed during the '20s and have contributed importantly to the growth of this industry.

ZIRCONIUM AND TITANIUM

We shall conclude our list of metals with a brief reference to zirconium and titanium, whose ores are abundant in the earth's crust and whose properties are quite different from most of the present commercial metals, but which have as yet been extracted from their ores in quantity only as ferroalloys for use in steel. The pure metals have been made on a laboratory scale. These metals present the paradox of chemical reactivity with nearly all gases but excellent corrosion-resistance under certain conditions. The reactivity with gases has made zirconium powder useful as a "getter" in radio tubes. These metals have high melting points and are very strong. These properties intrigue the minds of metallurgists and may well portend one line of progress, which is still ahead of us.

Special Alloys and Treatments

One of the fields in which the progress stimulated by the war has been most eagerly scanned since it has been made public is the field of high-temperature alloys. The supercharger, the gas turbine and the jet engine all deal with gases at temperatures beyond the range at which metals had previously been expected to serve under stress. Some 27 alloys reported to have been used contained nickel, chromium or cobalt in some combination as the major alloying ingredients, with smaller amounts of tungsten or molybdenum as secondary but vital constituents. It is interesting to learn that the life expected of these parts in military service was measured usually in hours, and that ingenuity of design to cool stressed parts played a major part in solving the problems involved.

The steam turbine yielded an overall efficiency of 25 per cent as compared with its predecessor, the reciprocating engine, and the gas turbine offers a further increase to 40 per cent, but the metallurgical problems to be solved for an economical life crowd toward the ultimate capacity of metals.

We have referred to a number of instances in which a nonferrous metal is applied as a coating to protect steel. Mention must be made of several important developments in methods of protecting the nonferrous metals themselves from corrosion. Remarkable results have been obtained through the anodic protection of inert oxide coatings on aluminum. The corrosion resistance of magnesium has been radically improved by chemical treatments producing chromate films, and chromate and phosphate films on zinc have come into wide use to improve its corrosion resistance.

A number of references have been made to the production of metals of greatly increased purity and the effect of this on the utilization of the metals This is a trend the importance of which it is difficult to overestimate. While to the layman it may sound paradoxical to meticulously remove all possible traces of other elements from a metal and then add from one to half a dozen elements to it to produce an alloy, the physical metallurgist knows that many of the most important modern alloys would be useless if they contained even the small amounts of unwanted impurities that differentiate modern high-purity metals from the less pure commercial grades that preceded them. It is not too much to say that in many an alloy the exclusion of a common impurity is fully as important as the inclusion of any of the intentionally added alloying elements.

A necessary concomitant to the industrial development of processes for producing metals of increased purity has been the development of standard grades and specifications for metals. Similarly, the increasing number of alloys and the great degree to which their properties are dependent on accurate formulation has made necessary standard specifications on the more widely used alloys. In this, and in the development of testing methods discussed in the following pages, our sister society, The American Society for Testing Materials, is a symbol of the dependence of engineers on specifications that will assure that the products developed by metallurgists will be furnished to them in uniform and dependable quality.

A point of importance that has been touched on in the discussion of both the alloys and the fabricating methods deserves some further emphasis. As new alloys have been discovered, modifications in fabricating methods have often been needed to realize to the fullest degree their potential advantages. Consequently, the thousands of new alloys that have been invented during this 75 years, many of them requiring special heat-treatment, new methods of welding, or other modifications in fabricating procedure, have served as a powerful stimulus to the development of fabricating techniques. Perhaps to an even greater extent the converse of this has been true. Ingenious fabricating methods offering great advances in speed and economy of production of metal parts and making possible parts of a size, shape, or complexity previously unheard of, have, virtually without exception, imposed more rigorous requirements on the properties of the metals and alloys employed. Many alloy developments are the direct result of the demand for metals more adaptable to an improved fabricating method. Alloys lending themselves to deeper and more severe drawing operations and capable of being more easily welded are examples of this type of development.

Fabrication of Metals

The subject of metal fabrication must be pursued a little further in order to complete the picture of progress that we have attempted to sketch.

The rolling of metals, a process that was well known but in a relatively crude stage of development in 1871, has developed, through the correlation of metallurgical and engineering skill, to a point where a modern mill bears small resemblance to its 1871 prototype. The hot-rolling of brass and the continuous rolling of brass and steel have been mentioned. To these must be added the development of the four-high and cluster mills, in which deflection of the working rolls is reduced by one or more supporting rolls. In various directions industry has found use for thinner and thinner metallic foils. The rolling equipment and techniques for producing foils as thin as 0.0002 inch constitute one of the most delicate and refined processes in use today.

Forging, one of the most ancient of the metal-working arts, has progressed apace. We have mentioned the introduction of the press as a substitute for the hammer, without which the huge forgings needed for modern machines of both peace and war would be impossible. In the other direction the rapid and accurate hot-forging of relatively small nonferrous metal parts in dies has been an important factor in modern mass production.

All through the nineteenth century, metallurgists were experimenting with centrifugal casting as a means of producing sounder castings of both ferrous and nonferrous metals. The centrifugal casting of pipe and wheels were natural applications for this method but not until after the First World War did the centrifugal casting of iron pipe assume its present major importance.

It was natural that the early work with the extrusion method should have been with the soft metal, lead. During the early part of our 75 years, ingenious development was going on in the extrusion of lead pipe bends and of lead cable sheathing. In 1894, Dick embarked upon the extrusion of brass, which subsequently has grown to be a fabricating method of major importance. With the introduction of aluminum, and later magnesium, the method was extended to these metals and their alloys. Many special, ingenious modifications of the extrusion method have been developed for extruding tubes, cartridge cases, projectiles, poppet valves, and many other parts. The remelting of pure electrolytic cathode copper has often been avoided by the direct extrusion of cathodes.

The cutting of metals has been mentioned in two connections. The high-speed steels, which hold their strength and hence their cutting edge at the red heats produced by heavy cuts and speeds, revolutionized metal cutting. In their turn they are being to a great extent replaced by the cemented carbides. These carbides of tungsten, tantalum and titanium approach the hardness of the diamond. Tools with cutting edges of these carbides cemented into dense, metal-like form by mixing with cobalt or nickel powder, pressing and sintering, not only cut faster and run longer without regrinding but cut materials too hard to machine by any previous method. Dies and rolls take advantage of the great abrasion resistance of these materials. It is estimated that half the metal now machined by single-point cutting tools is cut with carbide tools. Carbide dies have become more or less standard and carbide rolls for rolling very flat strip are superior because of their high resistance to deformation.

The die-casting industry is a child of this century. The attraction of a process that creates a finished part directly from molten metal in one operation is obvious. By forcing suitable alloys into accurately formed steel dies under high pressure, this ideal is achieved for many parts and closely approached for others that require only a minimum of further machining. The perfection of this process is quite as much a metallurgical as a mechanical achievement. The formulation of alloys (usually zinc or aluminum base) that under the rapid chilling of the water-cooled mold develop high strength, and the development of suitable steel for the dies, have required the skill of both ferrous and nonferrous metallurgists.

We will refer again briefly to powder metallurgy, which, as early as 1828, was used by Wollaston to fabricate platinum, and which, after a century of use as a method of fabricating metals the metallurgists could not melt and cast, has during the past 25 years been turned to the production of metallurgical structures of unusual characteristics such as porous bearings and "alloys" of immiscible metals or metals of widely different melting points. In special cases, it has served as a method of fabricating parts of normal metallurgical character but of shapes difficult to fabricate by other methods. It is one of the metallurgical processes still in the active stage of development.

Welding is a very old method of fabrication that has come to employ entirely new methods during the present century, which render it in effect a new art. Blacksmiths welded hot steel long before the beginning of our story, but the welding of today bears slight resemblance to that ancient art.

Thompson originated the resistance arc welding of metals in 1886, and this method, with the important and radical improvement of percussive welding introduced by Chubb, is the most important method of repetitive production welding. Arc welding, which was used as early as 1881 to weld storage-battery plates, and which by 1889 had been developed to the point of using metal electrodes for welding other metals, is too well known to need description here. Acetylene welding and cutting, which came with the turn of the century a few years subsequent to Vautin's discovery and Goldschmidt's development of thermit welding, round out the group of new welding methods that have revolutionized the fabrication of metal during the current century.

As methods of alloying and fabricating metals have developed, the need for more exact and more searching methods of testing has been met by refining old tests and inventing new ones. Impact testing and fatigue testing are wholly new, while the modern tensile machine with automatic recording of stress and strain on specimens from the finest wire to full-scale structural members, bears faint resemblance to "adding weights to a firmly suspended wire until it breaks." As demands of engineers have increased they have been met to some extent by reducing the factor of safety, or factor of ignorance as it is aptly referred to. This has been made possible in part by reducing the extent of our ignorance through nondestructive testing of parts actually going into service. In critical applications every part is tested. Magnetic tests for cracks and radiographic examination for blowholes or porosity are examples of such tests. Engineers can now directly and accurately evaluate stresses in actual stressed members by modern strain gauges that are readily cemented to the part, to record strain during actual service.

Relative Importance of Nonferrous Metals

Since this paper is directed to the nonferrous field, it would scarcely be complete without drawing attention to the increasing relative importance of the nonferrous metals. Throughout this period, there has been a steady growth in the percentage of the total tonnage of metals represented by the nonferrous group. Equally significant and interesting is the fact that a similar trend has been manifest in the position of the rarer and more expensive metals. The reader doubtless has sensed this as attention has been directed to the commercial importance of a score of metals, which 75 years ago were confined to use for coinage or ornamentation, were laboratory curiosities, or were not even known. It is not too much to say that many, if not most, of our modern electrical and mechanical equipment would cease to function if the small but vital parts made from such metals were suddenly to become unavailable.

It is the writer's hope that the reader of this necessarily brief glance at a significant fragment of history may share with him a justifiable sense of pride in the vital achievements of our profession during a period eventful in every phase of human progress.

Acknowledgments

The writer wishes to acknowledge the helpful collaboration of Dr. C. H. Mathewson in preparing this paper, and of a number of his friends in the Institute of Metals Division for their friendly and valuable criticism.

Seventy-five Years of Progress in Bituminous Coal Mining

BY HOWARD N. EAVENSON

HOWARD N. EAVENSON

Consulting mining engineer of Pittsburgh, Mr. Eavenson has spent virtually all of his professional life in the coal industry. He is President, Bituminous Coal Research, Inc., and an official of various coal-producing companies. He is the author of "The First Century and a Quarter of the American Coal Industry," of "Coal through the Ages" and many articles dealing with coal. He was President of the A.I.M.E. in 1934, and was the first Chairman of its Coal Division.

WHEN the A.I.M.E. was formed 75 years ago the bituminous coal industry was in its swaddling clothes, although it had been operating for more than a century and coal was being mined in every state now producing it, and its output had long passed that of anthracite. In 1871, the value of bituminous coal was about seventy per cent of the value of all metals produced and more than one fifth of the value of all products of mines, both metallic and nonmetallic.[1a] While many of the operating mines then shipped by rail, most of the development was along waterways, although the canal era of transportation was nearly at its end.

Coal mining is a heavy industry and one of the best measures of its progress is its output throughout the period. Fig. 1 shows this graphically from 1800 to 1945. From 1870 to 1910, the production—which is very nearly the consumption—almost doubled every decade, a most amazing growth. In 1918, in World War I, a peak was reached and a decline began, which ended in 1932. A gradual recovery then started, interrupted in 1938 but culminating in the record output of 1944, when, owing to World War II, a tonnage of 619,576,000 was produced. It is evident that the forces leading to the continuous increase ending in 1918 have spent themselves and that only unusual conditions will require so large a production again. The postwar conditions of World War II will probably

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[1] References are on page 245.

continue for several years, but what will happen after that is in the realm of prophecy.

In 1870, the per capita production was less than one ton; in 1918 this had grown to 5.6 tons but it has not again reached this figure, in spite of the larger total tonnage produced in 1945. The dollar value of coal produced from 1870 to the outbreak of World War I, as shown on Fig. 2, did not increase as rapidly as the tonnage, but in 1920 the value had almost doubled with every decade.

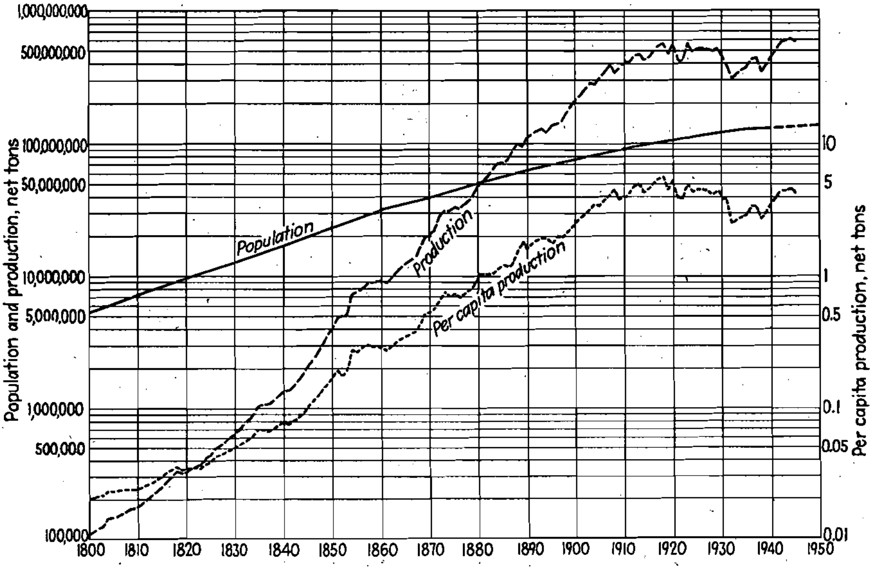

FIG. 1—*Production of bituminous coal, and population of the United States.*
Sources: H. N. Eavenson;[1c] Coal (1906) 18; Minerals Yearbook (1942) 848; Statistical Abstract of the United States (1941) 2.

After 1920, the value declined steadily until 1932, when it was about the same as it had been 23 years earlier, in 1909.[1a] Because of higher wages and higher costs, there has been a steady increase of annual value since 1932, but with little increase in profits. Data for the net income of the industry from 1917 are all that are available (Fig. 2).

Another yardstick of progress is the number of men employed in the industry. Curve *A*, Fig. 3, shows the number of men actually employed; curve *B* shows the average number of days worked per year, the fluctuations being caused by weather, business conditions and strikes; and curve *C* shows the production per man-day. The peak of employment was reached in 1923, but although a greater tonnage was mined in 1945 in longer working days.

because of the greater use of loading machines and conveyors and the increased percentage mined by stripping, it was produced by fewer men. The much greater use of all sorts of labor-saving machinery has enabled the men to produce more coal per day, as curve *C* clearly shows.

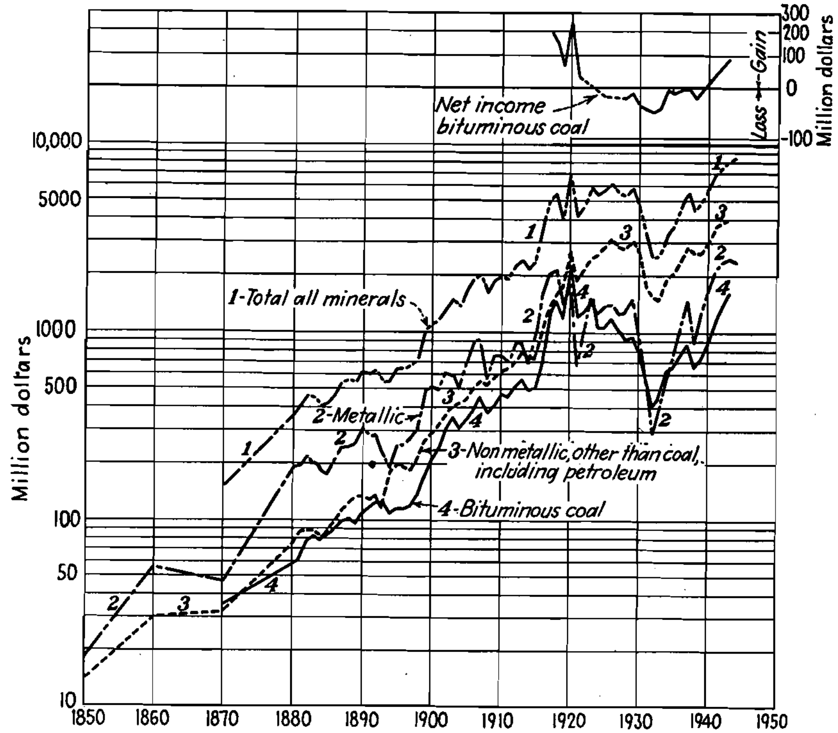

FIG. 2—*Values of mineral production of the United States.*

Sources: H. N. Eavenson;[1] Minerals Yearbooks, 1940 to 1944; Statistics of Income, Treasury Dept., Bureau of Internal Revenue, for 1928 to 1943, part 2.

Early Mining Methods

In 1871, all bituminous coal mined, with the possible exception of a few tons, was undercut by hand or shot from the solid with black powder, and it was all drilled and loaded by hand. The cars were taken from the face by animals (some coal in Illinois was hauled by dogs as late as 1903)[2] or were pushed by hand from the faces of the working places to the haulage roads, whence animal haulage took them to side tracks, or more probably to the dumping place. Some rope haulages were in use.

Nearly all the mines, except those near Richmond, Virginia, and in

Illinois, were drift or slope mines. Most of the tonnage produced was shipped as mine-run coal; only a small amount was screened. In many mines at that time the coal was forked instead of being shoveled into the cars, and the fine or slack coal was left in the mines. Preparation was very crude and, as far as is known, there were no cleaning plants in use, although one was in operation washing coal from the Pittsburgh bed in 1874.

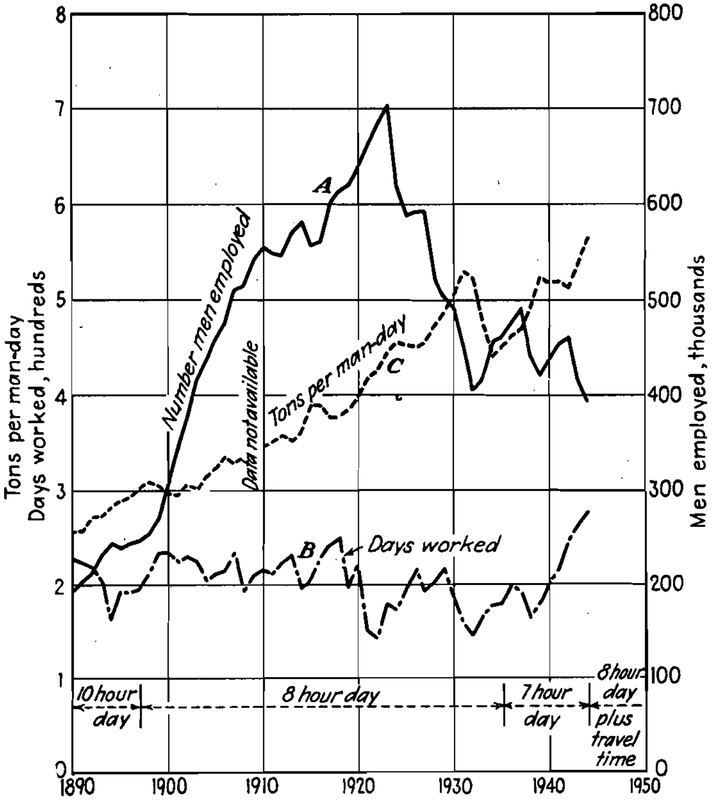

FIG. 3—*Employment and man-day production of bituminous coal in the United States.* Sources: Minerals Yearbook (1942); Mechannual (1945).

Even in 1871, efforts were being made to reduce the manual labor used in mining coal. Several patents for undercutting machines are dated prior to that year, and probably the first coal-cutting machine tried in a bituminous coal mine was in Brazil, Indiana, in 1873. The machine was driven by a 5-horsepower steam engine, which was intended to run later with compressed air. The cutter was a 4-foot diameter iron rim in which cutting teeth were set, the rim being driven from the engine by chain drives. The machine was mounted on small wheels, so that it could be moved along the face and from place to place. It could make a cut about 3½ feet deep. No further record of it can be found and probably it never passed the trial stage.

The first successful cutting machine was the cutter-bar machine put upon the market by the Jeffrey Manufacturing Co. in 1877. It was operated by compressed air, the engine being vertical and solid with the outside frame, and the bar was fed into the coal by means of a screw working through a movable nut. The cutter bar was rotated by a chain drive. Later the engine was changed to a horizontal position, and in 1889 an electric motor was substituted for it. These machines competed with the puncher machines for some years, but when the electric breast machine was placed on the market the cutter-bar machines became obsolete and were superseded, although some hundreds of them were in use. Few people in the industry now have ever heard of such a machine.[4a]

The next successful cutting machine was the Harrison compressed-air puncher, made by the George D. Whitcomb Co., of Chicago, and put on the market in the spring of 1880.[4b] This machine was soon followed by the Ingersoll-Rand puncher, about 1887, and in 1896 by the Sullivan Machinery Co. puncher, and some thousands of them were in operation in mines in many states in the late nineties.

Electrically Operated Machines

The cutter-bar machine was the first electrically operated undercutting machine. In 1894, the breast chain cutting machine was introduced by the Jeffrey Manufacturing Co., the Link Belt Machinery Co. and the Morgan-Gardner Electric Co. The three machines were alike in principle but differed in details. With these the cut was made the full depth of the machine—about 6 feet, and the width of the frame, about 3½ feet— then the machine was withdrawn from the cut and moved over its own width, to make another cut. This process was continued until the whole width of the available face was undercut. These machines were much simpler, faster and more easily operated than any of their predecessors.

About 1890, the Sperry electric longwall machine was brought out. Because of the limited use of longwall mining in this country, its manufacture was discontinued after several years.[4c] The Jeffrey Manufacturing Co. introduced a longwall machine about 1897, mainly for sale abroad. It was electrically driven and the cutting was done by bits in a disk; cuts as deep as 5 feet could be made.[4d] The Sullivan Machinery Co. brought out its longwall machine about 1892. It was a modification of the chain machine, and when the first cut was made the body of the machine was turned parallel to the face and pulled itself along the face, cutting continuously. This type of machine has been used steadily since that time and still is in use in some longwall workings.

A puncher machine driven electrically was brought out in 1890, the first one being driven through a solenoid and one a little later by a spring and cam drive. About 1894, the pneumelectric puncher appeared, in which the motor compressed the air that operated the pick. A number of these were made for several years, but while this type of machine had the advantage of an electric drive, it could not stand the hard service nor do as much work as the breast machine. None of the punchers just described are now in use.

In the late nineties, shearing machines were introduced to cut the coal face vertically instead of horizontally. The Sullivan Machinery Co. had an early one, and several makers of breast machines mounted their machines so that the bar would cut vertically and could be swung from top to bottom of the face. Shearing has never been as popular as bottom cutting, but at some mines it suits the seam conditions better, and it has persisted in use, until in recent years universal cutting machines have been brought out that undercut or topcut or shear, and can meet any conditions.

About 1896, an electrically driven rotating-bar longwall machine was introduced into an Iowa mine by Lee Brothers. The machine was successful but it had only a limited use for some years in[5a] Illinois, Iowa and Colorado.[5b]

About 1880, the Ingersoll company adapted its rock drill to cutting coal from a vertical post mounting, the machine being intended for cutting places on heavy grades where the ordinary type of machine could not be used. Later some of these machines, called the Radialax, were used for cutting out impure bands, or partings, in the seams. This type of machine was never used much, and none are used in this country now, although some are still being made in Canada.

About 1901, The Sullivan Machinery Co. introduced its continuous cutting machine, now known as the shortwall. The cutter bar was much narrower than that of the breast machine—when the initial cut was made, jacks were set at each side of the place and the machine pulled itself across the face by a chain fastened to the jacks. The machine was loaded and unloaded by its own power and required much less room along the face than the breast machine. The chain was later changed to a rope, and this type of machine is now made by the Sullivan, Jeffrey and Goodman companies, with slight variations, and has entirely superseded the breast machines. These continuous machines not only require much less physical labor than any previous type but are much lower and can be used in much thinner seams. They are being used in seams as low as 28 inches thick.

Some coal beds contain streaks of dirt, and where these are thick and soft enough to be cut by chain machines, it is frequently desirable to do the cutting in these partings; some beds also have tender roofs, which may fall with the coal when it is shot after being undercut, but which may be held up if the cutting is done at the top of the coal bed and the coal is shot up instead of down.

To meet such conditions, machines that could remain on the track, with rotating cutter bars at adjustable heights above the bottom, were necessary. The Jeffrey company brought out its arc wall machine in 1909, cutting a curved face. In 1914, the Goodman company introduced its straight-face machine. These machines were changed in details and in 1925 the Sullivan CLU machine appeared, which cuts on top or bottom and shears. All these machines had greater capacity and flexibility than the shortwall machines. Further developments have been made by all makers, and in 1935 the hydraulically operated universal machine appeared, which cuts or shears anywhere in the face and drills as well. This same type of machine mounted on rubber-tired wheels was introduced in 1942. These machines, in beds where height will permit their use, will cut much greater tonnages of coal with less effort and cost than any others, and their cost advantage increases with each wage increase. They are approaching the ultimate in design for machines for this type of work, but it will be many years before the shortwall machine finally disappears.*

Haulage

As has been said, in 1871 nearly all coal was taken from the face by animal haulage or pushed by hand to the mouth of the room, whence it was taken by other methods. The pushing of cars from the face was a relic of early days in mining and in this country persisted in only a few fields, where small cars were used and the beds were thin. In most fields it was never done. Hand pushing continued in some districts, notably in central Pennsylvania, until the late 1930s.

Animal haulage, both for gathering cars and for main-line haulage, was almost universal. Contrary to uninformed opinion, a horse or mule within its limitations is as efficient a hauling unit in mining as any motor yet devised. Where the coal bed is 5 feet thick or more, where the loaded mine cars do not exceed a gross weight of 5 tons, grades are not over 4 per cent and cars must be handled singly, no motor can do this work as cheaply as a mule, even where string teams must be used. The use of larger cars, the need for greater outputs and the increasing length of haulage have displaced animal haulage

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* The best accounts of the development of cutting machines are those of E. W. Parker[4] Later developments mentioned above are from private correspondence.

in all large and new mines, but in some small mines it will persist for some years.

Some rope haulages were in use in 1871 and until late in the nineties, and in some mines endless rope haulages were installed. When the electric locomotive demonstrated its feasibility for mine use, it soon superseded almost all rope haulages except those operating on very heavy grades.

In the early years, a few steam locomotives were used in some Pennsylvania and West Virginia mines, but their use was soon discontinued because of the smoke and gases emitted.[6] The tonnage hauled by them was never large. Compressed-air locomotives were put into coal mines in the early eighties. The first ones worked on low-pressure air, but the later ones used air of 800 to 900 pounds per square inch for transmission purposes. In the period 1904 to 1913, more than 300 mines used compressed air for cutting and hauling (mainly for cutting), but the superior advantages and lower cost of electric power for both purposes caused a steady decrease in the use of compressed air, and in 1926 only 39 mines were using it for cutting and no compressed-air locomotives were operating.

The earliest electric locomotive in a bituminous coal mine was a Jeffrey Manufacturing Co. machine working in an Ohio mine in 1888.[7] An electric locomotive was in use in Rock Springs, Wyoming, in 1892.[8] The Thomson-Houston Electric Co. was building electric locomotives for anthracite mines in 1889[9] and the Westinghouse company made its first mine locomotive in 1896.[10] These first machines were small and used 500 volts direct current; nearly all mine locomotives now use 275 volts, and machines weighing 40 tons with hydraulic or pneumatic brakes and contactor controls are in use in some mines, although 13-ton single or 26-ton tandem locomotives are the usual sizes. Their use is now practically universal.

Some gasoline locomotives were used in mines from about 1904 to 1915; they were not very satisfactory mechanically nor from a ventilation standpoint and their use has been discontinued. Locomotives driven by diesel engines are used abroad in coal mines, and have been satisfactorily used in several long rock tunnels in this country. Their use with proper air-conditioning devices is entirely feasible and will eliminate the danger from mine fires caused by the open wires necessary for electric locomotives using trolley wheels, as nearly all haulage locomotives do. When recovery from war conditions makes possible the manufacture of diesel engines and appurtenances of the proper sizes to suit mine haulage conditions, it is very probable that they will begin to replace the electric trolley locomotives.

As it was not practicable to extend the open wires necessary for trolley locomotives to the working faces, because of the dangers involved, it became necessary to develop a small locomotive using a trailing cable to place the cars in the working places. After storage-battery locomotives were tried unsuccessfully about 1898, a cable-reel motor was tried, the reel at first being turned by hand, then by friction against the wheels. In 1902 the present type was introduced, the reel driven from the axle or by a motor, and this type now gathers most of the coal produced, the later machines being of permissible construction, to allow their use in gassy places. Although a few storage-battery locomotives had been in use since 1899, it was not until about 1910, when battery makers became actively interested in such machines, that they became reliable enough for daily mine use. About 1913, several makers brought out gathering motors driven by storage batteries and, because of greater safety, many of these are in use. A few very gassy mines use storage-battery locomotives for main haulage as well as for gathering, and as experience obtained during World War II with storage batteries is applied commercially, the use of storage-battery locomotives, because of greater safety and the elimination of open wires, is certain to increase.

Loading

Ever since the late 1880s, experiments with devices to eliminate the drudgery of shoveling coal into mine cars have been going on. In 1888, the first Stanley heading-driving machine was brought from England and was tried in a Colorado mine. Apparently about ten of those machines were made here and were tried in Illinois and at one Pennsylvania mine about 1894 and later. While the machine operated successfully, the headings were too narrow for American conditions and the saving in cost was too small, and the use of this machine was soon discontinued. About 1908, the Ingersoll-Rand company installed an air-driven heading-driving machine in a West Virginia mine, but only one was built. In 1920, the McKinley heading driver was brought out, and a few of them are still in successful use.

The O'Toole cutting and loading machine was first tried in the Connellsville region in 1896 and several later models were used in the Pocahontas field in 1907 to 1914, but none are used now. In 1898, work was begun on the Coloder machine, and in 1903 the Hamilton loader was installed in an Illinois mine. The Myers-Whaley machine was first installed in a Tennessee mine in 1908 and this type of machine is still in successful use, although more for loading rock than for coal. In 1909, the Jeffrey company brought out an entry-driving machine, which has been used to some extent since then. A machine of the excavating shovel type was put in a Nova Scotia mine in 1911.

The commercial use of loading machines really began in the next decade. The Jones Coloder began operations in 1918 in the Pocahontas field, as did the Joy machine in the Pittsburgh region. In 1919, the first Oldroyd loader was put in a Pennsylvania mine.

In 1921, Joy machines began working in Illinois and West Virginia, and in 1922 the Ayrshire Coal Co. completely equipped one mine with Joy loaders and the Pocahontas Fuel Co. entirely mechanized one of its mines with Coloders. In 1923, the latter company loaded almost one million tons with Coloders, the first time any machine had made such a record. Since that time, many new loading machines of various types have been introduced, some of which have been successful. Recent developments are toward track-mounted machines of low height for loading into mine cars, and caterpillar-mounted machines loading onto conveyors or into rubber-tired shuttle cars, which discharge the coal onto conveyors. This latter combination is trending toward a trackless mine as far as haulage of coal is concerned.*

The use of mobile loading machines is not practical in beds less than 44 inches thick, but in these thinner seams mechanization has been along the lines of conveyor mining. The coal is undercut and shot and then loaded by hand onto conveyors, which take it from the working faces to loading stations, where it is put into mine cars usually, or onto other conveyors, which deliver it to mine cars or else extend out to the tipple. In any type of conveyor mining, the labor of shoveling coal onto the conveyor is much less than that of loading it into mine cars.

The first conveyor mining in this country was at a Pennsylvania mine in 1900, and for many years this type of mining was tried on longface or longwall working. Because of the amount of labor involved, longwall work has not been successful in this country except in a very few mines, and conveyor mining did not progress rapidly until about 1924, when machines suitable for room-and-pillar work became available. Three types of conveyors are now in general use: the endless chain and trough, the shaking conveyor, and the belt conveyor. In 1926, a loader for use with shaking conveyors, called the duckbill, was developed by the Union Pacific Coal Co., in Wyoming, and these are now fairly generally used where top and bottom conditions permit.[8,11] A recent development has been a very low loading machine dumping onto a conveyor instead of into cars.

In 1916, a pit-car loader, allowing the miner to shovel the coal into the bottom of the machine at the place, the machine placing it in the car, was introduced. Hundreds of these machines were installed in many fields, their use reaching its zenith about 1931. Since that time, the increasing use of mobile loaders has practically driven them from use.

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* A detailed account of the development of mechanized mining, with a chronology, is given by L. E. Young in Coal Mining Mechanization.[8]

Fig. 4 shows all the recorded data of production by various methods of loading since 1923, when the statistics were first collected.

Various machines for scraping the coal from the faces to cars on the headings, many kinds of power shovels and cutting and loading machines have been tried in various fields; most of them were not commercially successful, although some few of each type are in use.

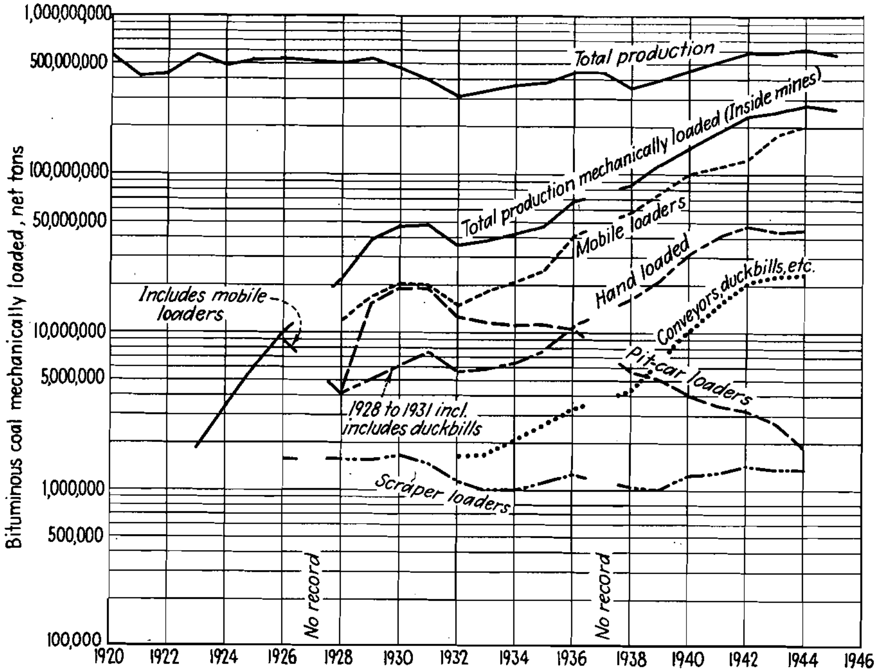

FIG. 4—*Production of bituminous coal in the United States by various methods of loading.* Source: Minerals Yearbook.

The development of all kinds of mechanization was delayed or stopped during the depression period from 1926 to 1934 because of constantly lowering wage scales; with the continually increasing rates since 1934, the installation of all kinds of labor-saving equipment has progressed rapidly and the rate of installation now is regulated only by the inability to secure the necessary machinery.

Mine Cars

At the beginning of the period discussed here, coal was hauled in pit wagons, small wooden affairs holding usually not more than one ton or one and a half tons. While many wooden cars are still used, most coal is hauled in steel mine cars holding from 3 to 10 tons with antifriction bearings, spring draft gears and sometimes automatic couplings. In the newest mines designed for mechanical loading, the mine cars cost from 30 to 40 times as much as the early pit wagons and carry nearly or quite as much as did the coal cars used on railroads in 1871.

All mine pumps are now driven electrically. Rock drills usually are driven by compressed air, the air being furnished by portable, electrically driven compressors. Some coal is still drilled by hand but for much of it electric drills are used, and many of the universal cutting and shearing machines in use have drills mounted on them and drill as well as cut the places.

Preparation Plants

In 1871, very little attention was paid to the preparation of bituminous coal. Much of the coal was loaded with forks, leaving the fine coal in the mines, and most of it was loaded as mine run. The portion of the output that was screened was run over bar screens, and not more than three, and usually only two, sizes were made. A washing plant was installed by a steel company near Pittsburgh in 1874 to clean slack coal shipped to it, and in 1880 there were 13 cleaning plants in western Pennsylvania.[12] The use of all these plants had been practically discontinued by 1900 and a quarter of a century elapsed before any more were built in that area.

As late as 1905, less than ten million tons of raw coal was cleaned in the entire country. The product was almost all used for making coke. The tonnage of coal cleaned increased from 1905 to 1917, then decreased sharply until 1921, since when the amount has increased steadily and rapidly. Now about 40 per cent of all bituminous coal mined is cleaned, and as the use of mechanical loaders increases the necessity for cleaning the product increases also. Now most of the coal used for metallurgical purposes is cleaned mechanically, not only to reduce the ash and sulphur contents but also to secure a uniform product, and a great deal of domestic coal, particularly the stoker-coal sizes, is treated in the same way.

The first preparation plants were very small. The record output in 1871 was of 89 tons per hour for nearly 13 hours, the coal being screened into three sizes, the larger two being loaded into barges and the smallest going to coke ovens. Several preparation plants now under construction are designed to handle 2000 tons per hour, and are expected to have an output of about 25,000 tons per day of two-shift operation. These plants resemble, and indeed are, manufacturing plants to turn raw coal into a number of sizes, all of which are of uniform quality and the best that can be produced from the mine-run coal, and in some cases the uniformity of the size consist of certain sizes is guaranteed. Perhaps in no other phase of the industry has progress been so great as in preparation, and certainly the average quality of all coal produced has never been so good as it is now. All available data of coal cleaned are shown on Fig. 5.

Stripping Mines

While the very earliest mines, in this country as well as in England, began by stripping the soil from the outcrops of the coal beds, the total amount of coal mined in this manner was small, partly because of the limited areas available and partly because such mining was all by scrapers operated by hand or by animals, and only small amounts of earth could be handled economically. The census of 1909 shows a total tonnage of 309,422 mined by stripping in that year.

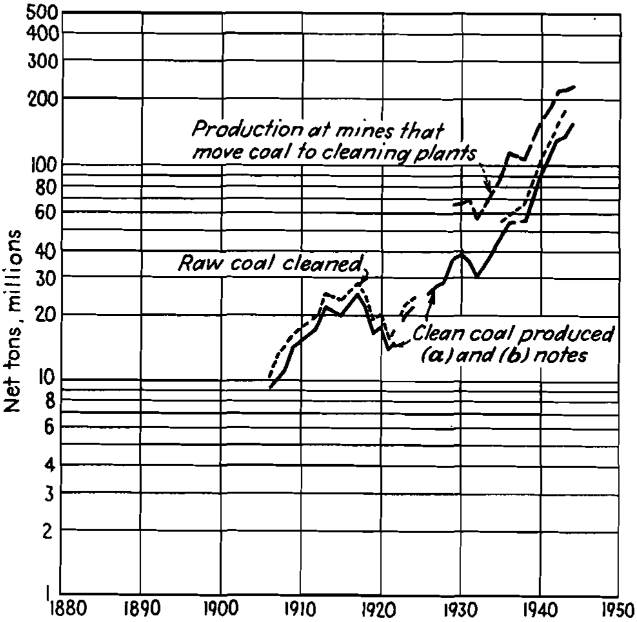

FIG. 5—*Bituminous coal cleaned in the United States.*
a. Does not include pneumatic methods from 1906 to 1923 inclusive.
b. Does not include coal cleaned at consumer plants.

Better types of excavating machinery stimulated interest in strip mining, and by the end of World War I more than eight million tons per year was being mined. The smaller amount of labor used in stripping gives that method of mining a great advantage in cost over deep-mining systems and has led to the development of excavating and handling machinery of capacities far exceeding those used in any other kinds of excavation. Electrically operated shovels with buckets holding 40 cubic yards, and with an operating cycle of one minute, are in successful operation and capacities of draglines and trucks have been increased proportionally. Better methods of drilling and shooting have been developed, so that now it is feasible economically to remove coal beds 4 feet thick with a maximum cover of 70 to 80 feet, a large percentage of which is rock. Better preparation methods have removed much of the prejudice among buyers against stripped coal, and in 1945 the production of bituminous coal by strip mining was over 100 million tons, and it has since increased. It is probable that for a number of years to come the percentage of strip-mined bituminous coal will not be less that 15 per cent of the total production. On Fig. 6 are shown the available data on tonnages of coal

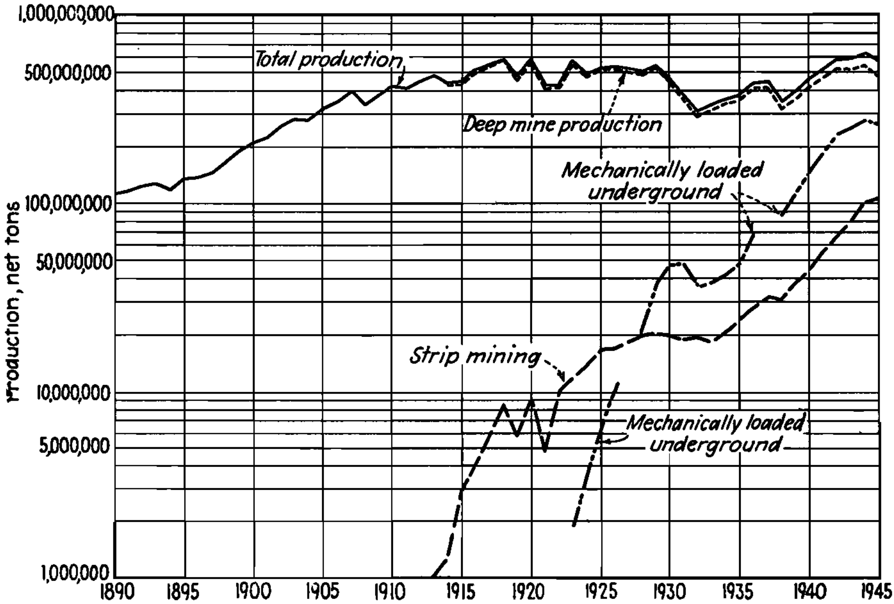

Fig. 6—*Deep and strip-mine production and mechanically loaded production of bituminous coal in the United States.*

Sources: Mechannual (1945); Minerals Yearbooks; H. N. Eavenson.[1]

mined by stripping, by mechanical loading underground, and the total deep-mined coal.

Recovery

No records are available showing the recovery of coal in the early days of mining, but it was undoubtedly low, as many pillars were left in the mine. With better methods and plans, the recovery gradually increased until in some states as much as 85 per cent of the coal was being removed. Since the introduction of machine mining, more coal has been left in place and the percentage removed has been decreasing. A large part of our most valuable coal reserves is being wasted, and this will continue until some state or national policy is evolved to remedy the situation. The coal is not being mined because under existing conditions it does not pay to do so.[13]

Safety in Mining

All kinds of mining, from the very nature of the occupation, are more hazardous than most other industries; and, because those employed in mines must protect themselves against falls of top or roof over their working places and must guard against haulage accidents as well, the number of accidents in mines cannot be expected to be as low as those in manufacturing industries using the same kinds and numbers of machines.

All the available records of numbers of accidents in bituminous coal mines are shown on Fig. 7. Until comparatively recently only the number of fatal accidents was reported; the numbers of nonfatal accidents are available only since 1930. It has been usual to compare yearly records by the number of tons produced per fatality. Since 1907, when serious attention was first really given to the question of accidents, data have been available to show the fatalities per million man-hours worked, the earlier figures being rather sketchy. The number of tons per fatality reached its nadir in the disastrous year of 1907 because of several severe explosions, but since that time, owing to compensation laws and costs, better inspection and mining methods, and continuous efforts by the operators, a practically continuous improvement in tons produced per fatal accident has been shown, and some reduction has been made in the number of fatalities per million man-hours worked. Since 1930; there has been a steady improvement in nonfatal accidents by both methods of comparison.

Fig. 8 shows the severity and frequency of all accidents between 1930 and 1942, the last year for which data are available. The number of man-hours lost on account of all accidents is calculated from the figures used by the United States Bureau of Mines, and shows a slow improvement.

Coke

In no part of the coal industry has the improvement during the past 75 years been so great and so satisfactory from a national viewpoint as that of making coke. In 1871, most blast furnaces (for pig iron) in various states were using coke as fuel, but many in Pennsylvania and Ohio were using anthracite and block bituminous coal. The use of the two last-named forms of fuel practically ceased before the end of the century, although one Ohio furnace still uses block coal for a special-purpose iron.

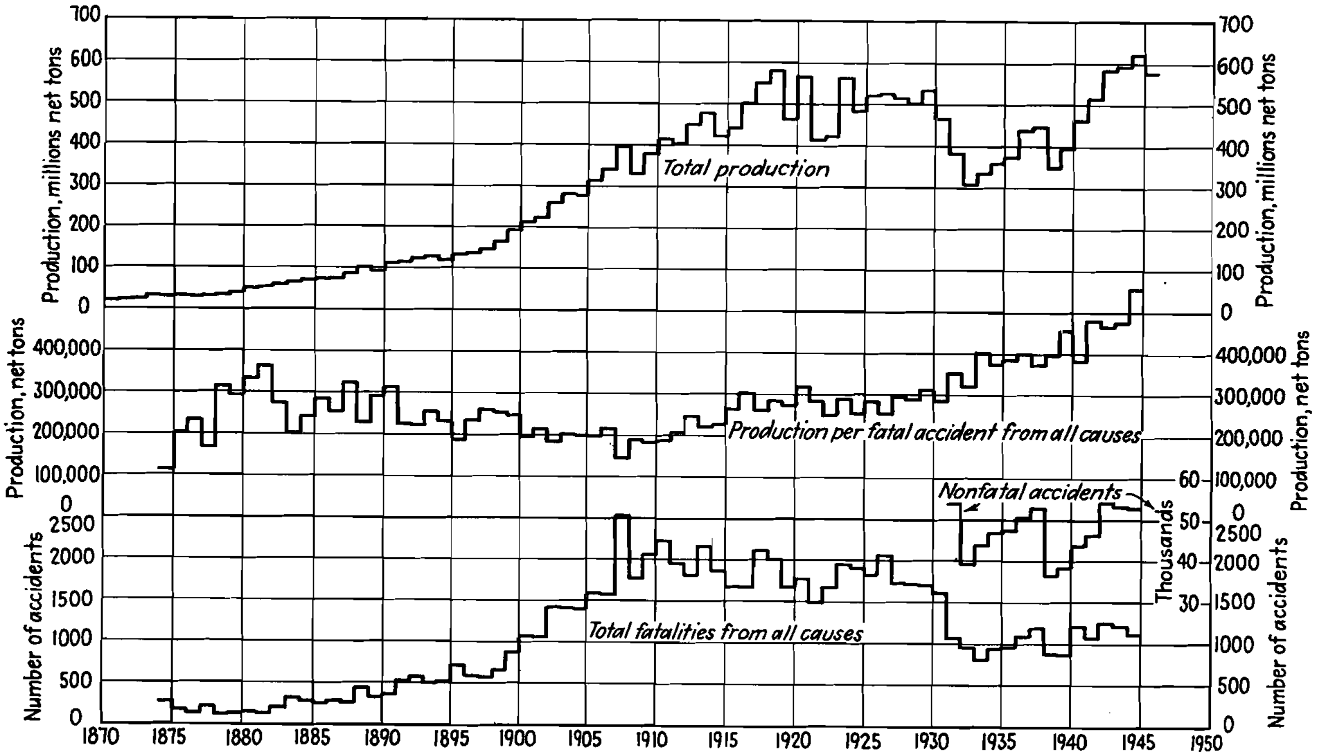

FIG. 7—*Accidents from all causes in bituminous coal mining in the United States.*
Sources: Coal Mine Accidents in U. S., Bureau of Mines; Minerals Yearbooks.

In 1871, there were about 1400 coke ovens in the United States, all of the beehive type. This number steadily increased until in 1909 there were 103,982 beehive ovens in the country; from that year the use of beehive ovens rapidly declined until 1932, when the 13,674 ovens produced only 1,468,855 tons of coke. The by-product ovens by that time were producing substantially all the coke used in normal times, and only a few of the beehive plants were in operation, to suit special demands or because of local conditions. In World War II, most of the old beehive plants that had coal supplies available were put in operation to meet war demands; when hostilities ceased, some of these plants continued in use because of the scarcity of by-product ovens—they are useful only to meet an unusual peak demand.[1b]

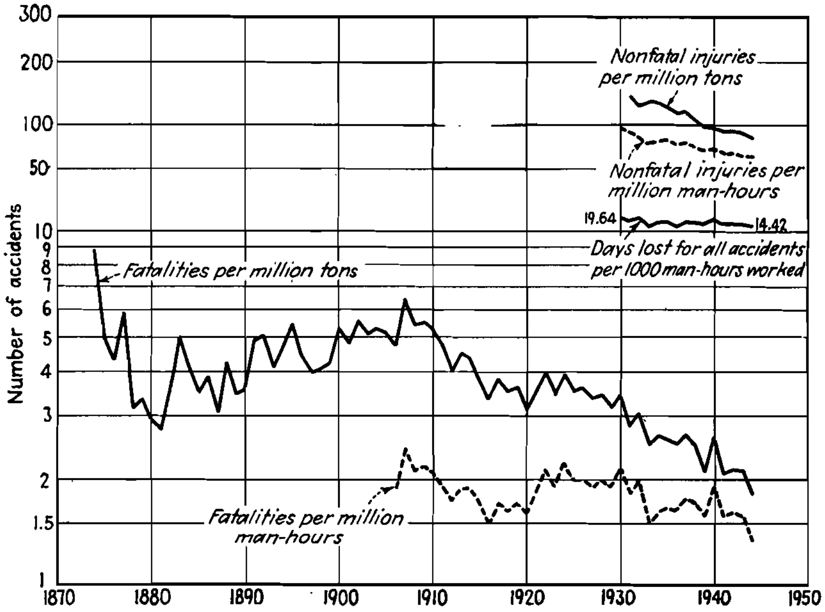

FIG. 8—*Severity and frequency of accidents in bituminous coal mining in the United States.* Sources: Coal Mine Accidents in U. S., Bureau of Mines, 1930–1942 inclusive.

The first by-product coke plant was built in the United States in 1893, and since that time the use of this type has gradually replaced the beehive, until now most blast-furnace plants of any size operate on by-product coke. By-product plants supply nearly all foundry and domestic coke and much of the manufactured gas used in the country. Their use has increased the yield of coke and saved millions of dollars worth of gas, tar, ammonium sulphate and many other chemicals that could not be recovered in the beehive process. In 1944, the 94 million tons of coal carbonized in by-product ovens produced 72 million tons of coke and breeze and $2.58 per ton of coal in by-products, which would have been wasted in beehive ovens. Many more kinds of coking coals are used in these plants than formerly was possible and most by-product coke is the result of blending two or three kinds of coal from widely different sources.

A number of plants have been built to produce low-temperature coke for the domestic market, and many millions of dollars have been spent in the attempt to produce such a fuel commercially. At present, two types of plant produce low-temperature coke, one of which apparently has overcome all the technical difficulties involved. In view of the increasing demand for smokeless fuels, and the elimination of smoke, the opportunity for such a fuel is greater than ever before—whether such a process will be successful as a commercial enterprise still remains to be seen.

Various Fuels

The use of briquettes and packaged fuel has never had the vogue in the United States that these forms of fuel have enjoyed abroad. They are used to a slight extent in most of our states and their use shows a gradual increase over the years, but the total consumption of both briquettes and packaged fuel requires less than one per cent of the bituminous coal output. With the increasing cost of raw coal and the reducing differential between the cost of delivered coal and briquettes, and the increasing demand for cleanliness and convenience in use of fuel, it is probable that the use of briquettes and packaged fuel will increase more rapidly in the future than it has in the past.

When this country was first settled, and for many years afterward, its only source of heat was wood, and until about a century ago practically all the fuel used for metallurgical purposes was charcoal made from wood. While no data exist to show the fact, it is very probable that until at least 1840, and possibly later, more heat was derived from wood than from coal. Oil and natural gas began to be factors as heat sources in the seventies. In 1890, estimates of the amount of heat derived from water power, wood, petroleum, gas, bituminous coal and anthracite became available and since that date the statistics have become increasingly accurate. On Fig. 9 all the available data are shown. This chart is different from those published by the United States Bureau of Mines because the amount of wood used during the years has been added to the Bureau's figures for other fuels. It is amazing that such a large quantity of wood is still being used, and while the total undoubtedly will decline somewhat in coming years, it is also certain that on farms in many parts of the country, particularly in the northeastern and northwestern states, wood will continue to be the fuel used. The last available data show that more heat was derived from wood than from petroleum used for domestic purposes.*

The percentage of heat furnished by bituminous coal has been decreasing almost steadily since 1907, the only exception being the period from 1938 through 1942, when the large upsurge of industry and the war restrictions on the use of oil reversed the tendency. The same forces that caused the decline are still in effect and the reduction in proportion of bituminous coal can be expected to continue until some limitation of supply of the liquid fuels occurs.

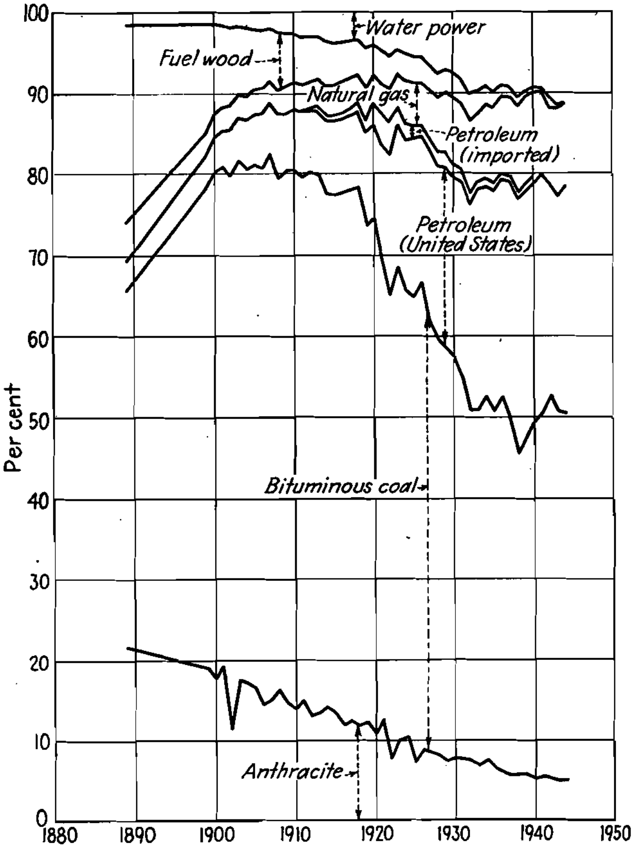

FIG. 9—*Percentage of heat requirements from various fuels in the United States.*
Sources: Reynolds and Pierson; Dept. of Agriculture *Bull.* (July 18, 1945); Minerals Yearbooks. Data for 1930–1940 estimated.

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* The only data on consumption of wood for fuel that the writer has been able to find are given by R. N. Reynolds and A. H. Pierson[14] from 1630 to 1930, and the U. S. Forest Service for 1941 to 1945.[15]

Coal Technology

Until about 1910, not much attention had been paid to fuel technology excepting in isolated cases; the cost of coal had been very low and there had always been an ample supply, and even when strikes occurred the output of coal produced by nonunion mines prevented any serious shortage. With World War I, conditions changed rapidly—prices rose, the "heatless" days, while caused by shortage of transportation rather than of coal, impressed the public greatly, and the disruption of sources of supply caused by war needs, all convinced users that something must be done to use coal more economically, or not at all. The rapid growth in the number of central power plants and in the use of their outputs had already been reducing the coal consumption per kilowatt-hour, and the installation of better equipment and methods by railroads and all classes of steam users effected large economies in the amounts of bituminous coal used.

Since 1919, when the first accurate data were assembled, central power plants have reduced the average consumption of coal from 3.2 pounds per kilowatt-hour to 1.3 pounds (the most modern plants use 0.75 pound); in freight transportation 170 pounds of coal moved 1000 gross ton-miles, while 115 pounds does the same work now; in making pig iron 3194 pounds of coking coal was required to produce one net ton while 2629 pounds is used now. These reductions vary from 17.7 to 59.4 per cent, and similar figures can be cited for almost any line of use.

Probably the most significant of all is the per capita production, or consumption, of bituminous. In 1870, the United States used less than 0.6 net ton of coal per capita; this rose steadily to 5.6 tons in 1918, then decreased to 2.5 tons in 1932, the bottom of the depression. From 2.7 tons in 1938, the effects of increasing business and war caused a rise to only 4.6 tons in 1944, when we were supplying not only our own war needs but also a large part of those of our allies (see Fig. 1). There was a slight decline in 1945 and this can probably be expected to continue for some years. It seems quite evident that advances in fuel technology and uses of other fuels have permanently decreased the amount used per capita—or at least that this will be true until reduced supplies of natural gas and petroleum make the use of solid fuels again necessary. This opinion does not consider the possible use of some kind of nuclear energy within a reasonable time, as this might change the entire fuel situation.

Wages and Hours

Because of the widespread character of the industry, and the fact that it was largely not unionized until 1932, it is difficult to give any average length of the days worked or of the wages paid. Fig. 10 shows the decrease in the length of the work day from 1890 to 1944, when war conditions caused its increase from 7 hours at the face to 8 hours plus travel time to the working places. It is a certainty that in the near future it will decrease to 7 hours including travel time. What it will be beyond that, no one can now tell.

The same chart shows the daily wage rate for inside day workers on the union scale from 1897. The average paid by the entire industry was somewhat less than this figure until 1927, and considerably less from 1927 to 1935; since that time, the complete unionization of the mines had made the average rate inside for all mines in the country as shown in Fig. 10. The average hourly earnings of inside workers are available for only the years since 1932, and, of course, when converted into daily earnings they are higher than the inside rates shown. Tonnage workers' earnings are always considerably higher than those of the day men.

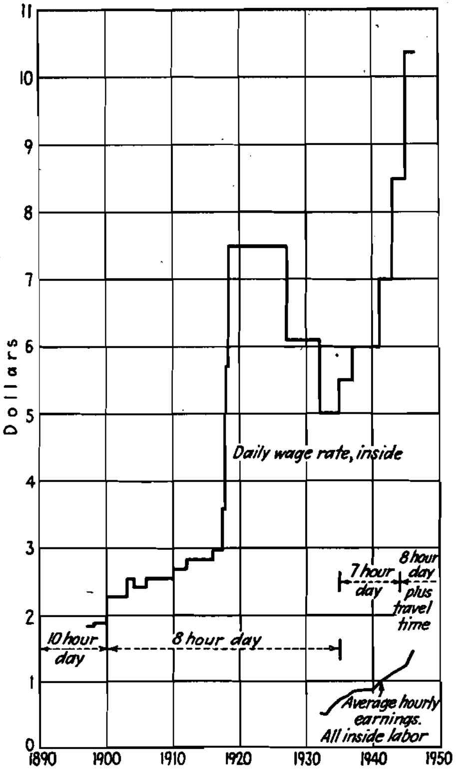

Fig. 10—*Inside daily wage rates, bituminous mines of the United States.*
Source: Mechannual (1945).

Labor Conditions

In 1871, only one or two states had a law regulating the mining of bituminous coal, and Pennsylvania was the only state inspecting coal mines. Now every state in which coal is mined has a mining law and an inspection department. Within the past few years, the inspection of all coal mines has been made a function of the United States Bureau of Mines, purely in an advisory capacity, and in cooperation with the various state departments. The present wage agreement between the Department of the Interior and the United Mine Workers makes the observance of all rules of the United States Bureau of Mines mandatory, regardless of any conflicts with state laws. While this arrangement at the time of this writing is not final, and has no sanction in Federal laws, there is little doubt that in the near future all coal mines will be definitely placed under inspection by Federal authorities.

Inside working conditions have been greatly improved, but there is still much to be done to make them what most operators would like them to be. Much of the future improvement must be along the line of education and discipline of the men themselves and at the moment this phase of management seems to be changing hands from the operators to the union, and what the ultimate results will be no one now can tell.

While there had been some unions in coal mines before 1871, and there were some at that time, there was no general unionization of mines until the late nineties, when the organization became statewide in Illinois, a position steadily maintained since that time. Within a few years, labor organization was largely perfected in Indiana, Ohio, Michigan and parts of Pennsylvania, and with some violent fluctuations most of these areas have remained union. The southern parts of the Appalachian region, with some minor exceptions, remained nonunion until 1933. Since that time, with the exception of some few mines having contracts with the Progressive Mine Workers, and a very few others still nonunion, all the mine workers in the United States have belonged to the United Mine Workers of America.*

In 1934, the writer made the statement:

> Experience of the last eight years has convinced nearly all coal operators that there can be no stabilization of the industry without stable labor conditions and wages, and the only way in which these can be attained, as the industry is now constituted, is by collective bargaining. It must be admitted that during the past two years the union leaders have been the most constructive force in the industry, but the power this small group now possesses of stopping the entire industry of the country within a few weeks is too much for any group of men to have, whether operators or union leaders, without responsibility to some superior authority.[19]

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* For detailed information, see C. Evans,[16] Andrew Roy[17] and Louis Bloch.[16]

Events during the war and the past few months have only emphasized this statement, and recurrence of the present conditions every one or two years can lead only to nationalization of the industry.

A Summing Up

In conclusion, it can be said that during the 75-year period 1871 to 1946, the bituminous coal industry has shown tremendous progress in its technical and technological aspects, which has enabled it at practically all times to produce the largest quantity of cheap fuel the world has ever seen. Much progress has been made in improvement of its mining and safety conditions, much remains to be done and will be done in the coming years.

From 1871 to 1920 was a period of fairly steady growth in output, and during this period the industry usually made some profits. Net profits vanished (see Fig. 2) in 1923, and not until 1939 did they reappear. Since then, while the industry as a whole has made profits, they are small considering the capital invested and the risk incurred, and many mines are now marginal and depend upon unusual occurrences to keep from losing money. Recent large increases in costs of coal, as compared with very small or no changes in oil and gas, have made the domestic coal market a precarious one for coal—this is its only profitable market, and if much of it is lost when competitive conditions are resumed many coal companies must cease operations. The outlook is not bright.

The research program started by the industry in recent years is intended to develop appliances to help coal keep its present markets as well as to create new uses for coal. It is hoped, and expected, that new uses will be found in chemical industries for coal or its derivatives as a base for chemicals, but all such uses can consume only a small portion of the volume of coal produced in this country, although such outlets would probably be profitable ones.

The real future for bituminous coal will be when, and if, the supplies of petroleum and natural gas are depleted to such an extent that coal must be used as a source for them—then, with its present uses, there should exist a market not only capable of absorbing the present capacity at all times but requiring a much greater output. Only a prophet can say when that will be.

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Seventy-five Years of Progress in the Anthracite Industry

BY A COMMITTEE OF ANTHRACITE OPERATORS UNDER THE CHAIRMANSHIP OF CADWALLADER EVANS, JR.

CADWALLADER EVANS, JR.
Pennsylvania was Mr. Evans' birthplace and practically all of his professional career has been in the coal-mining industry of that state, with brief interludes at mining gold and salt. In 1925, he joined the Hudson Coal Company and his headquarters have been at Scranton ever since. As Vice President and General Manager of that company, he has been directing the production of about 5,000,000 tons of anthracite coal per year.

THE American Institute of Mining Engineers was organized in the anthracite region of Pennsylvania by men who were primarily interested in anthracite. Its first meeting, at Wilkes-Barre, Pa., in the Northern Anthracite field, on May 16, 1871, resulted from a call sent out by three outstanding men of the anthracite industry: Eckley B. Coxe, R. P. Rothwell, and Martin Coryell.

The best known of these was Eckley B. Coxe, who was the manager of large holdings operated by him and his family, and who is remembered as the inventor of a special grate for burning very fine anthracite, known as the Coxe traveling grate, which is still very widely used.

R. P. Rothwell was a well-known consulting engineer of the region, as was Martin Coryell, who was associated with another well-known anthracite family, the Pardees.

There is no record of the discussions that resulted in this initial meeting, but it is safe to assume that the formation of the Institute was largely influenced, through appreciation by the founders, of the necessity for a free exchange of information covering the whole of the mining industry.

One of the rules adopted at the first meeting was:

> The objects . . . are to enable its members . . . to meet together at fixed periods for the purpose of reading papers upon and discussing subjects which have for their aim the economical production of the useful minerals and metals, and the safety and welfare

of those employed in these industries, and to circulate among its members, by means of its publications, the information thus obtained.

It is probable that this movement, which included the promotion of the "safety and welfare of those employed in these industries," was influenced by the increased complexity of the industry, and the influence that this complexity had upon the injury and death rate.

As the mines had been gradually extended to greater depth, and to territories where explosive gases were given off freely, the danger increased and the necessity for adequate means of preventing disaster became more and more apparent. Before the formation of the Institute there had been a number of such incidents, and the Legislature of the State of Pennsylvania had only a short time previously (on March 3, 1870) passed an Act known as "Anthracite Mining Laws." The stated purpose of the Laws was:

> To provide for the health and safety of persons employed in and about the anthracite coal mines of Pennsylvania and for the protection and preservation of property connected therewith.

A few years earlier, an Act having to do with only a part of the anthracite region had been passed, but this Act of 1870 covered the whole of the region, and it is possibly the first instance in the United States of a State having set up a compulsory safety code applying to mining operations. Before its enactment several of the large mining companies had been operating under their own printed safety rules, but the rules differed as between companies, and the action of the State, indicating the necessity for uniformity, undoubtedly influenced the minds of those who formed our Institute.

Looking into the reasons behind the formation of the Institute, we must remember the development of like institutions in other lands, particularly in Great Britain, where the South Wales Institute of Engineers, in part composed of anthracite miners, had been established in 1857. Its activities were undoubtedly known to our founders.

They were influenced, too, no doubt, by the spread of technical education in this country. The first engineering school, the U. S. Military Academy, had its beginning at West Point in 1802. It was followed by several specialized institutions, and by scientific departments in the older universities. The spread of specialized technical education began, however, only a few years prior to the formation of our Institute, when, in the period 1860 to 1872, nine institutions that specialized in technical education were founded:

Massachusetts Institute of Technology	1861
School of Mines, Columbia University	1864
Lehigh University	1865
Cornell University	1865

University of Illinois	1867
Worcester Polytechnic Institute	1868
Stevens Institute of Technology	1870
Alabama Polytechnic Institute	1872
Virginia Polytechnic Institute	1872

As a result of the call for the meeting on May 16, 1871, a sizable group of men, largely from Wilkes-Barre, met in the clubroom of the Wyoming Valley Hotel at Wilkes-Barre with R. P. Rothwell, of Wilkes-Barre, as Provisional Chairman, and R. W. Raymond, of New York, as Secretary. They appointed committees to attend to the formalities of the formation of the proposed Institute. At this meeting R. W. Raymond read an interesting paper on The Geological Distribution of the Mining Districts of the United States.

On the following day, May 17, 1871, the formal organization was perfected, with David Thomas, an ironmaster of Catasauqua, Pa., as President, six Vice Presidents and eight Managers (four of whom were from the anthracite region), and with Martin Coryell, of Wilkes-Barre, as Secretary, and J. Pryor Williamson, of Wilkes-Barre, as Treasurer.

Growth of the Anthracite Industry

The 75 years that have passed since have witnessed the greatest industrial development the world has ever seen, not only in the United States but all over the world. Unfortunately, records back to 1871 are not available, but in 1880 the value of minerals produced in the United States was $367,000,000 while in 1943 it had increased to $8,056,000,000, almost 22 times as much, if the purchasing value of the dollar be disregarded.

In considering the development of the mining industry of the whole country, it is natural to look at progress in the anthracite region, because it was one of the first large, consistent producers of mineral wealth in the country. Coal was mined in the region as early as 1755, commercial shipments being sent to the Government Arsenal at Carlisle, Pa., during the Revolutionary War, but it was not until 1808 that mining on a commercial scale really got underway. A steady growth followed, and when the Institute was founded in 1871 mining and preparation of anthracite was a large and expanding industry.

David Thomas, of Catasauqua, Pa., first President of the Institute, made the first successful experiment in smelting iron ore with anthracite, "the new fuel," and by the time the Institute was founded, the annual production of pig iron smelted by anthracite had increased to 957,000 tons annually, while at the same time the production of pig iron using bituminous coal and coke was 570,000 tons, and the production using charcoal was about 385,000 tons.

In 1871 the anthracite industry employed 37,488 men and produced

19,000,000 net tons of coal, while the bituminous industry in the same year produced 27,500,000 net tons. The anthracite industry reached its peak of 100,000,000 tons annual production during World War I, when it employed 156,148 men. Since then, owing to a variety of causes (including adverse public relations as a result of frequent and protracted strikes, and the imposition of a 10 cent tonnage tax by the State of Pennsylvania) it has lost a large portion of its market to competitive fuel, as will be seen from the fact that in 1945 the production was 55,900,000 net tons with 76,265 employees. However, it is still an important part of the economy of the eastern United States, and supports a very large population—larger probably than that supported by any other mining industry in the United States of America except soft coal and iron.

The greatest progress in the technical processes of the industry has been made since 1900, largely because of the introduction and improvement of mechanical devices of a variety of types, and the increased use of electric power, generated in this case by anthracite.

Mining Practices

The mining practices of the region are determined by the wide difference in physical conditions in the Northern region, where the seams are generally flat, and in the other subdivisions, where they are generally steeply pitching. The problems within each of these regions vary widely, of course, and within each region there have been many developments and changes in the practices that were standard when the Institute was founded.

The Northern field in particular has been greatly troubled by the presence over the coal bed of large cities and large rivers, which, in places, carry huge amounts of water.

Geologically, the anthracite field divides itself naturally into the Northern (comprising 176 square miles); the Eastern Middle (33 square miles); the Western Middle (94 square miles); and the Southern fields (181 square miles). For trade purposes the Northern field is generally known as the Wyoming field; the Eastern Middle as the Lehigh field; and a part of the Western Middle, together with all of the Southern section, is known as the Schuylkill field.

BREAST-AND-PILLAR METHOD

In nearly 40 of the years following 1871, the actual mining of coal continued in much the same fashion in which it was done when the Institute was formed; that is, the coal in place was drilled by hand and blasted off the solid by explosives, largely black powder, and under such conditions, coal could be produced economically only from seams of considerable thickness.

The breast-and-pillar method of work was universally followed, and in general the entire thickness of the seam—even though it was as great as 20 to 30 feet—was taken out in one operation, with roughly one fourth to one half of the total coal bed left to support the surface. Obviously, there was considerable waste, and at the initial meeting of the Institute, the first committee appointed was for the purpose of considering and reporting on ways of preventing the waste that was known to be going on. During the intervening years, the amount of coal wasted in mining operations has been considerably decreased, in part by improved methods and in part by centralization of control in large companies, which permitted the elimination of improper mining methods and centralized the management in the hands of groups that were progressive and provided with capital adequate to thoroughly develop the properties. The chamber (or breast)-and-pillar system has continued, time having proved it to be best suited to the conditions to be met where there are so many superimposed seams of varying pitch and thickness.

Some modifications of it have been introduced. Adequate pillars are now left along all boundaries, and in regions where mining can be properly planned in advance the workings are divided into panels, with a substantial barrier between the panels to localize squeezes that may occur.

When the Institute was founded the width of the chamber (or breast) varied greatly, sometimes running as high as 35 or 40 feet. With the passing years the systems of mining have been standardized and controlled through adequate surveying, so that today chambers (or breasts) vary from about 16 to 24 feet, depending upon the height of the seam and the condition of the roof.

More attention has been given to columnizing pillars between chambers, so that the pillars of one vein are exactly over or under those of the veins below and above; thus preventing what had frequently occurred in the past; namely, the pillars of one vein sinking or pushing through into the chambers of the vein below or above.

Gangways and airways at first followed the contour of the bed, so as to provide easy grades for mule haulage. The introduction of locomotives has eliminated the necessity for such meticulous attention to grades, and gangways and airways are now quite frequently driven "on line," permitting standardization of the length of the chamber and facilitating the use of mechanical loading apparatus in these chambers. The old practice of driving along contour lines is followed where necessary.

Because of the multiplicity of seams, it has seldom been possible to complete the extraction of the pillars immediately following the driving of the openings. As a consequence, workings may stand idle for years before final robbing is undertaken. During the last 75 years a great deal of attention has been paid to plans for eliminating this undesirable feature, thus enabling the quick removal of pillars soon after completion of first mining.

In the Southern field great difficulty was experienced in maintaining haulageways and airways in the thick, steeply pitching, sometimes friable beds, which entailed enormous expense for timbering. During the past 20 years great progress has been made in the winning of this coal, both solid and that remaining in crushed pillars, by means of level roadways driven in the solid rock beneath the beds, with inclined rock chutes tapping the beds or the crushed pillars at regularly spaced intervals. These rock tunnels are expensive, but they reduce maintenance and guarantee access to all the workings, despite movements in the bed.

MODIFICATION OF METHODS

With the passage of time the method of mining has been modified in many places in a variety of ways, principally by the driving of inclined chutes from which slanting chutes are driven, so that sections of the pillar can be robbed individually. In some of the thinner seams the conventional breast-and-pillar method, which involved the leaving of a heavy pillar, have been modified so as to drive the breasts extra wide, leaving pillars in place, with little attempt to recover them, but nevertheless recovering up to 75 per cent of the total anthracite.

The latest modification in heavily pitching veins, say those running from 60° to vertical, is to drive chutes approximately 30° across the pitch instead of straight up it. The U. S. Bureau of Mines is now making an intensive study of many other methods, some of them adapted from European practices, which it is hoped will enable even greater percentages of recovery from these steeply pitching beds.

The longwall system of mining has been used successfully in a few places where conditions are favorable, but mostly in the northern part of the field.

STRIPPING

Recovery of anthracite by the stripping process began early in the history of the region. The earliest instances are not recorded but it is well authenticated that a stripping was carried on at Jeansville in 1864, and in 1874 small strippings were operated at Beaver Meadow and in the Panther Creek Valley.

These early strippings were hand excavations, largely with wheelbarrows, dumpcarts or horse-drawn scrapers, and could be operated economically only under extremely favorable conditions. Small steam shovels were introduced early; there is a record of one used in 1881, of one cubic yard capacity, weighing about 35 tons, and by 1918 2-yard, railroad-type shovels weighing 70 to 80 tons were in common use.

The progress in the use of mechanical apparatus in the anthracite region has paralleled that of the nation, so that today there are many very large earth-moving machines, including the "walking dragline," with very long booms and large buckets. The first of these, introduced in 1931, had a bucket of 6 cubic yards capacity, with 160-foot boom. In 1944 a much larger machine—bucket of 25 cubic yards capacity—was put into operation in the Southern field, and today even larger machines (buckets of 45 cubic yards capacity) are being planned.

Coincidental with this change in the size and weight of the equipment, there has been a necessary change in the use of explosives, because with these larger machines it is not necessary to break rock into as small particles as was required with the smaller buckets of the early days.

In 1945 progress in stripping had become so great that 19 per cent of the total tonnage of the region was produced in this fashion. The percentage of the total coal in the bed that may be recovered by stripping is very high, compared with underground mining, and with the progress in the development of machines it is anticipated that still larger percentages of the total output will come from strippings.

The importance of stripping operations is most marked in the southern part of the region, sometimes known as the Schuylkill region, where, in 1945, there was produced from strippings 6,079,598 net tons, or 44.5 per cent, as compared with a production from underground sources of 7,591,622 net tons, or 55.5 per cent.

The size of the stripping pits has increased enormously, not only in length but in depth. Already some strippings have been undertaken that will require the removal of rock to a vertical depth of 400 feet from the surface of the ground to the bottom of the coal bed.

The ratio of vertical thickness of barren material removed to coal won varies from 7 feet of rock to 1 foot of coal, and occasionally goes as high as 15 to 1.

At places in the southern and middle parts of the field, the vertical thickness of the normal coal bed reaches as much as 45 to 50 feet, and in places these coal beds have been heavily folded, so that the actual thickness of the coal deposit approaches 100 feet. At one of these exceptional places a stripping was executed in which 42,000,000 yards of overburden was removed to recover about 8,000,000 tons of coal, or a ratio of 5 to 1, and at the present moment a stripping is in process of preliminary execution, in which it is planned to reach a folded coal bed having an actual thickness after folding of 100 feet. In order to recover this coal it will be necessary to remove, at places, as much as 700 feet of vertical thickness of rock, but the average will obviously be less. Some of our stripping beds average 3000 tons of run-of-mine coal per day, with peak outputs of as much as 10,000 tons.

MINING MACHINES

When the Institute was founded, men were thinking of the adaptation of machines to underground use. The records of our meeting at St. Louis in 1874 show that in Brazil, Ind., a machine known as the Monitor Coal Cutter had been placed in effective operation in a bituminous mine. Adoption of this machinery in the soft-coal industry was gradual and steady, but it was not until 1910 that the first successful use of undercutters was made in an anthracite mine, although experiments had been made earlier. There were many difficulties to be overcome, including not only the redesigning of equipment to meet the harder cutting conditions, but the education of foremen and men, and, as a consequence, the introduction of undercutting machines to the anthracite region has been slow.

Another factor entering into this is the nature of the veins, because in many cases undercutting is not necessary or even desirable. There always has been, however, need for conservation of human energy by mechanical drilling and mechanical loading, which, as regards coal mining, had their first wide applications in the anthracite region.

TABLE 1—*Distribution by Methods of Loading*

Method	Production, Tons	Percentage of Total
Stripping	10,953,030	17.2
Underground:		
Hand loaded 26,800,270 (64.2 per cent)	41,775,416	65.6
Mechanically loaded 14,975,146 (35.8 per cent)		
Washeries	9,600,180	15.1
Dredges	1,372,737	2.1
Total	63,701,363	100.0

Mechanical drilling by the use of a pneumatically driven tool known colloquially as the Jackhamer, was begun in the anthracite region during the First World War, although heavier pneumatic drills had been used prior to that time in rock work. After the lighter Jackhamer was introduced, it was rapidly adopted for drilling of blast holes in coal as well as in rock, and is today used universally. Hand drilling has become entirely obsolete.

In 1914 the first mechanical scrapers for loading run-of-mine coal into mine cars were introduced, and extension of their use has been steady.

Shaking conveyors for like use were introduced in the region in 1926, and have been widely adopted. During 1944, 23.5 per cent of the total production was mechanically loaded into mine cars underground, and by that date the distribution of the production as between methods of loading was as shown in Table 1.

EXPLOSIVES

The explosive originally used was black powder, introduced about 1818. Dynamite had been used before the formation of the Institute and was in general use for rock work, but black powder was preferred for coal. The first permissible explosives came into the region about 1907, and as these new explosives have been developed they have been adapted to the industry's needs. When the Institute was founded, practically all explosives were detonated with squibs or fuse, but in the past 20 years these relatively unsafe devices have been displaced, and most explosives now are detonated electrically.

TRANSPORTATION

When the Institute was founded, our mines were largely water-level drifts, and transportation was furnished by horses, mules and even oxen. In a few places the drifts were large enough so that small standard-gauge railroad cars could be taken underground. By 1871 mule haulage had reached its economical limit in many mines, and steam locomotives were introduced for general use outside, and occasionally for short hauls underground in mines having exceptionally good ventilation.

The difficulties, of course, were obvious, and the use of main and tail rope haulages became fairly general, the first recorded one being at the Buck Mountain colliery in 1883. This permitted the hauling of long trips for considerable distances, regardless of curvature of the gangway or irregularities in the grade, but it had many disadvantages. To overcome some of them, compressed-air locomotives were placed in many mines, especially those in which dangerous gases were present. The compressed-air locomotive had the advantage of great flexibility, but was expensive to install and maintain, and extremely unsatisfactory in performance.

In 1910 an attempt was made to use gasoline locomotives, but the question of controlling the exhaust had not then been worked out, and the experiment was not a success.

Apparently the first electric locomotive used in a mine in the United States was in the anthracite region. The Lykens Valley Coal Co. introduced it in 1887. A second one was put into use at the Erie colliery of the Hillside Coal and Iron Co. in 1889. These were pioneers of a system of transportation that is now almost universal. Except at a few places, for special service, mules and horses have disappeared from underground workings in the anthracite region. Compressed-air locomotives also have disappeared.

Transportation methods in slopes and shafts are the same today as they were when the Institute was founded, except for the substitution of modern steam hoisting equipment and a greater number of large, high-powered electric hoists, some of which have motors of as much as 1750 horsepower and rope speeds reaching 3000 feet per minute.

In 1871 the handling of cars at the head and foot of slopes and shafts was by the gravity method. During the intervening years a great number of shaft landings have been equipped with mechanical devices using car stops and car cagers to handle the cars on and off the cage, and as a result the speed of operation has been greatly increased, the number of men reduced, and safety improved.

During the latter 10 years of the period covered by this paper, a number of rubber belt conveyors have been installed for underground main road transportation, as well as for gathering coal from rooms and delivering it to secondary belts. The system, however, has not had wide application, being limited almost entirely to the Northern anthracite field.

In the early days wooden rails and steel or iron rails as light as 12 pounds per yard were in use. These have gradually been changed, so that today the rails are all of steel and on main roads are seldom less than 40 to 60 pounds per yard, and frequently, near shaft landings, are as heavy as 90 pounds. There has been little or no change in ties, however. Untreated ties are still used, as they were when the Institute was founded.

VENTILATION

There is no complete record of the ventilating systems in use in the region in 1871, but it is known that in the Northern field, where there were 198 mines, only 47 mines had fans, 86 were ventilated by furnaces, 17 by the steam-jet system, and 48 by natural currents of air. In the intervening years all the furnaces have disappeared and have been completely replaced by mechanical fans. The newest of these fans are high-speed, generally located on the surface.

For many years fans were driven exclusively by steam engines, but in later years a number have been operated electrically, with stand-by fans driven by steam or gas engines, ready for emergency use.

In the early days the control of ventilation underground was by means of stoppings made of wood, of dry walls of rock, or masonry walls laid in lime mortar. The use of wood for such purposes is now prohibited by law, except for temporary stoppings, and hollow tile and concrete blocks are superseding rocks for stoppings.

TIMBERING

Roof support is much the same as in 1871, wooden timber being still used almost exclusively. The only change is that there is more careful selection of the proper size of timber to be used, standardization of the method of framing, and closer supervision of the standing of the timber sets and the placing of lagging. Treated timber and steel sets are sometimes used, but not to a very great extent. In some special cases, steel timber sets or steel arches or concrete linings have been installed where long life is foreseen and maintenance charges for wood timbering are high.

The use of steel began about 1894 but it has not been widely extended, except in special locations where long life was clearly to be anticipated and continuity of operations was essential. During the past 10 years, roof support in the form of steel arches, and arches made of concrete blocks, have been introduced but they have had limited application.

PUMPING

In systems of pumping, tremendous changes have occurred during the life of the Institute. When it was founded, most of the water flowed to daylight by gravity, through water-level tunnels, though there were a number of pumps, either pole or rod-plunger pumps of the Cornish and Bull types, or direct-acting steam-driven plunger pumps. Some of these early rod-operated pumps were of tremendous size measured in inches, though not large when measured in gallons per minute. A common size of such a pump was 55 inches in diameter, 10-foot stroke, but operating only at four or five strokes per minute, and they were placed to operate either vertically or on the incline in a slope.

Steam pumps were known, of many forms, sizes and makes. The difficulty in the use of these pumps was taking care of the exhaust underground, and maintenance of the openings through which steam pipes had to be taken to the pump, owing to the excessive decay of the mine timber under the influence of heat and moisture.

Beginning about 1910, the character of steam pumps was greatly improved by the installation of triple-expansion pumps with condensers. These, plus improvements in the covering of the pipe, made possible the use of steam at higher pressure, but the period of service of such pumps was limited, because electric pumps were being developed rapidly. The first of these were huge triplex or quintuplex reciprocating pumps, which had great vogue for a number of years but were soon superseded by high-speed centrifugal pumps. It is safe to say that if it had not been for the development of these high-speed centrifugal pumps, many mines of the anthracite region that are producing today could not be operated.

A recent development in pumping practice is the introduction of the deepwell pump. This pump is on the lower end of the suction pipe, with the driving motor on the surface, transmitting its energy through a long shaft mounted in the discharge pipe, which carries the moving pump parts on its lower end. Such a pump is always submerged, and therefore cannot be damaged by sudden inrushes of water, and it can remove such waters and so restore operations without the necessity of spending huge sums to move pumps of the conventional type into the flooded area.

There is little or no statistical information on the quantity of water handled underground at the time the Institute was founded, but the Second Geological Survey in 1883 shows that in the Lehigh region, which is in the Eastern Middle field, an average of about 9 tons of water was pumped per ton of coal mined, some collieries going as high as 20 tons of water per ton of coal.

In that stage of development, Lehigh was the region with the greatest pumping problems, but with the passing of years the situation has changed, and at the present date the Northern field is the one most troubled by water. One of the large companies of the Northern field in 1945 pumped an average of 85,000 gallons per minute through an average head of 354 feet, or about 39 tons of water per ton of coal mined. This company has an installed capacity of 168,000 gallons per minute.

Drainage tunnels constitute an important link in anthracite mine drainage, particularly around the city of Hazleton. There is record of 22 such drainage tunnels, with a combined length of 138,000 feet. They are to be found in all the various subdivisions of the region; two are in the Northern part, one in the Southern part, and the remainder in the Eastern Middle and Western Middle.

The growth of the pumping problem can be visualized when it is realized that two hundred billion gallons of water was pumped during 1944, at a cost of about ten million dollars, which is considerably in excess of the quantity which the City of Philadelphia takes from the Delaware River for domestic and industrial water supply.

WATER PROBLEM

The tremendous increase in the amount of water appearing in the mines underground during the life of the Institute has led to the careful study of methods and the construction of means for keeping surface water from passing underground. Principally, these means take the form of wooden flumes and earthen ditches on the surface, which carry immense quantities of water during periods of wet weather. Some of the ditches are paved, either with rock or concrete, and one large anthracite company maintains more than 40,000 linear feet of wooden flume, ranging in width from 36 to 96 inches and about 24 to 90 inches deep. Of late years a number of semicircular flumes made up of wooden staves have been installed, and are being currently maintained.

Preparation Practices

Tremendous changes in the preparation of anthracite before it is sent to market have occurred. At the beginning of the industry, and until about 1830, coal received little preparation, except that which took place in the mine itself, and almost all the smaller pieces were left in the mine as worthless, which meant that only the thickest beds and coal of the very best quality could be mined at a profit.

There was gradual progress in the development of equipment to manufacture a wider variety of sizes, the large lumps being broken up with hammers and picks and passed over perforated plates, followed by the development of crusher rolls and inclined screening bars, and in 1871 preparation methods had advanced so that nine sizes were being marketed.

The breaker structures of that time were high wooden buildings equipped with two or more sets of cast-iron rolls covered with teeth, and with revolving screens for sizing. These were huge affairs, up to 15 feet in diameter, and sometimes 36 to 40 feet long. If the character of the run-of-mine necessitated the removal of slate, inferior coal or other impurities, this was done by hand picking, by boys seated over the chutes.

This method proved unsuitable as better burning devices were perfected, and about 1872 jigs were introduced, generally of the "pan" type. Thus the preparation of anthracite began to change from the original dry methods to the present wet methods.

CLEANING DEVICES

Plunger-type jigs were first made by Eckley B. Coxe and David Clark, in the Hazleton region, and by a manufacturer named Christ, at Tamaqua. About 1890, the engineers of the Lehigh Valley Coal Co. developed a jig that was very largely used, known as the "Lehigh Valley" jig. At the same time, other manufacturers and other companies were developing somewhat similar types. The Second Geological Survey of Pennsylvania, in 1883, had a splendid description of mining methods and appliances used in the anthracite field, by H. M. Chance, a member of the Institute; and in 1891 Eckley B. Coxe, one of our founders, presented a description of a new breaker built at Drifton, with steel frame, equipped with jigs, gyratory screens, rolls, automatic slate picker for flats, and on the whole the most advanced structure of its day (*Trans.*, Vol. 19).

In 1896, Frank Pardee, also a member of the Institute, built an unusual breaker at Cranberry colliery, which incorporated spiral chutes for lowering devices, so as to avoid breakage, and also his patented spiral for the cleaning of coal.

Many devices other than the jig were invented and tried for the separation of coal from the vein refuse. About 1890 a mechanical picker was invented, followed by a number of others, but they were inefficient and later were supplanted by jigs.

Shaking screens were first introduced about 1883, driven from crankshafts or from straight shafts with eccentrics. They have been modified and redesigned and standard equipment now is a modification of a screen known as the Parrish shaker, which was introduced about 1910.

SIZES OF ANTHRACITE

Prior to 1890 small sizes had been rejected as unmarketable, and were stored on the surface in huge banks called "culm piles," but about 1890 the development of jigs and improved cleaning apparatus made possible the repreparation of these piles. The effect of this change is shown in Table 2, which clearly indicates the beginning of the reclamation of the culm piles in the 1885 decade, and the increasing importance of the smaller sizes in each succeeding decade. Today very little is placed on culm piles, and those huge mountains of culm that accumulated during the earlier years of the industry are rapidly disappearing.

In the Northern field such piles have almost completely disappeared, having been recleaned, resized and sent to market, while in the other fields a like change is taking place, and it can be anticipated that within another 10 years the black piles remaining will have in them no marketable product.

The production of such coal was first noted in the Pennsylvania Department of Mines reports for 1894 as being 386,960 tons, the largest production, 10,527,481 tons, being in 1944. During all those years there was a steady trend from larger sizes toward the smaller sizes, as is shown by the figures in Table 2.

The capacity of breaker structures has increased steadily. The first record was for one having a capacity of about 200 tons per day. By 1887 this figure had increased to 500 tons per day, with a maximum of 1800 to 2000 tons, and by 1897 the average was 880 tons per day, with a maximum of

TABLE 2—*Breaker Shipments (Not Including Washeries or Dredges)*[a]
THOUSANDS OF TONS

Size	1875	1885	1895	1905	1915	1925	1935	1944
All sizes	19,650	31,500	47,000	68,700	77,000	57,200	44,350	54,000
Lump and broken	7,500	7,500	8,000	6,500	3,900	1,400	150	200
Egg and chestnut	11,000	18,500	24,500	35,400	42,300	37,300	24,400	27,800
Pea	1,000	3,500	6,500	9,400	9,200	3,000	4,700	4,500
Total domestic	19,500	29,500	39,000	51,300	55,400	41,700	29,250	32,500
Buck and smaller	150	2,000	8,000	17,400	21,600	15,500	15,100	21,500
Buck and smaller, per cent	0.8	6.3	17.0	25.3	28.1	27.1	34.0	39.8

[a] Quoted, in part, from Saward's Journal.

2600 tons, while today the maximum has increased to about 10,000 to 12,000 tons per seven-hour day.

In 1875, 38 per cent of all the coal mined was shipped as "grate" and larger, sizes that required very little crushing or preparation, while in 1935 (the last figures now available) the production of these sizes was less than one per cent of the total (Table 2).

Table 3 shows the percentage of sizes of commercial production from breakers, together with the average sales realization which, in turn, reflects the increased trend in the production of steam sizes.

TABLE 3—*Sizes Shipped from Breakers and Average Sales Realization*

Data	1880	1890	1900	1910	1920	1930	1940	1944
Total domestic, per cent	98.0	89.3	78.7	70.4	74.3	70.6	65.9	62.8
Realization					$6.46	$7.05	$5.24	$7.38
Total steam, per cent	2.0	11.7	21.3	29.6	25.7	29.4	34.1	37.2
Realization					$2.73	$1.87	$2.41	$3.42
Average realization, total production	$1.47	$1.43	$1.49	$2.12	$5.50	$5.52	$4.27	$5.91

Anthracite was first broken down in size with hand picks, but small cast-iron toothed rolls were introduced about 1844. These have been gradually improved in design, increased in size, and reduced in peripheral speed, and are now standard equipment, the larger ones with inserted teeth, the smaller ones with manganese segments bolted to cast-iron spiders.

WET PROCESSES

A very large proportion of the total product of the region is now prepared by the Chance process, which was first described by T. M. Chance at a meeting of the Institute in Philadelphia in 1918. This is a sand flotation process, using a fluid mixture of sand and water, with the specific gravity substantially that of marketable coal. As a result the refuse and other high-gravity particles tend to sink and the marketable coal to float. This process has had very wide application and is the system now most largely used.

Other processes now in use depend on classification by means of upward currents of water or flows of water through inclined launders. Examples of the former are found in the Menzies cone separator, the Wilmot Hydrotator and classifier, all of which are now widely used. The Rheolaveur process, introduced from Belgium between 1920 and 1930, is typical of separation by means of launders. In this process, sized run-of-mine and water are introduced into launders and separation is effected by the action of the flowing stream, much in the same manner as a river will effect separations in its natural flow. While upward jets are used at traps to extract refuse, these upward jets play no primary part in the stratification of the original mass into beds of coal, bone and slate.

All in all, the preparation plants as we know them today bear little or no resemblance to those in use when the Institute was founded.

DISPOSAL OF REFUSE AND SILT

Disposal of refuse on the surface is another phase of the anthracite business that presents a huge problem. It has grown in magnitude as each year has passed because the run-of-mine coal contains larger amounts of refuse each year, and the space available for storing it on the surface steadily becomes less. Originally the disposal of such refuse was entirely by cars hauled to the dumping point by mules, but these soon proved inadequate and in the past 20 years have been superseded by rubber belt conveyors, self-dumping lorry cars with locomotives, generally electric, inclined planes ending in belt stackers, and three-way dumpcars, moved either by electric locomotives or by rope haulages, together with a wide variety of combinations of the various means of transportation mentioned.

The importance of the refuse-disposal problem is easily visualized in a casual visit to the region, where can be seen huge mountains of refuse material, the by-product of all the anthracite produced.

Another important problem that has had to be faced in these last years, and which concerned the industry not at all when the Institute was founded, is that of disposition of the very fine particles of coal and refuse known as "silt" or "slush." In the early years of the Institute's history, quantities of this material were flushed underground and used for back-filling, but this proved extremely expensive and impractical and the material was largely deposited on the surface in huge piles.

In the past 20 years the problem of recovering the burnable fuel in the small sizes has received marked attention, so that today the major part of it is being recovered. It is removed from the flow of wash water in a thickener and reduced in ash content by a variety of processes, including the shaking table and Wilmot Hydrotator and classifier. For the past few years one large company has been experimenting with the froth flotation method, employing a hydroclassifier to remove the very small high-ash solids, and treating the resultant pulp in the conventional froth-flotation cell as developed in the metal-mining industry, but this process is as yet in an experimental stage.

Marketing Practices

One of the early recorded sales of anthracite was made in 1812, by Colonel Shoemaker, of Pottsville, Pa., who hauled nine wagonloads of anthracite to Philadelphia with horses. With great difficulty he succeeded in selling two of the wagonloads, but had to dump the remaining seven.

Commercial use of coal on a large scale did not begin until about 1828, when it was carried to market by canal and sold as "stone coal," or as "Susquehanna coal," "Lehigh coal," or "Schuylkill coal," depending on the region in which it originated.

About 1825 the name "anthracite" came into common use. The earliest of the large companies now operating was the Lehigh Coal and Navigation Co., chartered in 1820, followed by the Delaware and Hudson Canal Co. in 1823. Each of these concerns built canals to carry their product to market, one to Philadelphia, the other to New York, and it was necessary for them to build up a market, exhibiting and selling grates, stoves and other apparatus, and offering their product with the guarantee that if, after fair trial, it was not found to be satisfactory, refunds would be made.

COAL BURNERS

During the subsequent years there has been a steady development of methods and equipment for the burning of anthracite, and as a result it reigned almost without competition in its primary market, the eastern seaboard, until the first World War. In the period between World War I and World War II, competition from other fuels and other types of equipment for burning these fuels became so keen as to necessitate the formation by the industry of a cooperative association for promoting the design of equipment specifically for anthracite, so as to make it more convenient for the customer. Since that time the thermostat, the mechanical stoker, magazine-feed boilers and other conveniences have been advanced aggressively to the public, through the Anthracite Institute and Anthracite Industries, Inc., which were organized and are supported by the larger anthracite-producing companies.

Approximately 95 per cent of commercial anthracite is used in the New

England, Atlantic Coast states, and in eastern Canada, and approximately 86 per cent of the total production is used for home heating. The latest improvement in the burning of anthracite is just coming onto the market, a revolutionary device called the "Anthra-Tube," which was developed by the Anthracite Institute, and which burns the coal in a novel and highly effective manner.

STOLEN COAL

A factor that marks a complete change from the conditions that existed in 1871 has arisen since 1925 as the result of illicit mining and the sale of stolen coal. A depression in the industry caused many mines to close, particularly in the Middle and Southern fields. The employees, lacking income, began to mine coal on the outcrops, for their own use. This practice was allowed by the operators at its beginning, through sympathy for men who they knew were temporarily without cash income. However, the practice, which came to be known as "bootlegging," spread rapidly and grew into a sizable industry, the coal being marketed by truckers who came to the scattered openings, where the raw coal was crudely sized and prepared. It soon became a considerable item of competition, and endeavors to stamp it out were not successful, owing largely to the reluctance of the local juries to convict their friends of stealing an article through the mining of which those friends had made their livelihood.

At the beginning of World War II this misnamed "bootleg" industry had grown to sizable proportions, amounting to several million tons of coal per year, but during World War II it was largely eliminated, first because the men engaged in it secured employment, and, second, because of increased activity on the part of the State authorities. Now, with the easing off of demands for labor as a result of the end of World War II, "bootlegging" appears to be on the increase. In the meantime, however, the State authorities have taken more active steps to prevent it and to protect the owners of the coal in their rights of ownership.

Social Problems

The most important social problem is probably prevention of injury, with its corollary necessity for First Aid to the injured. It is interesting to note that the system of training men in Industry so as to aid their injured companions was first begun on this continent in the Northern anthracite field, in the Borough of Jermyn, Lackawanna County, a few miles north of Scranton, under the leadership of Dr. Matthew J. Shields. His practice as a physician showed the necessity for prevention of accidents, and, aided by a manual that he secured from the St. John Ambulance Society in England, he began the systematic training of men in 1899. There is no record of such an activity prior to that time.

First Aid training spread slowly, using a manual compiled by Dr. Shields, based upon the St. John Ambulance Society's booklet, and the holding of First Aid contests began. The first of such contests of which there is record was held in Scranton in 1906. The Red Cross took over the work and in 1910 Dr. Shields was appointed to direct the work. In 1913, Dr. Shields assisted the U. S. Bureau of Mines in writing its first "First Aid Manual."

SAFETY EQUIPMENT

As the danger from explosive gas came to be understood, the industry has steadily adopted the improved facilities offered, first the Davey safety lamp, then other improved models, followed in modern times by the electric lamp for illumination, generally worn on the head, with a flame safety lamp for gas testing.

Within the past 10 or 15 years, hard hats have been widely introduced to protect from slight head injuries, and are now used fairly universally. Safety goggles to protect from eye injuries have been introduced, but unfortunately are worn only occasionally, because of the difficulty caused by fogging of the lenses in warm, moist air.

The hard-toed shoe was introduced as soon as it became available and is now very largely used, and has led to a tremendous reduction in the number of slight injuries from falling objects striking a man's foot.

DUST CONTROL

During the past few years there has been considerable study of dust control. A number of the larger companies have made extensive progress in the installation of water sprays for the controlling of dust at its point of origin and for holding it down at other points. This work has been enormously stimulated by the fact that the anthracite industry, in its last wage agreement, accepted the provisions of the Occupational Disease Law of the State of Pennsylvania, which is an optional Act, and as a consequence is now responsible for the cost of occupational disease and is beginning an extensive program of education so as to prevent the creation of underground dust of all kinds, coal dust as well as rock dust.

SAFETY RECORD

One measure of safety in any industry is the number of people killed while working, and in this respect anthracite mining, along with bituminous, has made notable improvement, the number killed per thousand employees having decreased from 5.93 in 1870 to a low of 1.93 in 1945.

Measured on the basis of tons mined, the showing by the industry is equally good, the number of fatalities per million tons having decreased from 13.47 in 1870 to 2.60 in 1945. These figures are quoted from data supplied by the U. S. Bureau of Mines, as shown in Table 4.

TABLE 4—*Anthracite Mines*, 1870–1946[a]

Year	Production, Tons	Number of Employees	Number Killed		
			Total	Per 1000 Employees	Per Million Tons
1870	15,664,275	35,600	211	5.93	13.47
1880	28,649,812	73,373	202	2.75	7.05
1890	46,468,641	126,000	378	3.00	8.13
1900	57,367,915	144,206	411	2.85	7.16
1910	84,485,236	169,497	601	3.55	7.11
1920	89,598,249	145,074	491	3.38	5.48
1930	69,384,837	150,804	444	2.94	6.40
1931	59,645,652	139,431	383	2.75	6.42
1932	49,855,221	121,243	249	2.05	4.99
1933	49,541,344	104,430	231	2.21	4.66
1934	57,168,291	108,382	268	2.47	4.69
1935	52,262,883	102,808	274	2.66	5.24
1936	54,670,429	102,082	244	2.39	4.46
1937	51,745,442	99,085	215	2.17	4.15
1938	46,149,106	96,282	225	2.34	4.88
1939	51,345,701	94,331	211	2.24	4.11
1940	51,489,490	92,420	184	1.99	3.57
1941	54,114,961	88,948	194	2.18	3.58
1942	58,316,022	82,064	226	2.75	3.88
1943	59,505,666	79,381	226	2.85	3.80
1944	63,194,521[b]	77,500[b]	172	2.22	2.70
1945	54,400,000[b]	74,000[b]	143	1.93	2.60
1946	60,685,000[b]	77,000[b]	174	2.26	2.80

[a] Figures from Bureau of Mines.
[b] Estimated.

The causes of fatalities have varied through the years, although deaths from falls of roof inside the mines remain the predominant ones. Fatalities due to haulage grew rapidly after 1871, as haulage systems became more complex, and then declined as safer methods, particularly electric locomotives, were introduced.

Fatalities from gas and dust explosions have always been present, though they were low in the early years of the Institute, when the mines were comparatively simple and close to the surface. They mounted in the period around the turn of the century, but have decreased tremendously in late years, when surer methods of detection and prevention have been widely used and are now "standard" practice.

The same trend has been followed with respect to fatalities from explosives, which were a major problem from 1895 to 1930, but fatalities from this cause, too, have decreased in number as safer explosives have been invented and widely adopted, and safer methods of handling have been rigidly enforced by the operators.

Fatalities due to accidents in the shafts have responded to enlightened measures of protection, and have almost disappeared, although they were factors of the industry until about 1920.

All these conclusions are based upon Table 5, furnished by the U. S. Bureau of Mines.

TABLE 5—*Causes of Fatalities in Anthracite Mines*, 1870–1946[a]

Year	Falls of Roof and Face	Haulage	Gas and Dust Explosions	Explosives	Electricity	Machinery	Shaft	Misc.	Total Underground	Stripping	Surface	Total
1870	57	15	10	8		1	27	72	190		21	221
1880	90	38	21	11			5	50	185		17	202
1890	132	57	70	18			24	25	330		48	378
1895	185	53	32	46		2	18	28	364		57	421
1900	164	63	38	42	[c]		19	25	351		60	411
1905	296	82	34	62	5		42	32	551		93	664
1910	253	93	20	82	13		20	28	509		92	601
1915	261	80	34	79	4	1	10	57	526		60	586
1920	137	73	36	49	6	1	22	39	416		75	491
1925	170	56	43	53	4		4	20	350		50	400
1930	231	40	30	47	8	3	2	43	404	8[d]	32	444
1935	140	30	23	19	2	3	10	12	239	12	23	274
1940	105	36	5	8	7	2	3	6	172	5	7	184
1941	100	27	8	12	5		6	14	172	6	16	194
1942	132	37	9	13	6	1	1	11	210	4	12	226
1943	110	38	15	9	1	1	1	11	195	10	21	226
1944[b]	81	24	3	17	3		5	17	151	8	13	172
1945[b]	72	23	3	9	2	2	3	13	130	2	11	143
1946[b]	102	21	2	8	3	1	1	15	151	10	9	170

[a] Figures from Bureau of Mines.

[b] Tentative.

[c] First fatality from electricity reported in 1898.

[d] Stripping fatalities separated from surface accidents after 1930.

INDUSTRIAL RELATIONS

One of the vital problems of the industry has always been that of industrial relations. The industry was beset by strikes in the late '60s and early

'70s, sporadic movements at isolated locations, some of them under an organization known as the Workers Benevolent Association, which was short-lived. In 1887 the Knights of Labor entered the region with a vague program and ineffective strategy. Its organization covered all industries, not mining only, and also was short-lived. The need for organization by the mine workers themselves was clearly apparent.

The United Mine Workers came into the region about 1900, and in that year organized a strike that affected the entire industry except the employees of the Lehigh Coal and Navigation Co. That strike was settled but in 1902 the United Mine Workers called another industrywide strike, which lasted for six months and was accompanied by much violence, including fatalities. The strike was ended by the intervention of President Theodore Roosevelt, who took a then revolutionary step by intervening in a labor dispute that did not extend beyond the boundaries of a single state. The Commission he appointed brought in a report in 1903, which has been the basis of all subsequent agreements, and since that date the anthracite industry has operated exclusively under agreements between the United Mine Workers and the operators.

The Roosevelt Strike Commission set up a Conciliation Board, which has had a continuous and active existence down to the present time. It consists of the president of each of the three districts of the United Mine Workers, and three representatives of the operators. Failing to agree on disputes that come to it through a logical sequence, these disputes are referred to an arbitrator whose decision is final.

The establishment of the Board and this improved method of handling grievances did not end petty strikes, however, which have plagued the industry ever since its beginning, but the existence of the Anthracite Board of Conciliation and the chain of precedents it has built up have been a beneficial influence in industrial relations, so that the anthracite industry today offers the longest record of continuous contractual agreement between employers and their men that is afforded by industrial history in the United States—and in all the development of this system of industrial relations, the members of the Institute have had an active and creative part.

Sources of Information

This paper is a compilation of data gathered by a committee of the Anthracite Section of the A.I.M.E., consisting of:

Cadwallader Evans, Jr., *Chairman*
President, The Hudson Coal Co., Scranton, Pa.

John T. Griffith, Assistant Division Engineer, The Hudson Coal Co., Scranton, Pa.
H. H. Otto, Assistant General Manager—Engineering, The Hudson Coal Co., Scranton, Pa.
H. S. Gilbertson, Lehigh Navigation Coal Co., Lansford, Pa.
Wm. C. Muehlhoff, Chief Engineer, Philadelphia and Reading Coal and Iron Co., Pottsville, Pa.

This committee desires to acknowledge with thanks help given by the following:

Samuel Baker, Dean, International Correspondence Schools, Scranton, Pa.
Barrett-Haentjens Co., Hazleton, Pa.
W. L. Dennen, Engineer, The Hudson Coal Co., Scranton, Pa.
A. E. Dick, President, A. E. Dick Construction Co., Hazleton, Pa.
Edward Griffith, President, Glen Alden Coal Co., Wilkes-Barre, Pa.
W. J. D. Geary, Pennsylvania Power and Light Co., Wilkes-Barre, Pa.
D. Harrington, Chief Health and Safety Branch, Bureau of Mines, Washington, D. C.
Wilmot Jones, General Superintendent, Jeddo Highland Coal Co., Jeddo, Pa.
John Lloyd, Engineer (retired), Wilkes-Barre, Pa.
J. T. Ryan, Jr., General Manager, Mine Safety Appliances, Pittsburgh, Pa.
Vulcan Iron Works, Wilkes-Barre, Pa.
R. Y. Williams, Consulting Engineer, Pottsville, Pa.
G. L. Wilmot, President, Wilmot Engineering Co., Hazleton, Pa.

Seventy-five Years of Progress in Petroleum

BY EVERETTE LEE DEGOLYER

EVERETTE LEE DEGOLYER
Geology is Dr. DeGolyer's profession; petroleum is his business; and his reputation is world-wide. His most notable work probably was in successfully applying geology and geophysics to the search for, and discovery of, oil in the ground. His pioneer work in this field won him the Anthony F. Lucas Medal in 1940 and the John Fritz Medal in 1942. He served as Vice President of the A.I.M.E. from 1921 to 1926 and as President in 1927.

FIFTEEN thousand barrels of oil daily, the production of the United States 75 years ago, amounted to more than 90 per cent of world supply. Russia and Romania, neither of which produced as much as one thousand barrels daily, were the only other suppliers in substantial quantity.

The adolescent oil industry of the United States, a dozen years old in 1871, was still confined to the Appalachian region. Wells were drilled by cable tools; many of them were "kicked down" by manpower with a spring pole; and depths were measured in hundreds rather than thousands of feet—a 1000-foot well was a deep well. Casing was an innovation, come into general use only a few years previously and still so new as to be subject to bitter patent litigation.

Crude oil was packaged in wooden barrels and shipped by flat boat and barge on the creeks and rivers and by railroad. Such pipe lines as existed were only a few miles long. There were many refineries. Pittsburgh, Cleveland and the Atlantic seaboard were refining centers. Refineries were very small, however, and their operations consisted essentially in simple fractionation by distillation and treating for quality. The products in demand were burning oil or kerosene and lubricating oils. Oil was not yet used as fuel and gasoline was a nuisance to the refiner.

Retail marketing was through the local grocery stores. The customers' "coal-oil" can was sent to the store to be filled and was returned sealed with a potato jammed onto its spout.

GROWTH AND DEVELOPMENT OF THE OIL INDUSTRY

The history of the petroleum industry may be divided conveniently into three periods: (1) the lamp and lubricating-oil period, from the beginning of the industry in 1859 to about 1900, (2) the transition or fuel-oil period, from about 1900 to about 1910, and (3) the gasoline or motor-fuel period, from about 1910 to the present time. Substantially less oil was produced during the whole of the first period than is now produced in a single year. Together the last two periods, beginning about 1900, span the modern industry.

This classification is based upon the importance of products. The year 1900 as a dividing point between the first two periods, however, has an importance far transcending that of a change in type of products marketed. It is marked by a shift of important producing centers from east to west; a decline in the production of the Appalachian region and the development of bonanza fields in California, Texas and Oklahoma. It is marked also by the beginning of increases in production of crude oil so great that the industry had to find additional markets if it was to survive. This it did by invading the fuel market formerly held by coal.

The year 1910 as a dividing point between the second, or fuel-oil period, and the present, or motor-fuel period, is chosen somewhat more arbitrarily, and might be shifted eight to ten years forward by another student of the subject. I have chosen 1910 because by then the use of fuel oil had been widely accepted; because, with almost half a million motor vehicles in use, we were certainly on the threshold of the motor-fuel period, and because, with the dissolution of the old Standard Oil Co. in 1911, the industry found itself with an adequate foundation for expansion with which to begin to meet the tremendous demands that would result from the rapid increase in the use of motor transport.

TABLE 1—*Production of Crude Oil*

PER CENT

Region	In 1900	In 1910	In 1945
Appalachian	57.04	12.8	1.2
Lima-Indiana	34.19	3.4	0.2
Illinois		15.8	4.3
Mid-Continent		28.2	49.0
Gulf Coast		4.6	21.09
Rocky Mountains	0.69	0.16	2.8
California	6.79	34.84	19.0
Not accounted	0.29	0.65	2.4

Strictly from a production viewpoint, the history of the industry should be divided into an open-flow period from the beginning in 1859 to the establishment of proration as an effective control about the end of 1935 and a period of proration control from 1935 to the present. Distinction between these two types of production practice is important, but since the date of change occurred within the present, or motor-fuel, period it will be considered in the discussion of that period.

Some idea of the broader shifts in production centers from the condition 75 years ago, when production of crude oil came only from the Appalachian region, may be gained from Table 1.

Lamp and Lubricating-oil Period, 1859–1900

The oil industry generally reckons its beginning from the completion of the Drake well at Oil Creek, Pennsylvania, on Aug. 29, 1859. Successful wells, purposefully drilled for natural gas, had been completed near Fredonia, New York, as early as 1821, and petroleum in quantities great enough to make it a nuisance—in quantities greater than found in the Drake well—had been encountered in brine wells drilled in West Virginia, Kentucky, New York and Pennsylvania through the early 1800s. The significance of the Drake well lies in the fact that it was purposefully drilled for oil and in the chain of consequences that followed its successful completion.

Drake's sole guide to the location of his famous well was to drill near an oil seepage. His example was followed promptly and by 1871 wells had been drilled in most states where seepages were to be found. A dry hole was drilled in Kansas in 1860 and one in Wyoming in 1869. A well at Terre Haute, Ind., showed oil in 1865. A well that produced small amounts of oil for a time was drilled in the Canon City field of Colorado in 1862, another in the Nacogdoches field of Texas in 1866 and another in Overton County, Tennessee, in the same year.

Wells were drilled in Clark County, Illinois, in 1866–1867, "and enough oil was found to give the name Oilfield to the hamlet which sprang up during the excitement." Kentucky was swept by a campaign of wildcat drilling in the late '60s. California enjoyed an abortive oil boom in 1864–1865. Scores of companies were organized, some heavy oil was produced from tunnels, and in 1867 a well was drilled which for a few happy moments flowed over the crown block of the derrick.

All of these were false starts. Our 15,000 barrels daily of 1871 came entirely from the Appalachian fields; most of it from Pennsylvania, with small amounts from New York and West Virginia.

The history of oil production in the United States during the rest of the nineteenth century was marked by continued discovery and development of fields in western Pennsylvania, in New York, and in West Virginia; by the discovery and development of the famous Trenton lime rock or Lima-Indiana region of northwest Ohio and northeast Indiana; by development of substantial production in California and of production in modest amounts in Texas and Colorado. Some oil was being produced in Kentucky, Tennessee, Kansas, Oklahoma and Wyoming but the amount was too small to be significant.

Production in Pennsylvania continued to increase as the result of the discovery of numerous pools of moderate size, and reached a secondary peak of some 26,000,000 barrels for the year 1881, with the intensive development of the prolific Bradford pool. Its all-time peak of 31,424,000 barrels was reached for 1891 with the development of the McDonald pool in Washington County. Bradford was discovered by a small well in 1871 and had attention focused on it by the completion of a 70-barrel well in late 1874. By the end of 1876, development was proceeding at a rapid rate, and by the beginning of 1878 storage was full and the field was under pipe-line proration. Peak production was reached in September 1880 with an average daily production for the month of 69,000 barrels. McDonald was discovered in 1890 and developed so rapidly that it reached its peak production of 75,000 barrels daily in November 1891. The Sistersville pool, West Virginia, was discovered in 1891 and reached its peak production of 23,000 barrels daily in March 1893.

The Lima-Indiana region was opened by the discovery of a gas well drilled near Findlay, Ohio, in late 1884 and by the first oil well drilled in the spring of 1885. More than a million barrels was produced from the Ohio side of this region in 1886, the first flowing wells having been completed early in that year. In 1887, gushers of 5000 to 8000 barrels daily capacity were found in the Wood County portion of the area just north of Findlay, and Ohio's production for the year was more than 5 million barrels.

The Indiana section accounts for little more than 20 per cent of the total production of this important region and it lagged behind Ohio in development. Natural gas was discovered in September 1886 and some oil in the winter of 1886–1887, but the first commercial well was not completed until June 1890. Production increased rapidly until it reached a peak of almost 11 million barrels for the year 1905.

The production of Ohio surpassed that of Pennsylvania for the first time in 1895, and Ohio became the first oil-producing state of the nation, a position it continued to occupy until 1903, when its production was exceeded by that of California. Ohio reached its peak in production during the year 1896, when more than 20 million barrels was produced. One of the results of this first important discovery away from the fields of the Appalachian region was that the Standard Oil Co. for the first time entered the producing end of the business, with the organization of the Ohio Oil Co. in 1887.

The discovery well of the Florence oil field, Colorado, was drilled in 1876. From that time development was more or less continuous, and during the nineties the field produced from 1000 to 1500 barrels daily.

California, retrieving her failure of 10 years earlier, established production about 1875 with the completion of a small well in Pico Canyon, near Newhall. Except for a discovery at Puente, near Los Angeles, about 1880, development continued chiefly in the small fields of the Ventura-Newhall region until 1892, when the prolific Los Angeles pool was discovered. Development increased rapidly. By the end of the century production was at the rate of more than 15,000 barrels daily.

Small amounts of oil had been discovered in Texas at Nacogdoches in 1866, natural gas in Young County in 1871, heavy oil near San Antonio in 1886 and small shows at various other points. The first discovery of a field of commercial importance was the result of an oil show encountered on June 9, 1894, in a well being drilled for water by the City of Corsicana. The first oil well was completed Oct. 15, 1895, with a production of 2½ barrels daily. The production of the state for 1896 was 1450 barrels and for 1897 it was 65,975 barrels. More than one thousand barrels daily was produced in 1898 and by the end of that year runs were started in a small refinery built by the predecessors of the Magnolia Petroleum Co. The field reached its peak of production with 79,027 barrels for the month of August 1900.

Approximately one billion barrels of oil had been produced in the United States by the end of the past century, about as much as is now produced in a period of seven or eight months. Production for the year 1900 amounted to about 175,000 barrels daily. More than 91 per cent of it came from the eastern fields. Slightly more than half of this fraction came from the Appalachian fields and the remainder from the Lima-Indiana region. California furnished a little less than 7 per cent of the production; Texas, 1.3 per cent; Colorado, 0.4 per cent, and all other fields a little less than 0.25 per cent.

The production of the United States was exceeded by that of Russia for the first time in 1898 and the lead thus lost was not regained until 1902.

Exploratory wells were still being drilled near seepages, on trends or for any of a number of less valid reasons. Wells were still being drilled with cable tools, though the rotary, borrowed from the water-well driller, had been introduced into the Corsicana field. The deepest well, the Bedell, in Pennsylvania, had been completed to a depth of 5582 feet in 1897, but wells 2000 feet deep were still considered deep wells and very few had been drilled to depths as great as 3000 feet. Wells were still produced wide open as long as they would flow and then were pumped.

Pipe-line systems had been extended as far west as the Lima-Indiana region, refining had been improved somewhat but a refinery still consisted essentially and almost solely of a plant for primary distillation. Oil was beginning to be used as fuel but the products in chief demand were still kerosene and lubricating oils. Retail marketing had changed but little, but the tank wagon had been introduced and door-to-door distribution thus provided. Gasoline was still a troublesome product, though there was some use of it for gasoline stoves and torches and it was beginning to be used as a fuel in the newly introduced automobile.

Fuel-oil or Transition Period, 1900–1910

At the turn of the century came the spectacular discovery of the Spindletop field by the completion of the Lucas gusher on Jan. 10, 1901, with an estimated potential production of 75,000 to 100,000 barrels daily. Prospecting spread throughout the coastal plain of Texas and Louisiana and resulted in the discovery within the next few years of Jennings (1901), Sour Lake (1901), Saratoga (1902), Batson (1903) and Humble (1905). Spindletop cap-rock peaked with a production for the year 1902 of 17.42 million barrels; Sour Lake, for 1903 with almost 9 million barrels; Batson, for 1904 with 10.9 million barrels. Humble was proved as an oil field early in 1905 and its cap-rock production peaked during that year with 15.59 million barrels. Development was slow at Jennings. Shipments commenced in 1902 but its peak was not reached until 1906, when it produced 9.02 million barrels.

Meanwhile oil fields were being developed at various points in the Mid-Continent. Production from the shallow fields of southeastern Kansas amounted to almost one million barrels for 1903, and in the shallow fields of northeastern Oklahoma exceeded 1.3 million barrels in 1904. A pipe line was built from these fields to a refinery at Whiting, Ind., in 1904, by the Prairie Oil and Gas Co., and by 1906 it had been doubled. The famous Glenn pool of Oklahoma was discovered about the end of 1905 and its peak was reached with a production of 20.49 million barrels for 1908. The Gulf and Texas companies each built a pipe line to the Gulf Coast in 1907.

The Caddo, Louisiana, field was proved in 1906. It developed slowly, produced slightly more than 5 million barrels in 1910, and did not reach its peak until 1918, when 11.14 million barrels was produced.

The first of the important fields of the LaSalle anticline, eastern Illinois, was discovered in 1906, and by 1908 this group of fields had peaked with a production for the year of more than 33.5 million barrels. A secondary peak was reached in 1910, when almost as great an amount was produced.

California had not lagged. It had had to meet the necessity of finding new markets for rapidly increasing production before the United States east of the Rockies had been troubled with that problem. As one of its pioneer producers testified, "the problem is not to find oil but to find a market." During this period the many fields of the Ventura-Newhall district yielded a steady production of around 15,000 barrels daily. The Coalinga pools (East, 1900; West, 1901) developed slowly and almost reached their peak of production with more than 18.5 million barrels for 1910. Kern River (1899) developed more rapidly and peaked with 17.22 million barrels for 1904. The mammoth Midway-Sunset field (1900), second in rank of total production for the nation, developed slowly but jumped to the lead from 4.23 million barrels in 1909 to 20.39 million barrels in 1910. McKittrick (1898) developed slowly but peaked with an output of 5.80 million barrels in 1909. Brea-Olinda (1897) almost peaked with 6.28 million barrels in 1910. The Los Angeles City fields of Los Angeles (1892), Salt Lake (1902) and Beverly (1908) peaked with a production of over 5 million barrels in 1908. There were other minor fields, and overall California production steadily increased during this period from 4.32 million barrels in 1900 to 73.01 million barrels in 1910.

Production from the Appalachian fields declined gradually from 36.29 million barrels in 1900 to 26.89 million barrels in 1910, and that of the Lima-Indiana field from 21.75 to 7.25 million barrels annually. Kentucky enjoyed a brief period of increased activity as a result of which production for each of the years 1904 and 1905 was in excess of 1.2 million barrels, but production declined rapidly and by 1910 was down to less than half a million barrels. Minor production from Colorado continued and there was insignificant production from Michigan, Tennessee and Wyoming. Salt Creek, Wyo., was discovered in 1908 but serious development did not begin until 1911.

DEVELOPMENT OF FUEL-OIL MARKET

Oil must have been used as fuel occasionally and in small amounts since prehistoric time but the first recorded substantial use was in Russia in 1861. By 1863 it was being used for fuel as an atomized spray or gas and as early as 1882 the manager of a Russian railway had converted 143 of his locomotives to oil burning. Experiments were being made with the use of oil as fuel under marine boilers on the California coast as early as 1865, and in the late '80s experiments were being made with oil as fuel for locomotives. By 1897 oil was being largely used for fuel on a portion of the Santa Fe system between Barstow and San Diego in southern California and it was being used for brick and tile kilns and for heating the courthouse in Los Angeles. It seems probable that oil was first widely used as fuel in the United States in California, to which coal had to be brought from considerable distances and where it was expensive.

After the discovery of the Gulf Coast fields, the use of fuel oil mounted rapidly. By 1906 the railroads alone were using 15.57 million barrels annually. This use had increased to 24.58 million barrels for 1910 and to 33.6 million barrels for 1912.

The British Admiralty had pioneered in the naval use of fuel oil and in 1909–1910 the American navy installed auxiliary oil burners on the battleships "North Dakota" and "Florida." For 1912 the U. S. Geological Survey estimated the national consumption of fuel oil to be the barrel equivalent of one third of the nation's production.

The use of fuel oil, including gas oil and distillate, has continued to increase on trend parallel to that of gasoline, generally about 100 million barrels below it, but during the recent war practically on a parity with it. The important aspect of the fuel-oil period, however, is that during this period of production of oil far in excess of any amount that could be economically used in the manufacture of lamp and lubricating oils, and before the arrival of the period of great demand for motor fuel, the oil industry was able to maintain itself, and even expand, by finding a substantial place in the fuel market.

Gasoline or Motor-fuel Period, 1910

OPEN-FLOW PERIOD, 1910–1925

California

Production in California continued to increase. Coalinga peaked in 1912 with 19.54 million barrels; Midway-Sunset reached a peak of 50.025 million barrels in 1914. The price for oil had fallen to 30 cents per barrel in September 1910, increased to 60 cents per barrel for 28° gravity crude and held at that point until late April 1914. By July 1, 1914, crude was again down to 40 cents per barrel. Stocks increased in May 1915 to a high point of 60,829,315 barrels. Drilling operations fell to a low of 334 completions for the year 1915. From 1915 on, stocks were decreased until they reached a low of 20,930,000 barrels in 1920, and prices increased gradually from an average of 60 cents for 1914 to $1.409 per barrel in 1920.

Meanwhile Lost Hills (1910), East Coyote (1911), South Belridge (1911), North Belridge (1912) and Elk Hills (1919) had been discovered in the San Joaquin Valley. Ventura Avenue (1916) had been discovered. These did not immediately contribute substantially to overproduction. Montebello (1917) peaked at 12.1 million barrels for 1919 and Richfield (1919) peaked at 8.31 million barrels in 1922; both Los Angeles Basin fields.

With production thus reasonably stable and the outlook serene, there began to be discovered a galaxy of wonder fields in the Los Angeles Basin, the output from which all but drowned California in oil and dominated the oil market of the world for the next 6 to 8 years. Huntington Beach (1920) peaked with a production of 34.35 million barrels in 1923, as did Long Beach (1921) with a production of 68.81 million barrels and Santa Fe Springs (1921) with 79.78 million barrels. Torrance (1922) peaked in 1924 with 17.52 million barrels and Dominguez (1923), Inglewood (1924) and Rosecrans (1924) peaked in 1925 with productions of 13.32, 18.34 and 7.26 millions of barrels, respectively.

Texas and New Mexico

Gulf Coast—Further discoveries in the Gulf Coastal region and the opening of new regions began to lay the basis for the preeminence of Texas as an oil-producing state. The development of Vinton (1910), La., had shown the importance of flank sands, and there followed a new campaign of prospecting for similar deposits in known fields and on known domes not yet productive. Deeper sands were found at Sour Lake in 1913 and production increased to a near peak of 5.2 million barrels in 1914. Flank production was found at Humble late in the same year, and the production of the field increased to 11.06 in 1915. Deeper sands were discovered at Goose Creek in 1916, and the field peaked with a production of 8.9 million barrels in 1918. Production from flank sands was discovered at West Columbia (1917) and Hull (1918) and these fields peaked in 1921 with productions of 12.08 and 8.2 million barrels, respectively. The deep sands at Spindletop were found in 1926 and the field reached an all-time peak of 20.8 million barrels in 1927. Barbers Hill (1916) found important flank production in 1926 and 1927 and peaked in 1933 with a production of 8.08 million barrels. Conroe (1931), under proration, produced in excess of 15 million barrels each year in 1935, 1936 and 1937.

North Texas—Oil had been produced commercially from the Petrolia (1902) field of Clay County as early as 1904, but North Texas (Railroad Commission District No. 9) became important with the discovery of Electra (1911). Electra, because of large leasehold, was developed in a slow and orderly manner, and, although it is one of the nation's great fields, reached a peak of only 8.7 million barrels in 1913. The first boom came with the development of the Burkburnett Townsite pool (1918) and excitement reached a fever heat with the development of the Northwest Extension (1919), which peaked with a production of 17 million barrels in 1920. The North Texas district had produced a total of approximately 900 million barrels to the end of 1945 and almost half this oil had come from Wichita and Wilbarger Counties. From Wichita County alone has come some 400 million barrels, 85 per cent of which has come from the three bonanza fields of Electra (1911), Burkburnett consolidated (1912, 1918, 1919) and KMA (1931).

North Central Texas—North Central Texas (Railroad Commission District No. 7-B) also produced oil from an early date. Commercial production began between 1910 and 1914, but the first field of more than minor importance to be discovered was Ranger (1917), Eastland County, the discovery well for which was completed on Oct. 25. There ensued one of the wildest of booms, which, because of flashy production, collapsed almost as quickly as it had originated. During the five years 1918–1922, following the year of the discovery of Ranger, one third of all the 414 million barrels that had been produced from this district to the end of 1945 came from Eastland and Stephens Counties. The district contains a great number of pools. Pools with an estimated ultimate production of 25 million barrels or better are rare—three or perhaps four. There are perhaps six to ten pools of 8 to 10-million-barrel caliber and ten to twenty pools of 4 to 5-million-barrel type. From this size the pools grade downward to what one student terms productive "spots."

No equal period since the days of Spindletop has been more important in the oil history of Texas than the six months of 1920–1921, which saw the establishment of substantial oil production in four of her important regions —the fault-line region, in which Mexia (1920) was discovered, on Nov. 25; the Permian Basin of West Texas, in which Westbrook (1921) was discovered on Jan. 9; South Texas, in which Mirando (1921) was discovered on Apr. 17 and the Panhandle (gas 1918, oil 1921), in which oil was discovered on May 5.

Fault-line Structures—Gas had been produced from the Mexia structure since 1912 and comparatively small amounts of oil from the old shallow pools at Corsicana and Powell. The first really important production, however, was from the development of the Woodbine sand at Mexia (1920), which peaked with a production of 176 thousand barrels on Feb. 12, 1922, and with a production of 33.8 million barrels for the year. Far to the south another fault-line field, Luling (1922), producing from the Edwards limestone, was discovered and peaked with a production of 9.7 million barrels in 1925. Powell (1923) peaked with a production of 354,893 barrels on Nov. 14, 1923, and with 33.2 million barrels for the year 1924.

West Texas—The Permian basin of West Texas and New Mexico came into commercial production with the discovery of the Westbrook (1921) pool in Mitchell County. This was followed by the discovery of Big Lake (1923), Itan-East Howard (1925), McCamey (1925), Howard-Glasscock (1925) and various smaller pools. Pronounced leasing activities followed the discoveries of 1925, and Yates (1926), Hendricks (1926) and the Church-Fields-

McElroy (1926) were discovered. To this stage in its development the production of this province had suffered from lack of adequate transportation facilities, but during 1927 four major trunk pipe lines were built into the area.

Voluntary proration became effective in Yates on Oct. 1, 1927. Hendricks was prorated by the Railroad Commission of Texas on May 5, 1928 and the proration of Yates was taken over by it, July 1. Howard-Glasscock was prorated on Aug. 1. Big Lake peaked with a production of 11.1 million barrels in 1926, Church-Fields-McElroy with a production of 23.8 million barrels in 1927, Hendricks with a production of 58.7 million barrels in 1928, Howard-Glasscock with a production of 14.9 million barrels in 1928, and Yates with a production of 41.3 million barrels, also in 1928.

New Mexico—New Mexico was an oil-producing state from the early '20s as a result of the discovery of a number of minor fields in the San

TABLE 2—*Important and Bonanza Fields of South and Southwest Texas*

Field	Year of Discovery	Peak	
		Million Barrels	Year
Important Fields			
Government Wells	1928	6.6	1934
Greta	1933	5.4	1936
Seven Sisters	1934	3.6	1937
Loma Novia	1934	6.4	1937
Placedo		3	1937
Plymouth	1935	5	1937
Heyser	1936	3.5	1939
Aransas Pass	1936	3	1939
Benavides	1937	3.7	1938
East White Point	1937	4.5	
Bonanza Fields			
Tom O'Connor	1934	18.7	1944
West Ranch	1938	8.1	1944
Willimar	1940	2.8	1945
Merging across intervening King Ranch[a] of:			
Agua Dulce	1928		
Stratton	1931 1937		
Seeligson	1937		

[a] This gives promise of being second only to East Texas.

Juan Basin in its northwestern corner, but it did not become an important producer until the development of its Permian Basin fields in its southeastern corner. The earliest developments were at Maljamar (1926), Jal (1927), and Langlie (1927). Its major production followed the discovery of Hobbs (1928), Eunice (1928) with its Monument (1934) extension, Cooper (1929) and Vacuum (1929). Hobbs peaked in 1931 with a production of 12.8 million barrels, Cooper in 1936 with a production of 2.9 million barrels; Eunice-Monument in 1937 with a production of 21.9 million barrels. Vacuum produced 5 million barrels in 1944 and may not have reached its peak.

South and Southwest Texas—South and southwest Texas was also an area of unimportant production until it was opened with the discovery of the Mirando (1921) pool. In the earlier stages of its development, this area was preferred by independents. Wells were relatively shallow and cheap. With intensive development and deeper drilling, however, major companies became increasingly interested. Refugio (1922), which peaked in 1930 with a production of 11.7 million barrels, and Saxet (1923), which peaked in 1937 with a production of 12.8 million barrels, were the first really important fields. Some of the important fields of this region and the bonanza fields are listed in Table 2.

Texas Panhandle—The great Panhandle gas field was discovered by a gas well completed in 1918. Oil was found on May 5, 1921. The field peaked with a production of 40.09 million barrels in 1927.

Oklahoma and Kansas

Oklahoma again came into the limelight with the discovery of Cushing (1912) and Healdton (1913). Cushing peaked in April 1915 with an average daily production of some 300,000 barrels and produced 49.08 million barrels for the year. Healdton peaked with a production of 18.4 million barrels in 1917. Hewitt (1919) was also a major discovery of this period. Before production was again within bounds, Burbank (1920) and Tonkawa (1921) were discovered. Burbank peaked in 1923 with a production of 31.7 million barrels, as did Tonkawa with a production of 28.03 million barrels.

Meanwhile two important fields were discovered in Kansas: Augusta (1914) and El Dorado (1915). El Dorado reached a peak of almost 100,000 barrels daily for a few days in September 1917 and produced 29.2 million barrels in 1918, its best year.

With production still at a high point, 1926 and 1927 were marked in Oklahoma by the discovery of a galaxy of five major pools on the so-called Seminole plateau. Seminole City (1926), Bowlegs (1926), Earlsboro (1926), Little River (1927) and St. Louis (1927) are among the nation's 100 top pools and each has produced in excess of 100 million barrels.

A new oil-producing province was opened in western Kansas with the discovery of the Fairport (1923) pool, Russell County, 120 miles distant from the nearest production.

Wyoming

Small quantities of oil were produced in Wyoming beginning with 1894, but production first became substantial in 1912, with the development of the great Salt Creek (1908) pool. There was a boom of exploration in the state with the development of Big Muddy (1915). The peak of production for the state was in 1923, when Salt Creek peaked with 35.3 million barrels.

Arkansas

Arkansas became an oil producer with the discovery of the El Dorado (1920) field but became really important with the discovery of the great Smackover (1922) field, which peaked in 1925 with a production for the year of 74.4 million barrels.

Louisiana

For the period 1910–1925, there was no important development in coastal Louisiana. Jennings continued to decline and small fields such as Vinton (1910), Edgerly (1914), New Iberia (1917) and Lockport (1924), were developed.

In northern Louisiana development of production in DeSoto and Red River Parishes and in the Pine Island district kept production up and the development of Homer (1918) and Haynesville (1921) brought the production of the state to temporary peaks of more than 35 million barrels for each of the years 1920 and 1922.

Eastern Fields

There was no notable increase in production in the eastern fields during the period 1910 to 1925. Production was increased slightly in New York and Pennsylvania by the continued development of water-flooding, chiefly in the Bradford field; it was maintained in Indiana and Ohio and increased in Kentucky by continued drilling, and declined in West Virginia and Illinois.

STABILIZATION PERIOD, 1925–1935

As Ralph Arnold stated before this Institute at its New York meeting in February 1923: "The greatest need of the oil industry at this time, as in the past, is stability." The characteristic pattern of the industry from its beginning in 1859 to the reasonably effective establishment of proration about 1935 had been a rhythm of alternating periods of overproduction of crude oil, at times lasting for many years and accompanied by low, often inadequate and even disastrous field prices with shorter periods of production balanced with consumer demand or even real or anticipated shortages accompanied by high prices. As one student has said, "The industry is one of continual crisis; there is always either too much or too little."

The infant industry was barely two years old when the first of these crises occurred. Oil from the Drake well sold for $20 per barrel. This brought overproduction and a drop in price, and with the panic resulting from the outbreak of the Civil War, prices broke to an all-time low of 10 cents per barrel. Thousands of barrels of oil ran into Oil Creek, wells were "being plugged to save production" and by March 1862, "stopcocks are being applied to keep oil in the ground." By July 1864, with the suspension of specie payment, the price stiffened to a secondary high of $14 per barrel. This stimulated development and, with a wild speculation in stock-company promotion and a war tax of $1 per barrel levied by the Federal Government from April 1865 to May 1866, prices again fell. During the Pithole orgy of 1866, there was talk of a combine of producers to exact better prices from the refiner, but nothing came of it. During the depression of 1867 it was recognized that production was excessive, and that the only relief would be increased markets or curtailment of production. Within the month, however, there was "much excitement over alleged scarcity of oil." The industry was less than 10 years old but the characteristic pattern had been established.

In March 1872, Sunday shutdown of producing wells was achieved for a short time, and by the end of the year a short-lived and ineffectual agency had been formed to control the sale of crude oil. Apparently a shutdown of drilling was proposed but failed and a shutdown was proposed in the following year but nothing came of it. The Butler County fields were developed in 1874, with disastrous results. "The sheriff finds it necessary to keep ten or twelve deputies constantly employed cleaning out enthusiastic borers for half-dollar oil." The year 1876 was one of better prices. The price reached $4.2375 for December, which was the high point, not reached again in 20 years.

Meanwhile the flood of oil from Bradford came on. By 1879 there was "oil flowing on the ground for want of tankage." Attempts were made to control production but they failed, and in that year an exasperated producer, after reciting a belief that "the shortest way to two-dollar oil is through 25-cent oil," offered a resolution that "we favor the pushing of the drill as rapidly and as diligently as possible, until the goal of 25-cent oil is reached." The flood of Bradford oil continued to depress the market until the field's decline started in 1882. The industry continued in fair balance until 1887, when it again suffered from overproduction.

Curtailment of production was achieved during 1887, and it is said to have been the most effective until then in the history of the industry. Many wells were closed and when they "were opened again many of them flowed only about two thirds as much as before the shutdown," thus doubtless laying the foundation for the belief commonly held during the remainder of the open-flow period that a well could be completely closed only at the serious risk of impairing its productive capacity. Pennsylvania producers had to continue to endure lean years. Shutdown movements were proposed occasionally in this period, notably during 1890 and 1891 as the great Macdonald field reached its peak, but little is known regarding them. It was not until 1895 that the price for Pennsylvania crude oil again averaged more than $1 per barrel.

This early history, which I have recounted in some detail because it is typical of other regions as well, is the result of the fierce competition in oil production brought about by the rule of capture. An early Pennsylvanian jurist held that oil is *ferae naturae*, that it is not property until reduced to possession and that the landowner has the right at common law to drill on his land and produce oil therefrom even though it might be proved beyond question that some of the oil comes from neighboring properties. For the most part, the landowner leases his oil rights, retaining a royalty interest as part compensation. Courts have commonly held that the lessee must protect this royalty right by necessary offset wells, due diligence in operation, etc. In practice, therefore, the rule of capture has not only invited but has forced gold-rush tactics in the development and production of an oil field of divided ownership. The net result has been that wells were drilled as rapidly as possible, on absurdly close spacing patterns in many places, and produced continuously to their full potential capacity—open flow.

Efforts to restrict the great floods of production resulting from successful prospecting and open flow for most of the first quarter of the present century were largely through voluntary agreement between the producers or proration by pipe lines. They were a makeshift at the best and met with an absolute minimum of success. Apparently the producers reached some sort of agreement in 1896 as a result of the floods of oil from the Los Angeles Basin in California. There was a break in prices in 1910 as a result of overdevelopment of the San Joaquin Valley fields, and oil was down to 30 cents a barrel by September. It was about this time that various independent producers' agencies were organized, and the situation held reasonably well until the discovery of the great fields of the Los Angeles Basin. A voluntary scheme of proration was agreed to among the producers for certain areas in 1923. Statewide proration by voluntary agreement and under the jurisdiction of an umpire dates from 1929.

There was a great flood of overproduction as a result of the development of the Spindletop pool in Texas, and much oil was wasted, but no effective restriction was devised. In Oklahoma the peak of production for the famous Glenn pool in 1907 was marked by flagrant abuse of their control of pipe-line facilities by companies that owned the lines, and in bitter attacks on the lines by the independent producers. With the flood of oil in 1914 resulting from the overdevelopment of Cushing and Healdton in Oklahoma, the Oklahoma Corporation Commission came into the picture, and by its order No. 920, of June 5, 1915, restricted production in the Healdton field to market demand, and among other things prorated production to meet such demand on the basis of potentials. There were continued attacks by the independents on the pipe-line-owning companies and voluntary proration was arranged at Cushing with an umpire paid by the companies.

Wyoming also was in difficulties as the great Salt Creek field reached its peak of production in 1923. Salt Creek operators met several times in 1922 and organized the Salt Creek conservation committee. Suspension of drilling from Dec. 1, 1922 to May 1, 1923 was arranged and proration was managed until added pipe-line facilities could take care of the oil, in late 1923. This effort is regarded as having held the situation in check, "in spite of the failure of a small minority of the operators to support it."

With the discovery of the great fields of the Los Angeles Basin in 1920 and 1921 and the peak of their production in 1923, the widespread opening of new oil-producing regions in Texas in 1921 and peak or near peak production in the early '20s in Smackover, Ark., Mexia and Powell, Texas, Salt Creek, Wyo., and Burbank and Tonkawa, Okla., it had become reasonably apparent that the industry could not continue to survive under open-flow production.

Early attempts at voluntary proration were made as the result of the development of the Yates field in Texas and the group of fields on the Seminole plateau in Oklahoma. On Aug. 9, 1927, the Oklahoma Corporation Commission issued its order No. 3944, which provided for a continuance of the voluntary proration for Seminole, and on Sept. 9, 1928, it entered its first statewide proration order, No. 4430, which seems to have been the first statewide order issued by any state. By this order the settled fields were allowed full production and the eight flush fields in the Greater Seminole area were allowed to produce the remainder of the estimated demand of 700,000 barrels daily on the basis of percentage of potentials. The discovery well of the great Oklahoma City field was completed on Dec. 4, 1928.

Under the Act of 1929 the Railroad Commission of Texas conducted extensive hearings, and on Aug. 14, 1930, issued its first statewide proration order, effective Aug. 27, limiting the production of the state to 750,000 barrels daily. The discovery well for the great East Texas field was completed on Oct. 3, 1930, and within a few months four wells had been completed over a length of 25 miles. As gaps began to be filled in by development, this mammoth field was soon outlined. From this point on there is a long history of judicial attacks on proration, violations to and including actual theft, martial law in Oklahoma City and East Texas, until, by the summer of 1933, proration may be said to have become fully established in so far as fundamentals were concerned. Administrative procedure was still subject to considerable attacks but finally a workable method for statewide proration was established in Texas and became substantially effective with the passage of the Connally "Hot Oil Act" in 1935.

Statewide proration is effectively administered in the states of Texas, Oklahoma, Kansas, Arkansas and Louisiana. California, Wyoming and Illinois have no conservation acts that admit of state-controlled proration. California, with occasional assistance such as the Petroleum Code of the National Recovery Administration (NRA) in 1933 and 1934 and the wartime controls of the Petroleum Administration for War (PAW) during World War II has managed to struggle along with statewide proration by voluntary agreement since 1929.

PRORATION PERIOD, 1935–

During the period from 1935 to the present there has been no considerable change in the fields east of the Mississippi River except for the discovery of considerable amounts of new production in Illinois, important fields in Mississippi and the establishment of moderately substantial production in Michigan in 1929. At the beginning of the period, production in Pennsylvania was increasing as the result of water-flooding operations at Bradford, and it reached a peak of 19.2 million barrels in 1937, since which time it has declined to approximately 13 million barrels annually.

West Virginia has declined slowly from 3.9 million barrels in 1935 to a little less than 3 million barrels at the present time.

As the result of the use of geophysical methods, new fields were discovered in Illinois in 1937 and the state reached a new peak of production in 1940, with 147.6 million barrels. Clay City Consolidated (1937), Louden (1937) and Salem (1938) are the bonanza fields but a great number of smaller fields have been discovered.

Mississippi became an important oil-producing state with the discovery of Tinsley (1939), and a number of additional fields, of which Cranfield (1943) appears to be the most important, have since been discovered.

Geophysical methods were introduced into the United States in 1922 and were a spectacular success in the Gulf Coastal region of Texas and

Louisiana. This area, which previously had been the most difficult in the United States to prospect, with the introduction of geophysics, micropaleontology and various improvements in rotary drilling, became one of the best areas for successful prospecting.

Among the bonanza fields discovered in Texas were Sugarland (1928), Thompson's (1931), Hastings (1934), Old Ocean (1934), Katy (1935), Webster (1937), West Ranch (1938) and Oyster Bayou (1941).

As a result of the more favorable proration schedules that prevailed in Louisiana during the late '30s, the Louisiana coast has been even more intensively prospected than has the Texas coast. Deep production discovered in 1929 at Jennings (1901) greatly enhanced the importance of that field. Among the bonanza fields discovered are Caillou Island (1930), Iowa (1931), LaFitte (1935) and Paradis (1939). In northern Louisiana the Rodessa field (1930), extending into northeastern Texas, was a most important discovery and in Arkansas, Schuler (1937) and Magnolia (1938) were the chief discoveries.

In northeastern Texas, Van (1929), Talco (1936) and Hawkins (1940) were the important discoveries of the period. In South Texas, the Darst Creek and Salt Flat fields were discovered in 1928 and Darst Creek was considerably extended in 1935. One of the most important fields of this area is the Tom O'Connor (1934) field.

During this period West Texas has been prospected with great success. Among the bonanza fields not previously mentioned are Ward-Estes (1929), North Cowden (1930), Goldsmith (1934), Seminole (1936), Slaughter (1936), Wasson (1936), Fullerton (1942) and the deep production at Keystone (1930), which was discovered in 1943.

In Oklahoma the most important discoveries since the development of the fields of the Seminole plateau are Fitts (1933), Cumberland (1940) and West Edmond (1943).

Development in Kansas has been chiefly in the fields of the Barton Arch in the western part of the state, the region that was opened with the Fairport (1923) discovery. Most of the fields are relatively small and only Silica (1931) appears to be of bonanza proportions.

In the Rocky Mountain area the chief developments have been the deeper sands at Lance Creek (1918), which were discovered in 1937, and the Elk Basin (1933) deep sands, discovered in 1942.

The Rangley (1902) field of Colorado, in which deep sands were discovered in 1933, has recently undergone intensive development.

Voluntary proration has served very well in California, largely as a result of the tolerance of the big companies throughout this period, and production held around 200 million barrels annually until the recent war demands caused an increase in old production, as a result of which the state is now producing in excess of 300 million barrels a year. Prior to the development of the bonanza fields of the Los Angeles Basin, California oil had not invaded the eastern part of the United States in substantial quantities. Some 55 million barrels of crude oil was shipped to eastern refineries in 1923. This was the high year of crude shipments and they had practically ceased by 1928. Gasoline shipments started in 1925 with some 14 million barrels and reached a peak in 1929 with almost 23 million barrels. With the development of the East Texas field, and particularly as a result of hot oil, which is estimated to have reached a peak of 200,000 barrels daily in 1933, and of hot gasoline, California was crowded back into her old Pacific Coast territory. By 1938 shipments were less than 5 million barrels.

Kettleman North Dome (1928) reached a peak of production in 1936 with 29.1 million barrels. The Ventura Avenue field (1916) has become increasingly important with the discovery of deeper sands, and Santa Maria Valley (1934) and Coalinga Nose (1938) have been discoveries of major proportions.

The series of fields discovered from 1936 to 1938 as the result of geophysical mapping includes Ten Section (1936), Greeley (1936), Rio Bravo (1937), Coles Levee North (1938) and South (1938) and Paloma (1939), which are of bonanza proportions.

ADVANCES IN PRODUCTION TECHNIQUES

The ability of the oil industry to increase its production during three fourths of a century from the modest 5.2 million barrels of 1871 to the estimated record-breaking total of 1731 million barrels for 1946 depends upon many things, the most fundamental of which are that the oil deposits were there to be found and that markets were great enough to take the production. As engineers, however, we are chiefly interested in the techniques that have made possible the solution of the problems of finding and producing the oil. One of the most important elements has been the development of the art of prospecting. I have reviewed this subject elsewhere and will not touch upon it here.[1] Other elements of equal importance have been our ability to drill wells to increasingly greater depths and to secure a maximum amount of information by their drilling and our increasing knowledge of the physical nature of oil occurrence with a resultant ability to better manage production.

The Rotary Drilling System

The rotary, introduced to the oil industry by the Baker brothers, water-well drillers from South Dakota, was first used during the development of the

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[1] References are on page 301.

Corsicana, Texas, field in the late '90s. A form of rotary had been used for drilling water wells in the Gulf Coast since as early as 1880 and the artesian well at Galveston in 1891 to 1892 was drilled to a depth of 3070 feet by this method. The Gulf Coast rotary is said to have been developed by the modification of an old type of diamond drill manufactured in Holland, and Redwood notes that the rotary drilling system, as well as all other water-flush systems, are modifications of a method invented by an Englishman, Beart, the machinery for which was designed by a French engineer and known after him as the Fauville system. It was first used in drilling a well in 1846 at Perpignan, France.

In the earliest uses of the rotary system, clear water was used for circulation and the function of mud in building and supporting the walls of the hole was not recognized. Attempts were made to follow the hole down with casing as was the general practice for wells drilled by cable tools. This gave rise to great difficulty, cuttings settling and binding the drill stem to the casing when it became necessary to suspend circulation in order to insert a joint of pipe. Benjamin Andrews, Jr., claims to have been the first to discover the wall-building function of mud and to have drilled the first open holes without attempting to keep them cased beyond a surface string of pipe.

In the early days the rotary was suitable only for soft-rock country. No other system could be used in the Gulf Coast region. It was first used in California, apparently, about 1905 or 1906 to drill "the soft sands and shales near the surface" in the Santa Maria district, the wells then being finished with cable tools. In 1908 to 1910 it was used more widely in California but wells were still drilled-in with cable tools.

Because of the impossibility of drilling hard rock with the primitive rotary, the "combination rig" was designed, probably in California, and by 1916 most of the deep drilling in the Sunset-Midway field had been done with that rig, "the water string being set with rotary and the hole finished with cable tools." Even at that early date, however, a few companies drilled the entire hole with rotary. "But fortunately this custom is becoming less popular than formerly," gently complained a prominent geologist who had just completed an intensive study of the field. The rotary had always been used almost altogether in completing wells in the Gulf Coast. The rotary and combination rig were also used in Mexico in the early 1900s.

With the invention of the rock bit in 1908, by Howard R. Hughes, came the only fundamental and basic change in the rotary system yet achieved by the oil industry. The rotary could now drill hard rock and with the continued improvement of the rock bit the need for the combination rig disappeared.

At this point, however, the rotary was still far from the perfect tool it has become. Some coring was done with the so-called basket barrel—a short length of drill stem or casing, the bottom of which was toothed or notched. Recovery of core with this primitive tool was so unsatisfactory, however, that the tool should have been called a sampler rather than a core barrel. Samples were screened from the returning mud of the circulating system and it was not uncommon for oil-bearing or gas-bearing formations to be passed through without recognition. As late as 1922 the author finds himself objecting violently to the use of the rotary system for drilling a wildcat well.

With continued improvement, through increased size, better design, the use of better materials and provision for increased and better application of power, the use of the rotary has spread to other areas. It is commonly used throughout Texas, New Mexico and Louisiana; through Oklahoma since the early '20s; in the Rocky Mountain area; in Illinois since 1937; and is occasionally used for deep wells in that last stronghold of cable tools, the Appalachian area. It is in common use in foreign fields. As early as 1925 an English engineer with worldwide experience in drilling, and acquainted with all drilling systems in actual use, summarizes a discussion of drilling methods thus: "The modern rotary is, however, revolutionizing drilling practice and except in hard, compact sandstones or limestones, it is replacing all percussion systems."

The rotary of the '20s, however, was strictly a hole-making device. Its improvement to its present state of perfection came about through the development of a series of techniques and inventions improving as to quality and quantity the information that could be secured by drilling a rotary well and giving greater flexibility to its testing and completion.

The first of these improvements and accessories was the introduction of the improved core barrel and improved coring practice, by J. E. Elliott in 1921. This was initiated by the establishment of a special coring service in California but the use of the technique spread rapidly and soon became common practice wherever the rotary was used. Hole surveying was perfected about 1925 and from it came directional drilling in the early '30s. Drill-stem testing came about 1926.

The greatest of all improvements, however, resulted from the introduction of electrical logging by the Schlumbergers in the earliest '30s, of gun perforation by Lane-Wells a year or two later and of stage cementing, which followed gun perforation almost immediately and almost as a corollary. With the electrical log a geological record superior to any other could be secured of all formations penetrated by a well from top to bottom. Moreover, valuable information as to oil, gas and water content of porous formations could be secured. With gun perforation a hole could be opened through casing at any point for testing. This allowed holes to be drilled to any possible and desired depth, cased and subsequently tested at any desired point. This allowed for great economy in operation and in casing and permitted many wells to be drilled to much greater depth than otherwise would have been feasible. Stage cementing was not only a great improvement over older practice but provided a flexibility in testing and retesting as to depth and as to amount of zone tested, precise almost to inches, which had not been attained by any other method. Each of these three techniques greatly enhanced the value of the other two and the three of them together have made the rotary system supreme over any other system for exploration as well as exploitation.

Another improvement of fundamental importance to deep rotary drilling was the introduction of mud control and conditioning. Other important developments in drilling and testing have been the wire-line core barrel and side-wall coring but these are of subsidiary rather than primary importance.

The Gas Concept

The fundamental concept governing modern oil-production practice is that all producible oil in the reservoir contains gas in solution. Such oil-gas solution has lower viscosity, lower specific gravity and lower surface tension than the oil after the gas has been separated from it, and consequently can move more easily through reservoir rock than would be possible otherwise. The expansion of gas in solution, once pressure gradient has been established by the opening of a well, is the single agent in many fields and a potent agent in most fields, which moves the solution through permeable reservoir rock to the well. In all but fields of highly efficient water drive it is the agent that lifts the solution from the bottom of flowing wells.

The essence of this concept was discovered in the very dawn of the industry. A certain Mr. Briggs proposed the still useful carbonated-water analogy before the American Philosophical Society in 1865. John F. Carll, oil expert to the Second Pennsylvania Geological Survey, elaborated upon it in 1880 in a report of that survey, using the homely example of a barrel of beer for comparison.

These clear and early statements of the nature of oil and gas occurrence and production, however, received but slight recognition. There ensued a period, termed by one outstanding student of reservoir management "the dark age," when the function of gas energy in oil production was all but forgotten. Wells were completed and flowed to the limit of their capacity. No effort was made to conserve gas—indeed, the amount of gas produced was not even measured. No method had yet been invented for determining the amount of gas in solution per barrel of oil in the reservoir and the usefulness of gas-oil ratios as an index to production efficiency had not yet been discovered.

The United States Bureau of Mines was organized in 1910 and one of the earliest efforts of its petroleum division was a series of surveys of waste in oil fields. The results of these surveys were published by 1913–1914 and their findings were strictly of underground waste from premature flooding of producing sands as a result of inadequate casing and cementing practice and of surface waste.

One of the earliest if not the first statement of the rediscovery of the gas concept was in a notable paper which comes very close to our present understanding, published by L. G. Huntley in 1913. After noting reduction of specific gravity* of the oil-gas solution in the reservoir as a result of the waste of gas and that such change in gravity "indirectly affects the production," he states specifically:

> The practice of allowing the free escape of vapors instead of endeavoring to make each cubic foot of gas in expanding perform its quota of work in the expulsion of liquid petroleum, is a direct cause of the decline of flowing wells. It is almost as direct a factor in the decline of pumping wells, as the intra-strata gas pressure is the means of keeping up the continuous movement of the fluid toward the well when the well is pumped.[2]

The date of what may be regarded as technological acceptance of the concept may be fixed with precision. J. O. Lewis, then a petroleum engineer with the Bureau and a few years later its chief petroleum technologist, was coauthor in 1916 of a paper on underground waste, which recognized only waste by premature flooding of sands and by migration and dissipation to other sands.[3] A paper on methods of increasing recovery published by Lewis the following year presents a clear recognition of the function of gas. He notes:

> When a well is drilled through the impervious strata, capping an oil sand, the pressure is released at that point and an avenue of escape from the oil and gas is afforded. The gas absorbed in the oil immediately expands and flows toward the hole, moving oil with it . . . There can be no doubt that the predominant expulsive force is the energy stored in the compressed gas absorbed in or associated with the oil . . . As it is the energy contained in the compressed and absorbed gas rather than the oil that is exhausted, it is but logical to judge the efficiency of the producing method largely by the relative quantities of gas produced with each barrel of oil. If by a change in method the producer lessens the proportion of gas with each barrel of oil, he should increase the total recovery of oil correspondingly, even if the rate of production is temporarily reduced somewhat.

Lewis considered the solubility of gas in oil and viscosity but seems not to have had at that time any clear idea of the importance of dissolved gas as a viscosity-reducing agent.

General acceptance of the concept by the industry can be fixed with almost as great precision as its technological acceptance. A committee known

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* It must be noted that in the early days of petroleum engineering the term "gravity" also connoted viscosity qualities.

as the Gas Conservation Committee of the American Petroleum Institute was appointed in 1927, under the chairmanship of E. W. Marland. The committee met on Sept. 11 and 12, 1927, and appointed a technical subcommittee to gather, collate and report back all available information, including the opinions of qualified scientists and engineers regarding the importance of natural gas in the conservation and production of petroleum and the best means for its efficient utilization. Through a series of regional committees, the technical subcommittee collected this information and reported its findings at a meeting in Ponca City, Okla., on Oct. 17. This meeting was attended by members of the Gas Conservation Committee and by approximately 250 executives, operators, attorneys, petroleum engineers, scientists, and others. This committee and the subcommittees developed and stated the gas concept in detail. The material collected was restudied and a report was prepared by the United States Bureau of Mines in cooperation with the American Petroleum Institute and published by the Institute in 1929.[4]

One cannot conclude a consideration of the historical development of the gas concept without directing attention to the contribution of Henry L. Doherty. In a notable and historic paper presented before the Institute in February 1925 he said, among other things:

> Gas, in some cases to an energy value of more than the entire energy value of all of the oil that is recovered, is blown to the air; and this in spite of the fact that if this gas were conserved, it would greatly increase the amount of oil recovered and would enable every barrel of oil to be raised to the surface without the cost of pumping.[5]

Furthermore, Doherty is responsible for the experiments carried on at his instigation and under his direction, which resulted in the classic paper on our understanding of the nature of the gas-oil solution, by Beecher and Parkhurst,[6] presented before this Institute in 1926. Among the more notable conclusions are that:

> At a pressure of five hundred pounds and a temperature of 70°F., it was found that a natural gas such as is associated with the oil would reduce the viscosity about 50 per cent when a given crude was saturated with the gas. . . . A large percentage of oil which present production methods fail to remove from the sand is held by capillarity. As the gas dissolved in the oil escapes, the surface tension is increased and likewise the capillary force which is a measure of the surface tension. If this increase in surface tension could be prevented during the process of extracting oil from the sands, a greater volume of oil should be recovered.

Interstitial or Connate Water

We now know that all oil sands, with extremely rare exceptions, have an interstitial water content equal to 18 to 50 per cent of the volume of the pore space. It is believed that 30 to 35 per cent may be accepted as an average, though probably it is on the high side. The importance of the discovery of this fact is that all previous estimates of the percentage of oil recovered from a sand, and of the percentage of oil left in the sand and not recoverable, are proved to be in error, and that many of the laboratory experiments upon the passage of oil through dry sand are known to be valueless as representing a condition apparently not met with in nature. The discovery that all sands contain interstitial water is of fundamental importance in any estimate of the amount of oil originally in place and, consequently, of the amounts that may be recovered and that are not recoverable by economic methods.

It is surprising that we should have come so slowly to an understanding of the theoretical necessity of the occurrence of interstitial water, and that we should have been so long in actually proving its existence. In a paper published in 1915, Washburne[7] seems several times upon the verge of discovering theoretically the probability, and indeed almost the certainty, of the existence of interstitial water, but misses it. Roswell Johnson[8] even introduced a paper with the question of what becomes of the connate water that once must have occupied the pore spaces in the sand, but he hardly comes as near to a solution of the problem as did Washburne.

Interstitial water first came to the attention of the American petroleum industry through a paper by Lindtrop and Nikolaeff.[9] These students concluded from their laboratory study of the displacement of oil by water in sands of different sizes of grain that it is very important to consider the relatively large amount of water retained by the sand after ordinary production of a well ceases. They found experimentally that 18.2 per cent of the pore space was filled by interstitial water and they concluded:

> If the fundamental deduction about the content of connate water in strata together with oils is later proved, then the recovery of oil is greater than previously was supposed and some of the existing calculations regarding additional oil recovery must be lowered.

This suggestion seems to have attracted no attention.

The first definite information regarding the occurrence of interstitial water in a core from a producing oil field is by O. L. Brace.[10] He says:

> It has long been recognized that connate waters tend to resist the replacement action of oil and gas. This is specifically true of water occupying those finer interstices that constitute an appreciable percentage of the voids. Within a producing area, the fact that the produced oil is clean is no index to the presence or absence of moisture in the sand, since the forces that held the water in place during oil migration would perform the same function during oil extraction. . . . Included moisture constitutes an important but little understood factor bearing on the exact solution of these problems. . . . Sand cores were distilled and their fluid content analyzed. Cores from the center of the field, where no water had appeared with production, were found to contain moisture to the extent of 16 per cent of the fluid.

Garrison,[11] about the same time, presented a more elaborate explanation of the physical conditions of oil-water equilibrium in the reservoir rock, saying:

> This conception of water as a network of capillaries in equilibrium with the oil throughout the reservoir is contrasted to that of definite levels of oil-water contact connoted in the terms 'edgewater,' 'coning,' or 'nosing' of water.

Wilde and Moore, of the Humble Oil and Refining Co., in their discussion of Brace's paper, were inclined to think that the samples analyzed had been contaminated by drilling water but they appear to have been impressed enough with the argument to make the matter a subject of investigation by the research department of their company. Upon the conclusion of this investigation, Schilthuis[12] suggested:

> 1. The reservoir rock is completely wet by connate water and does not contact either oil or gas directly.
> 2. Oil and gas exist in the larger and interconnected pore spaces.
> 3. Connate water completely fills the smallest crevices and capillaries, particularly those that are discontinuous or sealed entirely.

Also that the data presented:

> indicate that the minimum average connate water saturation even at extremely high permeability is probably upward of 10 per cent, . . . it has been observed that connate water exists in gas-bearing formations to the same or possibly even greater degree than in oil-bearing formations.

ADVANCES IN REFINING TECHNIQUES*

The growth and development of the industry has been controlled by the amount and type of products that could be marketed, and the periods into which its history has been divided have been determined largely by the dominant type of product. The variation in yield of products in response to varying demands for them during these periods is shown in Fig. 1. In 1880 the yield of kerosene averaged 75 per cent on crude, with gasoline only about 10 per cent and lubricants making up most of the remaining 15 per cent. By 1901 the kerosene yield had fallen to 50 per cent, with the gasoline yield remaining essentially constant. About 1903 the fuel-oil yield began to rise rapidly, reaching a peak of 55 per cent in about 1918 and then declining. The

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* Through the courtesy of H. C. Wiess, president of the Humble Oil and Refining Co., I am indebted to Dr. H. D. Wilde, manager of the Refining Technology and Research Department of the company, and to his associates, for the following history of advances in refining techniques. Dr. Wilde and myself have arrived independently at a similar division for the history of the industry except that he places the end of the fuel-oil period and beginning of the motor-fuel period at 1918 instead of 1910. I am interested to find that the break point between his period of thermal and catalytic conversion coincides with my break point between the stabilization and proration period.

gasoline yield began to rise about 1909 and reached a value of about 45 per cent in 1930, leveling off at about this value for the next 10 years.

When kerosene was superseded by fuel oil as the dominant product, the actual production of kerosene did not decline but its importance was overshadowed by that of fuel oil. Actually the production of kerosene in 1918 was considerably greater than it was in 1900, but it was of relatively minor importance when compared with the production of fuel oil. The same is true of fuel oil and gasoline in the period following 1918.

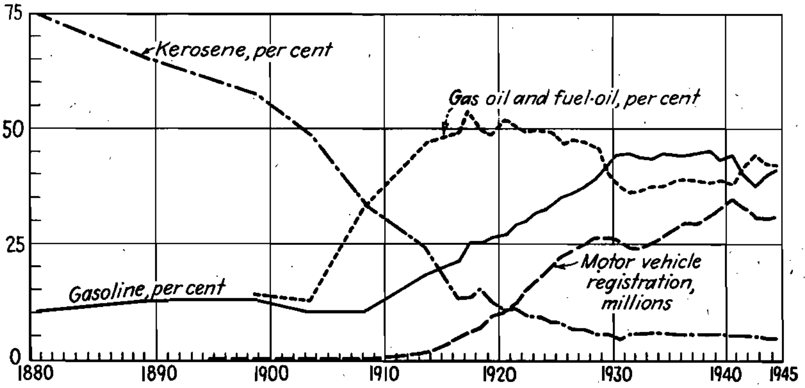

FIG. 1—*Yields of refined products from crude oil.*

As shown in Fig. 2, the curve of crude oil production from 1859 to 1946 is easily broken down into three major periods, corresponding respectively to the times when kerosene, fuel oil and gasoline were the dominant products. There are some indications that the industry may be entering a new period in which the production of chemicals is becoming predominant. These chemicals are either marketed as such or are used as ingredients of the traditional petroleum products.

As for the dominant products, there have been three major periods in refining processes and techniques. The first of these may be termed the era of physical separation, which lasted through the time that kerosene and fuel oil were the dominating products. The second period, the era of thermal conversion, started when gasoline began to be dominant and lasted until the middle '30s. It was then succeeded by the third and last period, the era of catalytic conversion and synthesis.

During most of the era of physical separation, the industry made very little use of engineering and scientific principles, with the result that progress was very slow; but between 1905 and 1915 the more progressive companies began to add research and engineering staffs and to apply their findings to plant operations. Since then research and engineering have grown in importance and have greatly accelerated the development of new and improved processes. Without the intensive application of research and engineering, the catalytic processes that are so important today would not have been developed.

Physical Separation

As long as kerosene, lubricants and fuel oil were the principal products from petroleum—that is to say, until the end of World War I—these products were present in crude in sufficient abundance and of adequate quality to meet all requirements. Hence, during this period refining consisted primarily of physical separation of components in crude without effecting any appreciable change in chemical composition. This separation was supplemented by simple treatment of the products for improvement in color and odor.

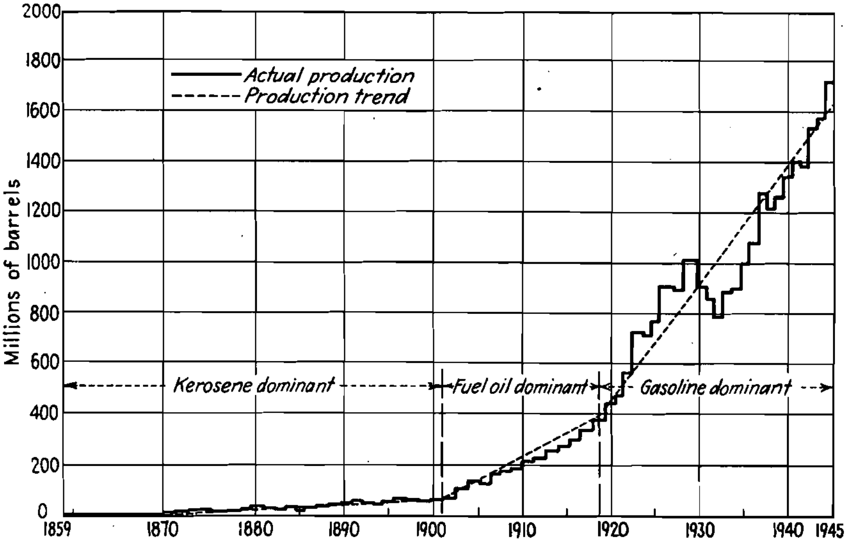

FIG. 2—*Production of crude oil in the United States (millions of barrels).*

The outstanding process for physical separation is distillation, which serves to separate the components, or groups of components, according to their relative volatility or boiling points. The earliest oil refineries consisted of small batch stills or distillation units, not unlike in size and design the moonshiner's still of today. These simple stills, operating at atmospheric pressure, had very low capacities, and were incapable of making a sharp separation. The cheesebox still, introduced in 1876, provided more capacity but only slight improvement in sharpness of separation. All of the early equipment was of the batch type and it was not until 1885 that the first continuous shell-still battery was placed in service.

Until 1911, when the pipe still made its appearance, heat was supplied through the walls of the vessel containing the boiling oil. The pipe still was novel in that the oil is heated, under pressure, by pumping it at high velocity through pipes suspended in a furnace-type heater and then discharging the hot oil into a flash chamber, where vaporization takes place. Vacuum distillation, which permits the distillation of heavy materials at lower temperatures than would be required at atmospheric pressure, was first employed commercially in 1920.

In any simple distillation process the sharpness of separation is inherently very poor. For example, the gasoline so produced contains substantial amounts of the lighter kerosene components and the kerosene contains substantial amounts of the heavier gasoline components. In order to improve the sharpness of separation, it is necessary to rectify or fractionate the vapors from the distillation step. Simple fractionating columns were added to oil-distillation units, commencing about 1916, and the more efficient bubble-cap column about 1924. The combination of distillation and fractionation has undergone steady improvement and is today capable of marvelous accomplishments. Many modern installations are capable of separating the lighter hydrocarbons (through the octanes) as individual compounds of high purity.

In the manufacture of lubricants, distillation alone is not enough, since in most cases the distilled stocks contain wax that must be removed. In all dewaxing processes the stock is first diluted with a nonviscous liquid, then it is chilled to crystallize the wax and the wax crystals are removed. With naphtha as the diluent, gravitational settling was introduced in 1865, filter pressing in 1880 and centrifuging in 1920. The use of special solvents such as propane or a mixture of benzene and ketones in 1927 permitted the use of efficient continuous rotary filters for removal of wax. Propane deasphalting for the removal of asphalt from heavy lubricant stocks was introduced in 1927.

Solvent extraction processes provide a means of physically separating components from a mixture according to type rather than according to boiling point. These processes are relatively modern, as the earliest was use of liquid sulphur dioxide for the removal of inferior, smoke-producing components from kerosene. Although used in Europe as early as 1909, it was not applied in this country until 1924. Liquid sulphur dioxide was adapted to the removal of poor-quality components from lubricating oils in 1927. Later, phenol (carbolic acid) was used for this purpose in 1930 and furfural in 1933. More recently (about 1941) solvent extraction was applied to the segregation and purification of toluene and butadiene.

Throughout the era of physical separation (and continuing into the present) it has been necessary to remove impurities present in small amount for improvement of color and odor. Sulphuric acid, and alkalies such as caustic soda, have been used since the earliest days for treating petroleum products. The problems of odor caused by the use of sour, sulphur-bearing crudes were first solved by the Frasch process in 1895 and later by the plumbite or "doctor" sweetening process in 1910. Bone char was used as early as 1860 for improving the color of lubricating oils; the use of fuller's earth for this purpose was introduced in 1898 and clay contact filtration in 1920.

Thermal Conversion

The rapid rise in number and use of automobiles during and following World War I greatly increased the demand for gasoline, not only in volume but also in relation to the demand for other petroleum products. In order to bring the supply into balance with the demand, it was essential that some of the heavier components of the crude be converted chemically to the lighter gasoline components. Conversion of this type is called cracking.

Although some cracking of the heavier components occurs in distillation processes, especially if they are not carefully controlled, this was not recognized for a long time and was not put to commercial use. The Greenstreet vapor-phase cracking process was developed in 1908 but it was not efficient and its use was extremely limited. The Burton pressure still, in 1913, was the first successful large-scale application of cracking and a large number of these pressure stills were constructed by the industry in the following years. These stills had the inherent disadvantage of operating on a batch basis. From 1916 to 1930, the industry devoted much research and engineering effort to the development of and improvement of continuous cracking processes. These were highly successful and resulted in keen competition between the sponsors of the various processes.

All of these processes use heat and pressure only and hence employ thermal conversion to accomplish cracking. Fortunately, in addition to increasing the yield of gasoline, cracking also produces a gasoline of higher quality, as measured by octane number, than that occurring naturally in the crude. Encouraged by the good results obtained in thermal cracking, the industry then successfully applied thermal conversion to other processes such as reforming (1931), polymerization (1935), alkylation (1940), and production of butadiene (1942).

Catalytic Conversion and Synthesis

Although the thermal conversion processes were very effective in meeting the current demand for gasoline and other products, the industry began to realize that these processes were not particularly selective; i.e., they could not be controlled for the production of a single compound or single group of compounds. As a result, in thermal conversion the yield of desired products is low and substantial amounts of undesirable or less desirable by-products are produced. However, research demonstrated that through the use of appropriate catalysts, processes with a much higher degree of selectivity can be developed and even single compounds can be synthesized. This has served as a powerful incentive for the development of catalytic processes that are becoming so prevalent today. The adoption of these catalytic processes has been very rapid, for it was only a little more than 10 years ago, in the middle 1930s, that they were first employed on a substantial scale. It is true that hydrogenation of petroleum was used commercially as early as 1930, but soon thereafter the price relationship between crude and fuel oil changed materially and the process lost its economic attractiveness and was not widely adopted by the industry.

Catalytic cracking processes have had a profound effect on refining operations. These processes have the advantage that the yield of gasoline is higher and the yields of fuel oil and dry gas are lower. Furthermore, since they are rather selective in the production of olefins and aromatics, the quality of the gasoline is considerably better, and these processes produce the desirable light olefins, such as butylenes and pentylenes, in abundance. Consequently they are replacing and superseding thermal cracking processes to a large extent.

The first catalytic cracking process to reach commercial development was the Houdry process, employing the catalyst in fixed beds. A 200-barrel per day unit was installed in 1934 and the first large-scale unit was placed in operation in 1939. The first full-scale commercial unit of the Fluid process, using a moving bed of fluidized catalyst, was placed in operation in 1941. The first full-scale commercial unit of the Thermofor process, using a moving bed of pelleted catalyst, began operating in 1943. These various processes were of great value in the production of aviation gasoline and synthetic rubber during World War II.

Catalytic polymerization and isomerization processes played an important part in the production of aviation gasoline during the war. The phosphoric acid (U.O.P.) polymerization process reached the stage of commercial development in 1935 and the sulphuric acid process in 1934. Alkylation, using sulphuric acid as the catalyst, was first used commercially in 1938 and using hydrofluoric acid in 1941. The isomerization of butane to isobutane and of pentane to isopentane became commercially successful in 1941.

Hydroforming, a catalytic process for dehydrogenation, or the removal of hydrogen, was used extensively during World War II in the manufacture of toluene from petroleum. The first commercial unit began operating in 1941. In peacetime the process is used for improving the octane number of gasoline or for the production of aromatic solvents.

Another catalytic dehydrogenation process of great importance is the one used for converting butylene to butadiene, needed for synthetic rubber. The process reached the stage of commercial application in 1943.

The petroleum industry is growing rapidly in importance as a supplier of specific chemicals. A number of plants have been installed and many more are contemplated. All of these processes for the production of chemicals employ catalytic conversion. Among the earliest processes was the production of alcohols from refinery olefins, which reached commercial development in 1918 to 1920. This has been followed by the development of many other processes, including those for such diverse chemical products as ethylene glycol, ammonia, formaldehyde, acetylene, acetic acid, glycerin, toluene and butadiene. The production of chemical products appears still to be in its infancy, so there still remains room for important developments in this field of catalytic conversion.

Technical Developments

This brief review of refining progress emphasizes the tremendous technical advance that has taken place between the simple operation of the early days and the very complex processes of today, most of which has occurred during the past 15 to 20 years. Formerly refineries were run by practical men with little or no technical background or experience, whereas today the industry needs large staffs of scientists and engineers not only to provide the required technical control and supervision of the processes already in operation but to explore and develop new processes and improvements in the present ones. Technical developments are now being made so rapidly that unless a refinery has a technical staff to keep abreast of new developments it runs the risk of getting hopelessly behind. The technical and research effort is being expended not only on the production of the traditional and indispensable fuels and lubricants but also on a rapidly expanding list of special products and chemicals for which the vast storehouse of hydrocarbons in petroleum and their derivatives serve so ably as raw materials.

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Seventy-five Years of Progress in the Nonmetallics

By Oliver Bowles

OLIVER BOWLES

Active for 33 years in the United States Bureau of Mines, Dr. Bowles is an outstanding authority on both the technology and the economics of nonmetallic minerals that come under the aegis of the Institute's Industrial Minerals Division. He was the second Chairman of the Division and is now a Director of the Institute. Dr. Bowles is Vicechairman of the Editorial Committee for "Industrial Minerals and Rocks," a 950-page volume now being revised for a new edition.

Two striking events marked the year 1871—the establishment of the A.I.M.E. and the beginning of the portland cement industry, the most spectacular of all the nonmetallics in its development. Just as David Saylor's first portland cement, made in a little mill at Allentown, Pa., in that year was the forerunner of a mighty industry, the products of which in 1942 were made in 155 plants scattered throughout the country (having attained a value of nearly $300,000,000), so the Institute from its small beginning has attained a membership of many thousands, likewise decentralized into a series of individual sections of wide geographical distribution. Concurrent with the establishment of the Institute was also the invention of the steam drill, followed by the compressed-air drill about 1904. These mechanical drills were so immeasurably in advance of the hand drill and hammer used previously that quarrying and mining of present-day magnitude could never have been attained without them.

Some outstanding occurrences have marked this eventful three quarters of a century. The concrete age, with its enormous demands for cement, aggregates and steel, is of primary importance. Of interest also is the shift of fertilizers from the organic to the mineral field. Nitrates, primarily obtained

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from manures, originated later in the natural nitrate beds of Chile and in atmospheric nitrogen. The source of potash has shifted from wood ashes to sylvite and other minerals, and of phosphate from bone meal to phosphate rock. These prolific mineral supplies have increased farm productivity enormously.

Certain special techniques developed during this period have promoted greatly the recovery of minerals from the earth and their concentration. Outstanding among them are the Frasch process for bringing molten sulphur from wells that penetrate sulphur-bearing rocks and the circulation of water deep within the earth to dissolve salt and permit its removal as brine. Geophysical exploration has assisted in determining the extent and location of hidden deposits of nonmetallic minerals, even those as commonplace as sand and gravel. Froth flotation, once deemed applicable only in the treatment of metallic ores, is now utilized on many nonmetallics, including cement raw materials, phosphate rock, fluorspar, feldspar, clay, talc, halite and sylvite.

Such striking progress has been made in the technique of froth flotation that some nonmetallic mineral industries are reversing their former role of pupils and becoming teachers. The ferrosilicon heavy-media process of separation is a recent innovation. Dry methods of concentration, including air tabling and magnetic and electrostatic treatment, are applied to many nonmetallics. New methods and equipment have been devised for pulverizing to subsieve sizes and for measuring such sizes in terms of specific surface. Air separation of fine powders and air transportation of pulverized products have found a useful place in many nonmetallic mineral industries. To reduce labor requirements a trend is gaining momentum toward increased mechanization and automatic instrument control of grinding, calcining, and other milling processes.

During this period also the frontiers of mineral exploration have been extended beyond the solid earth to include the air as a source of nitrogen, argon and other elements and the sea as a source of salt, magnesium compounds and bromine. The number of minerals put to work has grown greatly during this 75-year period, and the tonnage of production has multiplied many times. The population of the United States, which was about 41 millions in 1871, had grown to about 140 millions in 1946. Thus nearly 100 million new customers for mineral products have appeared, and with marked advances in standards of living the needs of each have greatly multiplied. It is not surprising therefore that a production value of $56,000,000 for all nonmetallic minerals in 1880, the first year for which records are available, should have grown eighteen-fold to a value of over a billion dollars in 1945.

When the Institute was established, the mining of nonmetallics was of small consequence. Over 80 per cent of the recorded production consisted of heavy clay products and stone, nearly all of which was employed in building construction. Sand and gravel doubtless were used in considerable quantities, but so large a proportion came from local sources that no statistics of output are available. Today the nonmetallics comprise about 25 major products and scores of others having relatively smaller commercial value. They include building materials, chemical raw materials, fertilizer materials, ceramic raw materials, abrasive materials, refractories, and miscellaneous minerals. These diversified commodities are applied in innumerable ways that affect in varying measure the experience of every individual.

The histories of the individual nonmetallic mineral industries that follow are necessarily brief and incomplete, but an effort has been made to cover concisely the events and circumstances that have been most significant in shaping the destinies of these industries.

BUILDING MATERIALS

Building in its broader sense includes residences; industrial, recreational, educational and religious buildings; public buildings and public works; highways; bridges; and every other form of construction devised by man. Nonmetallic minerals or their products are essential to virtually every type of construction and in many instances constitute the major part of the structure. Both in quantity and value, building materials comprise by far the largest group of the nonmetallics. They had even greater relative importance in the Colonial period, when shelter ranked with food and clothing as the most insistent fundamental needs of the pioneers.

The principal nonmetallic mineral commodities used in construction are dimension stone, slate, crushed stone, sand and gravel, cement, heavy-clay products, gypsum, lime and asbestos. The major events and circumstances in the growth and development of these products are outlined herein. Lime is omitted from consideration under building materials, because it is used most extensively as a chemical raw material and is therefore considered in that group.

Dimension Stone

Cliff-dwellers' habitations walled with stone furnished human shelter long before white men reached America. When the colonists began to establish permanent settlements, stone was utilized to some extent for home construction. Rough boulders were generally available. Later stone was taken from the solid ledge, and gradually great stone-quarrying and fabricating industries evolved.

The principal varieties of stone used are granite, marble, limestone. sandstone and slate. As slate has certain unique features, it will be considered in a later section. The granite industry has been developed principally in New England, Georgia and Minnesota. The chief centers of marble production are in Vermont, Tennessee, Georgia and Alabama. Because conditions favor quarrying and fabrication, about three fourths of the limestone sold as blocks or slabs is produced in Indiana. Other centers are in Alabama and Texas. The principal sandstone quarries are in Ohio, but other contributory states are Kentucky, New York, Pennsylvania, Connecticut, West Virginia and Wisconsin.

Granite is used principally as building and memorial stone, with minor output for curbing, paving blocks and flagging. Marble is used for interior and exterior building and decorative applications, as well as for memorials. Limestone in blocks is used for building almost exclusively. Sandstone is employed chiefly as building stone, with a smaller output for furnace blocks, grindstones and other abrasive stones, curbing, paving stones and flagging.

Soapstone, a unique type of dimension stone unrelated to the major groups already discussed, is quarried chiefly in Virginia. The products of the quarries in Albemarle County, where quarrying was begun more than 60 years ago, are adapted for making laboratory table tops, sinks, tanks, fume hoods, switchboard panels, laundry tubs, furnace blocks for paper mills and in architectural uses. Another unique type is a siliceous rock known as "greenstone," quarried near Lynchburg, Va., for use as a building stone and for steps and floor tile.

New England granites were the first stones used extensively for building in the United States. A court house and several churches were built of granite in Boston about 1833, and Bunker Hill Monument, of Quincy granite, was completed in 1843. Early in the nineteenth century granite was quarried also in Maine, Connecticut and Pennsylvania, but the great granite industries of Barre, Vt., and St. Cloud, Minn., were later developments. The Vermont marble industry did not become important until after 1850. Georgia marble was first fabricated in a small mill in 1840. The well-known Triassic sandstones of Connecticut and Pennsylvania were quarried as early as 1833. The sandstone industry centered near Amherst, and Berea, Ohio, first attained importance after the Chicago fire of 1871. Millions of tons of sandstone were shipped from these quarries for rebuilding the city. The Indiana limestone industry did not become prominent until about 1890. Statistics for 1880 show a stone production value of over $22,000,000, or more than 12 times the value of the cement output in that year.

QUARRYING METHODS

Stone quarrying is an ancient industry. Pyramids, obelisks and ancient temples represent the toil of innumerable slaves extended over many decades.

The advance from obelisk to modern office building represents many steps, every one marked by accelerating speed. The only notable advances in quarrying and manufacture have been crowded into the past 75 years.

Primitive quarrying in America involved hand drilling followed by wedging or the use of black blasting powder. A new impulse was given to the industry by the invention of the steam drill, which was introduced about 1871, that magic year in which the A.I.M.E. came into being. Compressed-air drills were first used about 1904. Granite, being a very hard rock, is quarried by drilling, blasting or wedging. Experiments on the use of a wire saw in granite quarries were in progress in 1945 and 1946. A crude channeling machine that was an adaptation of the percussion drill was introduced in Vermont marble quarries as early as 1880.

Quarry methods have advanced progressively with the invention of explosives and of steam, compressed air and electrical machinery; but, except for the changes that have come about as a consequence of the general evolution of mechanical equipment of all kinds, there have been few innovations in stone quarrying.

FABRICATION AND SUBSTITUTE MATERIALS

Much greater advancement has been made in stone fabrication than in its quarrying. Shaping with crude hand tools and hammers has been superseded by mechanization, which has grown until now stone is fashioned in great mills equipped with overhead traveling cranes, gang saws, planers, drills, lathes and polishing machines. Diamond-tooth and carborundum saws are among the more modern developments. Pneumatic tools speeded up the process of carving tremendously, and sand-blast carving—introduced more than 30 years ago—marked another long stride in progress.

The invention of steel skeleton-frame construction profoundly influenced the use of stone. The 12-story Home Insurance Building completed in Chicago in 1885 is said to be the first building in which the weight was carried on the frame. Thus began the skyscraper era. Most of these great structures are classed as stone buildings, but the stone is merely a veneer 4 to 8 inches thick; thus the quantity of stone used in a modern building of a given size is merely a fraction of that in olden days when walls were of solid masonry.

The employment of portland cement, which was begun in the United States in 1871, also affected the use of stone adversely. The ease with which concrete could be shaped into any desired form and its ability to harden quickly into a stonelike mass led to its wide acceptance for constructing walls, steps, sidewalks and other structures for which stone previously had been used extensively. The stone paving-block industry has been particularly hard hit by the use of concrete. A production of 49 million blocks in 1923 dropped to less than a quarter of a million in 1945.

The development of other new construction materials has also exerted a retarding influence on the use of stone, although to a lesser degree. Thus glass, stainless steel and aluminum have replaced stone to some extent.

These unfavorable factors contributing to a reduced demand for stone date back many years; nevertheless, stone consumption reached a peak in the late '20s, when the value of building-stone sales reached nearly $44,000,000. This high level was attained because the retarding influences were more than compensated by extensive public building programs.

Depressions and wars are inimical to the prosperity of the building-stone industry. It is not surprising therefore that production value in 1944 had dropped to only $2,769,000—the lowest point in the recorded history of the industry. Many firms adapted their equipment to undertake war contracts for fabrication of products not requiring stone, but late in 1945 these contracts ended and in 1946 the stone industries were in process of reconversion to their original functions. An enormous potential market for building stone loomed ahead because of the many years' accumulated need for post offices, churches, educational and recreational buildings, court houses, and many other types of public and private construction.

What the future holds for stone is problematical. The profound influence of the war on nations and individuals has its counterpart in the effects that wartime designs and new materials will have on the building trades. Synthetic and tailor-made building materials of many kinds may replace stone to some extent. Stone products do not lend themselves readily to mass production, therefore labor will continue to be an exceptionally important item in production costs. With the prospect of wages becoming an increasingly large factor in the total cost of building construction of all kinds, stone will face growing disadvantages.

Slate

Slate quarrying was begun in the United States in 1734, in the Peach Bottom district on the Pennsylvania-Maryland border. Slate was quarried in Georgia as early as 1850, and slate from the Virginia deposits was used for roofing the State capitol about 1787. The quarries of Lehigh and Northampton Counties, Pa., now the most productive area, were opened by Welshmen long before 1871. Welsh slaters also migrated to the New York-Vermont slate region. By 1871 the roofing-slate industry was well established, and a ready market was found for its products as population increased and industry developed.

Although a small production has been recorded for various other states, the industry has been centered for many years in five areas: (1) Lehigh and Northampton Counties, Pennsylvania; (2) the New York-Vermont area; (3) Monson, Maine; (4) the Peach Bottom area near the Pennsylvania-Maryland border; and (5) Buckingham County, Virginia.

In 1879 the number of squares of roofing slate manufactured exceeded 367,000, valued at about $1,231,000. Until 1884, production was confined almost exclusively to roofing slate, when for the first time a millstock value was recorded. Millstock, consisting of blackboards, school slates, electrical panels, steps, baseboard, etc., was much the smaller part of the industry for many years. In 1909 roofing slate constituted over 80 per cent of the total value of sales. In later years millstock products attained a value one half to two thirds as great as that of roofing slate. In 1943 millstock output exceeded roofing slate in value, but it has many competitors.

By 1908 roofing-slate sales exceeded 1,333,000 squares. In 1915 they dropped below one million, and since that time there has been a steady downward trend. In 1945 sales were less than one thirteenth of those in 1908. It is significant of the slow progress of the slate industry that the quantity produced in 1879 (367,000 squares) was almost exactly the same as the average for 1937 to 1941.

The great decline in the use of roofing slate resulted from competition with wooden shingles and asbestos cement, asphalt composition, and metal roofing. Competition has been difficult because slate is not adapted to mass-production methods and therefore is handicapped by the high cost of manufacture. About 1910 Vincent F. Lake invented a slate-splitting machine, which attracted considerable attention but never was applied commercially. Slates are split in the same manner today as 100 years ago. Another unfavorable factor is the high proportion of waste which ranges from 70 to over 90 per cent of gross production.

Because of its unfavorable competitive position, the slate industry has never attained marked prosperity. The value of sales reached a high point of 12½ million dollars in 1926, in the midst of a building boom and under the influence of cooperative effort sponsored by the National Slate Association, which was active for only a few years. The value of output dropped below 8 million dollars in 1930 and thereafter has ranged from 5½ to 7½ million dollars. One third to more than one half of this value consists of granules used in making composition roofing.

Open-pit quarrying is used almost exclusively in the slate industry. Several Pennsylvania quarries exceed 400 feet in depth, and one is more than 700 feet deep.

To assist in solving the waste problem, the Federal Bureau of Mines in 1926 introduced the wire saw as a substitute for channeling machines in making primary cuts in quarries. Within 3 years, 30 such machines were in use in Pennsylvania, and it is estimated that they saved the industry about a quarter of a million dollars a year by reducing waste and by cutting down greatly the cost of quarry operation. The method has been used in no other slate district.

Slate is a very enduring, dignified and attractive roofing material, and has many advantages for millstock uses; but, until better technique is generally accepted and until more aggressive sales and promotional policies are practiced, the future of the industry is not bright.

Crushed Stone

Very little crushed stone was used until after the Civil War. Volume demand began late in the nineteenth century with introduction of water-bound macadam roads. Its use was confined almost exclusively to road building until 1898, when substantial demands began to develop for concrete aggregate, furnace flux and railroad ballast. By 1906 ballast had become an important product; in fact, many quarries produced only ballast, chips and dust.

The use of crushed stone in concrete for foundations of buildings was initiated about 1900. The rapid subsequent growth in volume of production is due in large measure to the phenomenal increase in output of cement, with which it was used as aggregate. Such demands were supplemented by the rapidly growing need for limestone in the metallurgical, chemical and processing industries. In 1886, when separate figures were first compiled, the output of crushed and broken stone was smaller in volume than that of dimension stone. In 1942 the quantity of crushed stone sold (194,537,030 tons) was 144 times as great as that of dimension stone.

Deep-hole blasting in well-drill holes was employed as early as 1902 in projecting railroad cuts. A few years later the method, which was quite revolutionary, was introduced in quarries, and by 1915 it was accepted as standard practice in virtually all large quarries. The large and unwieldy blocks of stone produced by deep-hole blasting delayed acceptance of the method in some quarries, but this difficulty was overcome by introducing larger shovels and crushers and by adopting secondary blasting. Air-operated, hand-held hammer drills made secondary drilling an easy problem. The decided advantages of deep-hole blasting in reducing costs and increasing blasting efficiency were speedily recognized. The evolution in the use of explosives and in blasting methods is covered in the section devoted to cement.

For many years stone sledged to one-man size was hand-loaded into dump cars or carts. The first mechanical loaders were steam shovels of the railroad type that required preparation of road bed and laying of tracks along the quarry face. Steam shovels were gradually replaced by electric and compressed-air shovels, and the railroad type was superseded by the crawling, caterpillar tractor shovel. The capacity of loading equipment has increased tremendously. The primitive ¾-yard dipper has been succeeded by 2-yard, 4-yard, 10-yard and even larger dippers.

On relatively level quarry floors stone was commonly transported by horse or mule in early days, or in cars pushed by hand. Dump carts were replaced by dump cars operating on narrow-gauge tracks. In large quarries steam locomotives were used to haul trains of cars on level floors or on moderate inclines. Where the crusher plant was at a considerably higher or lower level than the quarry floor, inclined cableways were employed. When tracks for power shovels were eliminated, the next step was to dispose of them for stone transportation. This was accomplished by substituting gasoline or diesel-driven motor trucks; at first with solid rubber tires, later with pneumatic tires. Truck capacities increased progressively.

Chain gangs sledging rock on highways represent the crudest means of crushing stone. Organization of the American Institute of Mining Engineers predated by 4 years the first mechanical crusher, as the first power-driven machine for fracturing stone was a Blake-type jaw crusher manufactured in 1875. For many years the largest jaw crusher made had a 24 by 36-inch opening, but in 1915 one built for use in a traprock quarry had a 60 by 84-inch opening. Jaw crushers with 40 by 60 and 56 by 72-inch openings are in common use today. The first gyratory crusher was manufactured about 1879 by the Eagle Iron Works, of Chicago, Ill. A No. 9 with a 20-inch opening was the largest made for many years; then crushers appeared with 36 to 54-inch openings. In 1919, a 60-inch gyratory is said to have crushed more than 4,000,000 tons of stone in a single season.

A primitive screening plant consisted of a simple rotating (trommel) screen and bucket elevators to two bins, one for concrete stone or ballast and one for fines. In some plants the trommel was replaced in the late 1920s by the "cataract grizzly"—a series of rotating disks with openings between them. Later vibrating screens were widely used. The demand for cleaner stone led to the introduction of washing equipment, and washing accompanied sizing, either in trommels or on vibrating screens.

Primitive crushing plants built of timber were replaced by structural-steel and reinforced-concrete buildings. A modern crushing plant may be 10 stories high and equipped with elevators. Housed within it are primary and secondary crushers, bucket elevators, belt conveyors, and a series of screens to prepare stone in a great variety of sizes to satisfy exacting specifications for many different uses.

Progressive mechanization of stone quarries and crushing plants has affected the output per man strikingly. The annual production per man employed had increased from 1200 tons in 1913 to 2800 tons in 1936.

A recent development is the manufacture of stone sand, to be used as a substitute for silica sand where natural sand is not readily available.

The output of crushed stone increased rapidly after 1910 and by 1924 had reached 130,000,000 tons a year for all purposes. It is not surprising, therefore, that by the middle 1920s many quarries on deposits at or near the surface were becoming difficult to operate because of exhaustion of the more easily available material and the increasing depth of overburden that had to be removed. This condition developed most rapidly where limestone beds dipped at moderate to steep angles under heavy overburden. As a consequence, underground methods of mining stone were developed in many localities. In 1925, when the Federal Bureau of Mines undertook a comprehensive study of underground limestone mining, at least 64 such mines were in operation, some of them producing more than 3000 tons a day. The trend toward underground work is increasing as more and more quarry operators face growing difficulty in pursuing open-pit work.

Sand and Gravel

When the Institute was established in 1871, probably there was little activity that could be classed as an organized sand and gravel industry. Nature was kind when it laid down many sand and gravel deposits, for it sorted and classified them by size; thus in early years in many localities the plasterer or other user could by judicious selection procure from near-by native banks sand of suitable grain size. Many sand and gravel deposits were easily available; gravels dug from roadside pits were used to surface roads. The first statistics on sand and gravel—those for 1902—show a sales value of about $1,400,000, but so much of the production was obtained by the consumers themselves from local pits that the figure given probably represents very inadequately the extent of the industry at that time. That condition no doubt existed for some years; but, as the requirements of the users became more and more exacting and as the demands became too large to be supplied from local sources, a progressively larger part of the production originated with organized sand and gravel companies, which had equipment to size and wash the products to conform with consumers' needs.

During the past 45 years the industry has grown from small roadside pits and modest plants equipped with simple screens to large corporations selling millions of tons each year and owning plants representing huge capital investments in land and equipment. In the peak year of 1942, output exceeded 300,000,000 tons valued at $188,000,000. Production had increased

150 times over that recorded in 1902. The sand and gravel industry now leads all the inorganic nonmetallics in the quantity of materials handled.

In early days sand was used in mortar and plaster, as engine sand, and later for glass manufacture and other industrial uses. The gravel was discarded. However, with the development of transportation facilities, a market for gravel developed for surfacing highways and ballasting railroads. The demand for gravel increased enormously when concrete came into general use. In 1905, the first year in which sand and gravel were reported separately, gravel represented only one fifth of the total; in 1945, it was nearly two thirds of the entire output.

One striking development in the industry is the enormous growth in the use of sand for industrial purposes. Seventy-five years ago sand was a very commonplace material having a few simple uses, chiefly in the building trades. With growing industrialization, the uses multiplied to include sand for molding, glassmaking, filtering, abrasive, engine, furnace, pottery, sand-lime brick, sodium silicate, silicon carbide and other applications.

Three quarters of a century ago excavation equipment consisted of shovels and carts, with the possible addition of rough inclined screens to separate the pebbles. As the size of plants increased, mechanical equipment was added. In modern sand and gravel plants excavation is accomplished with various types of equipment, such as power shovels, dragline excavators, power scrapers, slackline cableways, hydraulic giants; hydraulic, clamshell, ladder or dipper dredges. The type of equipment used depends upon the character of the deposit and operating conditions. Sand and gravel are obtained from three types of deposits—bank, pit and marine. Bank deposits are generally worked dry. Pit deposits may be worked either wet or dry. Marine deposits (river, lake or ocean) involve underwater operation. Floating dredges are commonly used for marine recovery.

The excavated material may be transported in cars hauled by locomotives or by rope haulage, aerial trams, motor trucks, belts, pumps and pipe lines, barges or towboats.

The first important step in the technology of preparation was the classification of sand and gravel by size. Although it is recorded that between 1812 and 1814, when gravel roads were first built in New York, some attempt was made to grade the gravel by size, it appears that sand and gravel were first separated mechanically at Louisville, Ky., in 1894. After that date classification rapidly became more general.

With increasing knowledge of the behavior of sand and gravel in use, requirements became more exacting and important progress was made in plant design. Screening and washing equipment were widely adopted. In the late 1930s classifiers were introduced in several plants to fractionate sands into several sizes that could be combined in any proportions desired to produce a sand having a definitely controlled modulus of fineness.

With growing demands for a wide range of industrial sands, rigid specifications were established, both as to size classification and purity. During the past 10 years many refinements in purification have been perfected. For treating sand to make it suitable for pottery and the better grades of colorless glass, scrubbers are used to separate iron oxide from the surface of sand grains. Concentrating tables may be employed to remove iron-bearing minerals. Acid leaching, recently introduced, may reduce the iron content as low as 0.01 per cent. Fine grinding is accomplished in some modern plants with air-swept tube mills controlled by "electric ears."

An interesting reversal in trend has characterized the use of finely divided sand in aggregates. About 1910 engineers and architects began to stress the importance of clean aggregates, and for the next 25 years coarse sand was considered best for concrete. Since 1935 portland cement has been ground much finer than formerly, and we are now in the midst of a reversion to the former practice of retaining fines in the sand aggregate.

A trend has been apparent toward decentralization of the industry into smaller units with portable plants. Although the portable plants have the advantage of location, large, well-equipped plants have a decided advantage in preparing materials to meet rigid specifications.

During the industrial depression of the 1930s, noncommercial production —that is, production by governmental agencies (Federal, State or municipal) —attained large proportions. Market demands had diminished greatly, and make-work organizations to bolster employment flourished. In 1923 noncommercial production was only 1.5 per cent of the total; in 1940 it had grown to 44.9 per cent. Fortunately for the organized industry, that trend is now reversed. Noncommercial output in 1945 was only 22 per cent of the total.

Cement

Portland cement was invented by Joseph Aspdin, a British bricklayer, in 1824, but its development was slow and tedious. Not until 47 years later was its manufacture begun in America—coincident, as mentioned before with the establishment of the Institute. Another type, known as natural cement, was made much earlier. This type, made by calcining an argillaceous limestone at a comparatively low temperature, was first used in constructing the Erie Canal, begun in 1817. Natural cement was preponderant for many years. The difficulty of obtaining a satisfactory mixture of raw materials and of securing the right temperature for calcination, together with the higher cost of manufacture, greatly retarded the growth of the portland cement industry. For 21 years portland cement held second place, but in 1897 it overtook natural cement. Two years later natural cement attained its all-time high record of a production value of about $4,800,000, and thereafter it declined gradually. Portland cement, on the other hand, attained a production value of nearly $6,000,000 in 1898, and from that date its growth was phenomenal. The construction of endless ribbons of paved roads penetrating every section of the country, a concomitant of the automobile age, was a primary incentive for the marvellous expansion of the cement industry during the 1920s.

Cement touches the experience of virtually every individual. The growth of the industry producing it, from insignificance 75 years ago to its present enormous magnitude, is one of the most dramatic events in the history of mineral production. It is now one of the major industries of the United States, having an annual production value in 1942 of nearly $287,000,000 and a plant investment of about $600,000,000.

The development of the cement industry has been marked by radical changes in products, processes and equipment. Virtually the only product made for many years was a slow-hardening portland cement that required about 14 days to attain adequate strength. The demand for greater speed in construction and the advantage of using concrete structures promptly after they were made led to the development of high-early-strength cements that would permit use within 48 or even 24 hours after pouring. The detrimental effects on ordinary cement of sea water, alkali soils and other chemical agencies led to development of the puzzolanic or other chemically resistant cements.

The era of enormous dams that began with construction of Boulder Dam created serious problems of disseminating the heat generated in the setting of cement, and this led to invention of low-heat and moderate-heat types specially designed for massive concrete structures. Meanwhile, ordinary portland cements were greatly improved in quality. It has been found that addition of air-entraining agents improves the resistance of concrete to freezing and thawing.

The process of cement manufacture evolved gradually from very crude beginnings. Calcination was first accomplished in vertical or shaft kilns, some of which were designed for continuous operation. They had been developed in Europe and were used in American plants because the American industry had as yet no designs of its own. For these shaft kilns the raw materials were briquetted, dried and placed in the kilns by hand. The process was slow and cumbersome and required much labor. Rotary kilns gradually came into use. In 1893 only 25 per cent of the cement was made in rotary kilns; in 1894, 40 per cent; in 1895, 41 per cent; but it was not until 1899 that production in rotary kilns exceeded that in shaft kilns. The latter were still in use as late as 1907 or 1908. The trend toward rotary kilns was accelerated when it was realized that, under American conditions, there was much greater advantage to be gained by saving labor than by saving fuel.

The first rotary kilns were 40 feet long and 4 or 5 feet in diameter. A 60-foot length was established as standard for some years, and the first movement toward long kilns took place in 1903 when Thomas A. Edison introduced kilns measuring 8 by 150 feet in his New Jersey plant. By 1911 kilns 210 feet long were in use, and some kilns at present approach 500 feet.

The lengthening of kilns was due in part to conversion of dry-process to wet-process mills. Most of the early cement mills were of the dry-process type; that is, the raw materials were pulverized and fed to the kilns in a dry state. It was found, however, that wet grinding was more economical and that uniform mixtures could be obtained more readily in slurry tanks than by blending dry mixtures. Accordingly, the wet process became more popular. The greatest disadvantage of the wet process was the cost of removing the water. It was claimed that the same output of clinker could be obtained by the wet process as by the dry if 30 feet was added to the length of the kiln. As evaporation is a costly method of removing moisture, most modern wet-process mills have introduced filtering equipment between slurry tank and kiln.

Powdered coal is commonly used for cement-kiln fuel. Unit coal pulverizers that discharge directly into rotary kilns, introduced about 1940, reduced the dust-explosion hazard and eliminated the need of storage bins for pulverized coal.

The Griffin mill was the most popular grinding equipment employed in cement plants for many years. In 1906 or 1907 tube mills came into general use. At first the tube mill was preceded by a ball mill, but later the combined ball and tube mill—the compartment mill—appeared. Electric-motor drives were first used in a cement plant in 1899.

Primary crushing methods have not changed greatly. Gyratory and jaw crushers were in common use in early years, and Fairmount rolls (single slugger roll with baffle plate) have been long in use, particularly in Pennsylvania. When deep-hole well drills began to take the place of tripod drills about 1914, larger and larger crushers were employed to reduce the large masses of rock thus produced.

Hand loading in quarries was succeeded by steam shovels of the railroad type, and these were followed by caterpillar-tread electric shovels of the full-revolving type. Thus tracks for shovels were eliminated, and the next step was to eliminate tracks for locomotives and cars. In 1925 motor trucks were first used for quarry haulage, but they were not employed widely for many years thereafter. Track haulage is still advantageous under certain conditions, particularly where heavy tonnages and considerable distances are involved.

Both explosives and methods of blasting have been greatly improved. The early explosives were quick-acting, sensitive nitroglycerin dynamites; then ammonium nitrate was found to be more effective, as it was slower in action, had greater heaving power, promoted better fragmentation and reduced blasting hazards, and finally, electric blasting was a great improvement over slow-burning fuse, as it permitted accurate control and timing. A more recent development was the delay-action blasting cap, which permitted the outer section of a multiple-hole blast to be discharged slightly before the inner sections, resulting in improved fragmentation. Cordeau, a trinitrotoluene fuse introduced in 1913, is a safe and effective means of exploding charges.

Multiple-hole blasting in high benches has been developed scientifically. The depth, spacing and burden of holes are accurately gauged and the quantity of explosive is carefully calculated according to the tonnage of rock to be broken and its hardness and toughness.

Cement rock, a natural mixture of clay and limestone in approximately the proper proportions for making cement, is abundant in the Lehigh district of Pennsylvania, and its presence is the principal reason for concentrating a great cement industry in that territory. Mixtures of limestone and clay quarried separately, however, have constituted the principal raw materials for cement. Slag and limestone have become important sources. Many years ago marl was an important raw material, but marl plants have almost disappeared from the scene, partly because of the difficulty of dredging, particularly in the winter, and partly because the size of marl deposits is generally too limited for long use without excessive haulage.

Exact proportioning of raw materials has always been an important problem in cement manufacture. If the limestone deposit is of constant composition laterally and vertically the problem is simplified. In many quarries such constancy does not obtain, therefore selective quarrying and judicious proportioning of rock from different sections of the quarry have been followed. In some places where the limestone is too low in lime, high-calcium limestone has been shipped in occasionally from distant points as a necessary additive.

The year 1933 marked a step of progress in cement technology so important that it rendered unnecessary in many places either selective quarrying or the addition of corrective materials. A microscopic study of the limestone quarried for cement making at Valley Forge, Pa., revealed the fact that the impurities consisted of discrete particles of feldspar, clay, iron oxide and other minerals mechanically separable from the calcite, and it was found further that such separation could be accomplished by froth flotation. When flotation equipment was placed in operation at this plant, the composition of the raw mix could be corrected without selective quarrying. Flotation is now employed at several other plants where the cement rock is low in lime; thus it becomes possible to increase the lime content not by addition of high-calcium lime but by subtraction of the excess aluminous and siliceous components. The use of froth flotation has become standard practice at several cement plants in the United States and in foreign countries.

Plant efficiency has been improved considerably during recent years by better kiln insulation, by automatic instrumentation controls, by improved grinding equipment assisted by air-quenching of clinker, and by improved quarrying, crushing and transportation equipment.

The Portland Cement Association was organized in 1902. In contrast with the wide scope of its later activities, its original function was to solve the perplexing problem of the return and re-use of cloth cement sacks, a difficulty that was overcome in large measure during later years by substitution of nonreturnable, multiple-wall paper sacks. For the speedy acceptance of cement in highway construction, much credit is due the Portland Cement Association for its rigid insistence on inspection and strict adherence to specifications in the early days when poor-quality concrete would have retarded its acceptance by road builders immeasurably. The Association has occupied a leading position in cement research, both in its own laboratories and through work sponsored by it at the National Bureau of Standards.

Heavy-clay Products

Although the manufacture of brick, tile and similar materials is a part of the ceramic industries covered in a later section of this historical review, the heavy-clay products are building materials and accordingly deserve consideration under that heading.

Clay working is one of the most ancient nonmetallic mineral industries. The aboriginal Indians made pipes, cooking utensils and other objects of clay long before America was discovered. They even constructed dwellings of adobe brick before white men arrived.

Clay working was the first nonmetallic mineral industry to attain commercial importance in the United States. From a small beginning in Colonial days the industry made rapid growth. History records that in 1870 there were 3950 establishments manufacturing clay products of all kinds and that the annual value of output exceeded $36,000,000. Brickmaking spread westward and had attained importance in the Middle West by 1870. From manufacture of common brick the industry expanded to include such products as terra cotta, roof, floor and wall tile, sewer pipe, paving brick (first used in 1872), and firebrick. Clay-products industries sprang up in almost every state, but the greatest developments were in Ohio, New Jersey, New York, Pennsylvania, Illinois, Indiana, Missouri and California. Their growth was influenced chiefly by the volume of building construction within reasonable shipping distance of the deposits. Although well established and widely scattered 75 years ago, the clay-working industries made remarkable growth during the following three quarters of a century. By 1900 the value of clay products sold was approaching $100,000,000 a year; by 1910, $170,000,000; and in 1920, $374,000,000. In 1926 it had reached more than $430,000,000; but in 1930, because of the industrial depression, it had dropped to $275,000,000. During the recent war years, when building construction of the type that employs heavy-clay products was almost at a standstill, production dropped to a mere fraction of its prewar volume.

Brick plants in early years were very simple and were operated by crude methods and machines. As late as 1915 it was not uncommon at the smaller plants to employ spades and wheelbarrows or horses and scrapers for stripping. Power shovels, draglines, and other modern machines were introduced gradually. Excavation of clay from pits by wheel scrapers or steam shovels has been superseded in part by electrically driven caterpillar shovels. When in some localities the industry found it desirable to use consolidated shales as raw materials, blasting became necessary or shale planers were employed. Transportation by horse carts was followed by the use of cable cars, railways, belt conveyors, or gasoline-driven tractor trucks.

For many years after the heavy-clay-products industry was established the clay was generally used just as it occurs in nature, but when better and more uniform products were desired preparation processes became necessary. In modern plants the clay may be passed through granulators, crushers, conical rolls or other equipment. Pug mills are employed to accomplish thorough mixing.

The laborious method of molding clay into bricks by hand, as employed by the children of Israel under their Egyptian taskmasters, persisted, with some improvements, for many centuries. Hand molding was employed in small brick plants in America even into the nineteenth century. From simple hand molding three processes developed—the stiff-mud process, whereby the clay is extruded through a die and cut with wires; the soft-mud process. which requires shaping in molds, and the dry-press method, by which clays in a nearly dry state are shaped under high pressure. Preparation methods must be modified to suit the process employed. Ceramic laboratories are now utilized to test the burning temperature, color, shrinkage, abrasive resistance and other properties of clays and clay products, in order that the available supplies may be used in making products for which they are best adapted.

Clays and shales are so widespread and diversified in the United States that a sturdy growth in the brick and tile industries is anticipated to meet the demands of prospective expanding construction.

Gypsum

Hydraulic mortar made of gypsum calcined at a high temperature and plaster of paris resulting from calcination at a moderate temperature were known to the ancient Egyptians and Greeks. The Romans were familiar with the use of gypsum as a fertilizer.

In the United States the use of gypsum as land plaster was known to the settlers as early as 1800 during their westward migration. It was first used for this purpose in Virginia about 1835, in Michigan about 1842, and shortly thereafter in increasing quantities in other states. The earliest recorded domestic manufacture of plaster of paris was about 1835. The raw rock was ground in a corn mill and calcined in a cauldron kettle. Only small quantities of calcined gypsum were made for many years thereafter. In 1871 the gypsum industry was primarily a land-plaster industry. The rock was calcined in a small way in Michigan before 1870, but the first calcining mills in Iowa and Kansas did not begin to operate until 1872.

The earliest available statistics—those for 1880—show a production value of about $400,000. Until 1899 growth was slow because the use of gypsum as land plaster was declining. In 1880, half the gypsum sold was so used; in 1904, only 10 per cent; in 1913 only 2 per cent and in 1930 less than 1 per cent. Small quantities of domestic gypsum as land plaster are still used, but anhydrite ($CaSO_4$), a form of calcium sulphate imported from Canada, has maintained its popularity for application to peanut crops in the South.

In 1899 for the first time the value of production exceeded one million dollars. The growth from that time was rapid because calcined gypsum was finding much wider use as wall plaster. This use was supplemented also by a growing demand for raw gypsum as cement retarder. By 1908 about 11 per cent of all gypsum mined was so used, in 1913 the amount had increased to 16 per cent, and since 1934 it has ranged from 15 to 24 per cent.

The history of the gypsum industry in its early years is replete with failures. Many operations were started on deposits having unfavorable working conditions, markets were inadequate, or competition was too aggressive. Scores of failures are recorded, but in later years more advantageous deposits were found, and the industry gradually came under the control of larger, more substantial companies.

The great expansion in the gypsum industry since 1920 is attributed to the development of a variety of building materials, such as wall plaster, plaster board, wall board, lath, precast partition blocks, tile, and roofing slabs. Such products have attained tremendous importance in construction, as they are well suited for rapid building. Another factor that promoted wide acceptance was the growing demand for the use of fireproof materials. Building products have dominated the industry for the past 25 years and have stimulated rapid growth. From a value of about $27,000,000 immediately following the First World War, the value of sales had reached more than $47,000,000 by 1925. Activity declined greatly during the industrial depression, but recovery was rapid thereafter, and the sales value had reached $69,758,442 in 1941. It must be emphasized, however, that this figure represents the value of finished gypsum products. The production of crude gypsum in that year was 3,811,723 short tons valued at about $7,000,000. The growth in crude production has been moderate; as early as 1909 it was 2¼ million tons. The striking gains have been in the variety and value of finished products.

Gypsum deposits are distributed unevenly in the United States. East of the Mississippi River they are not numerous; to the west they occur in hundreds of localities, some of them very extensive. Eastern deposits are confined to New York, Ohio, Michigan and Virginia. The market demands of the populous East are far greater than can be supplied from the deposits in those states, but from the earliest days of the industry the domestic output has been supplemented by shipments from extensive deposits in the Maritime Provinces of Canada. Gypsum is similarly imported by water from Mexico to California but on a much smaller scale.

The supply of natural gypsum is supplemented by gypsum formed as a by-product where phosphate rock is treated with sulphuric acid in the manufacture of superphosphate.

Gypsum is mined in some localities in open-pit quarries, but where overburden is too heavy underground mining, usually by room-and-pillar methods, is followed. Gypsum drills easily and is broken with low-grade explosives. Gypsite, an earthy variety abundant in some of the Western States, is excavated with scrapers.

Buhrstones, widely used for grinding gypsum, were succeeded by disintegrators and later by roller or hammer mills equipped with air separators. The principal calcined product is plaster of paris, which is made by heating the gypsum at a comparatively low temperature (330° to 340°F.) which drives off three fourths of the water of crystallization. A special product, Keene's cement, originally made in England, is manufactured by calcining at a much higher temperature and adding alum, borax or some other chemical to promote setting.

The technology of manufacture and the quality of the products have been improved greatly through the years. The design of calcining kettles has not changed greatly, but an important advance in technology was the invention about 1940 of a heated hammer mill that would grind and calcine gypsum in a single operation. Since 1940 gypsum plaster has found important uses in making molds for precision casting of various nonferrous metals and alloys. Tests and specifications developed by the American Society for Testing Materials and the Gypsum Association have promoted improvements in products and expansion in uses.

Three major changes have characterized the gypsum industry: (1) a drastic decline in use as fertilizer; (2) a great increase in demand for raw rock as retarder in consonance with the phenomenal development of the cement industry; and (3) the substantial growth in variety and volume of building materials. At present the industry appears to have attained greater stability. Fertilizer markets are small but reasonably constant. Cement-retarder sales are linked with continuing activity in cement manufacture, which seems to be assured, and demands for building materials are trending upward.

Asbestos

The history of the asbestos industry, to be at all adequate, must extend beyond the confines of the United States. Although this country is the largest manufacturer of asbestos products in the world—the output of its factories being valued at more than $100,000,000 annually—it has to depend upon foreign countries for 92 to 96 per cent of its raw asbestos supplies. Domestic production was very small for many years. The first recorded production of 150 tons (in 1880) came from Georgia, South Carolina, Maryland and New York. From 1882 to 1885 production ranged from 1000 to 1200 tons a year but did not again reach 1000 tons until 1900. The small output from 1890 to 1894 was confined to the Western States, and that of the years 1895 to 1901 was obtained at widely scattered points in both the East and the West. Virtually the entire production before 1905 consisted of amphibole asbestos, which was too weak for spinning but was used for asbestos cements and paints.

A deposit of chrysotile asbestos, which is the chief variety used throughout the world, was uncovered by a woodcutter on Belvidere Mountain, in northern Vermont, in 1892 or 1893. Most of the asbestos of this area is classed as "slip-fiber," as contrasted with the prevailing "cross-fiber" veins in Canada. Very little is suitable for spinning. A mill was erected in 1902 but operated only 6 months. Another mill, built in 1907 in a different locality, began to produce in 1908. In 1909, Vermont, with an output of 3085 tons, was the chief producing state and in 1911 produced more than 7000 tons.

In 1912, Vermont was the only producing state, but thereafter it had no record of output until 1929. Since that year it has been an active producer, having the only large asbestos mining and milling operations in the United States. The bulk of the United States production, which reached a maximum of 24,391 tons in 1941, originates in Vermont. In 1942, a new quarry was opened, and a considerable quantity of long-fiber is obtained from it. As it is variable in quality and difficult to fiberize, it has not yet been adapted for use in spinning.

Chrysotile asbestos was first discovered in Gila County, Arizona, in 1872. Many cross-fiber veins embedded in dolomite have been found in this county, and numerous small mines have been opened. The soft fiber is of excellent spinning quality, but harsh fiber of lower quality also occurs. Mining is costly, markets far away, and the area shows little promise of furnishing a substantial supply.

Deposits are known in many other states but appear to be too small or too poor in quality to become consistent producers. The United States has never furnished more than 4 to 8 per cent of domestic requirements.

The largest foreign source of supply is the Thetford mines- Coleraine district of Quebec, Canada, which has been a famous producer of chrysotile asbestos since 1878. Production has reached more than 450,000 tons a year, most of which is exported to the United States. The second largest source of supply is Southern Rhodesia, which also produces chrysotile. The Union of South Africa furnishes two varieties, blue asbestos and amosite, which are found in quantity nowhere else in the world and which are used quite extensively in the United States.

Soviet Russia has large deposits of chrysotile asbestos. There have been substantial imports from that country into the United States at times but the U.S.S.R. has large asbestos-products plants that consume most of the domestic production.

Amphibole asbestos deposits are worked in small open pits. Power-shovel loaders operate in open quarries in Vermont, but the Arizona fiber is mined from underground drifts. The Canadian operations were originally open pits, but during the early 1930s a complicated block-caving system was introduced and is now employed by several companies. Mining costs have been reduced thereby, and winter operation has been facilitated. Both open-pit and shrinkage-stoping methods are followed in Rhodesia. Underground mining is general in the Union of South Africa, while open quarries are operated in Soviet Russia.

Asbestos milling in Vermont and Canada consists of crushing, drying, disintegrating with "cyclones" and "jumbo" machines, screening and removing fiber with suction fans.

Asbestos products were made in the United States before asbestos was mined in Canada. Asbestos paper manufactured at Waltham, Mass., in 1876 was made of Italian fiber. The spinning and weaving of asbestos into textiles began more than 60 years ago. Fireproof garments and theater curtains were important products. Woven brakebands for automobiles were first used about 1907 and before many years became the most important woven products. Only the long fibers can be used for textiles. Asbestos packing for steam glands was first used in that eventful year 1871.

Heat insulators constitute an important branch of the asbestos-products industries. Asbestos mixed with silicate of soda was first used for heat insulation in 1866. Asbestos-magnesia pipe covering appeared about 1885. Asbestos paper, first made in 1878, has become an important product, particularly for making air-cell pipe covering. More asbestos paper is now made in a day than was made in an entire year 35 years ago. Asbestos pipe and boiler coverings are of many kinds.

The largest application of asbestos at present, the manufacture of asbestos-cement building materials, is of comparatively recent date. Asbestos-cement roofing was first made in Austria about 1900 and in the United States about 1903. Other products are flat and corrugated sheeting, wall board, mill board, and floor tile, millions of square feet of which are made every year.

Among the numerous and diverse miscellaneous uses are acid filters, fireproof paints, arc welding, wire covering, molded articles, furnace cements, table pads and refrigerator linings. At least 75 large plants and numerous small plants manufacture a great variety of asbestos products.

No satisfactory substitute for asbestos for most of its uses has yet been found. Continued growth in the asbestos-products industries is to be expected. The deposits of Canada and Africa are extensive enough to furnish supplies for many years, but there is a crying need for the discovery and development of more extensive deposits in the United States.

FERTILIZER MATERIALS

The need for addition of fertilizers to arable land increases progressively as cropping is repeated. Virgin topsoil generally has considerable natural fertility, but successive harvests gradually deplete it of the elements necessary for crop growth unless steps are taken to replenish the supply. Although this is accomplished in part by stock farming, by growing leguminous crops, and by plowing under organic matter, the demand for additive material in the form of mineral fertilizers has attained increasing importance as farming has become more intense.

Seventy-five years ago the modest needs for mineral fertilizers were supplied by a small domestic phosphate-rock industry, by moderate imports of potash, chiefly from Germany, and by small imports of nitrates from Chile. Contrasted with these limited demands, the insistent call for fertilizers in 1945 and 1946 surpassed all previous records, and such demands were worldwide.

No substantial decline in demand is in prospect during future years. Proper nourishment for a growing population depends increasingly upon the adequacy of supply of fertilizers; accordingly, the industries producing them are to be regarded as essential to the well-being of the nation at all times, in peace or in war.

Phosphate Rock

Extensive deposits of rock containing a high percentage of calcium phosphate provided a basis for an important fertilizer industry in the United States. It is estimated that reserves of phosphate rock in the United States exceed 10 billion tons. Phosphate, like potash and nitrogen, is essential to plant growth, and its addition to soils is indispensable if fertility is to be maintained.

The use of phosphate rock as a land fertilizer was begun on the east coast of England about 1842 or 1843. In the United States production was begun in South Carolina, and the first shipments were made from Charleston in 1867. An export trade to Europe was developed shortly thereafter. South Carolina was the only producing state for many years.

The most eventful dates in the history of the industry are 1888, when the Florida deposits were first utilized; 1893, when the "blue rock" of Tennessee was found; and 1896, when production began in the "brown rock" fields near Mt. Pleasant, Tenn. As the phosphates of Florida and Tennessee are of higher grade than those of South Carolina, the industry in the latter state gradually languished until it disappeared. A small tonnage was obtained in Kentucky, Arkansas, Pennsylvania, Alabama and South Carolina between 1896 and 1926 and from the Western States since about 1906, but Florida and Tennessee dominate the industry.

Seventy-five years ago the industry was confined to South Carolina. No statistics are available for 1871, but output probably reached a value of several hundred thousand dollars a year, because 9 years later, in 1880, the first year for which figures are available, sales were valued at about $1,124,000. The value of sales gradually increased during the next 23 years, reaching more than $5,000,000 in 1903. Thereafter, with development of the high-grade deposits of Florida and Tennessee, production increased rapidly. The maximum annual output before the First World War was 3,111,221 long tons, valued at $11,796,231, in 1913. The marked decline that characterized the war years was due in part to the diversion of sulphuric acid from manufacture of fertilizers to the production of munitions.

With a greatly increased farm gross income, together with a strong demand for farm products to supply the needs of a Second World War and its aftermath of food shortage throughout the world, the output of phosphate rock has increased tremendously during recent years, exceeding 5 million long tons in 1943 and reaching 5,800,000 tons in 1945.

Attention was directed to the immense phosphate deposits of the Western States (Idaho, Montana, Utah and Wyoming) about 1906, and production in that area in 1909 was about 0.5 to 1 per cent of the United States total. Production during recent years has been confined to Idaho and Montana, where underground mining of hard, bedded phosphate rock is in progress, and increased to about 2 per cent of the total in 1930 and 5.5 per cent in 1944.

The technology of both mining and preparation has made tremendous strides since 1871. In 1888, when the Florida deposits were first worked, the overburden was removed by wheelbarrows or with mules and scrapers, and the underlying phosphate pebbles were separated from the finer materials by simple screening. Steam shovels were used later, followed by hydraulic methods. Since 1926 the overburden has been removed chiefly by means of electrically operated draglines.

Florida phosphate rock was mined with pick and shovel until about 1900, when some operators introduced railroad-type steam shovels. It is now generally mined with hydraulic giants and pumped to the washers or recovery plants.

The most notable advance in the Tennessee and Florida fields has been in the treatment of the crude rock. From the simple washing and screening processes used in early years the industry has gradually developed the most advanced methods of beneficiation. The matrix, composed of sand, clay and phosphate rock (pebbles and fines in the land-pebble districts), has for some years been processed by desliming, scrubbing, screening, classification and selective concentration. Generally 80 to 85 per cent of the phosphate in the matrix is recovered.

One of the most progressive steps was the application of froth flotation. With such equipment, large quantities of the finer matrix previously discarded may be recovered. So much progress has been made in phosphate milling that several plants in Florida and Tennessee are reworking waste banks accumulated during earlier mining. For instance, in 1941 a Florida producer operated a mill equipped with 36 agglomerate tables having a combined capacity of 30 tons an hour of high-grade concentrate recovered from tailings.

About 85 per cent of the mill product is acidulated with sulphuric acid to make superphosphate for fertilizer use. About 10 per cent is employed for baking powder and in making disodium and trisodium phosphates for silk weighting. Smaller quantities are used for various chemical and industrial applications. Ground phosphate rock is sometimes applied directly to the soil. Electric-furnace production of elemental phosphorus, promoted actively by the Department of Agriculture and the Tennessee Valley Authority, especially in Tennessee, attained importance about 1937.

Increasing quantities of phosphate rock are used in cattle feed. As all phosphate rock contains a small percentage of fluorine, which is harmful for such use, processes for defluorination have been developed, and have grown important since 1940.

Until quite recently prosperity in the industry has depended in large measure on the extent of export trade, which in prewar years absorbed 25 to 40 per cent of total production. During the Second World War, with foreign markets cut off and shipping space reduced, export trade dropped to only 7 or 8 per cent of total output. Such losses were more than compensated by the heavy domestic demand.

Active markets for phosphate rock are in prospect for several years. Heavy domestic demands will continue as long as farm income remains high. Some improvement in the war-depressed export trade is to be expected; however, the high-grade deposits of Soviet Russia and the rejuvenated industry of North Africa will offer keen competition, and United States producers may have to be satisfied with less of the European market than they held in prewar years.

Potash

The story of potash production is one of the most dramatic in the history of American mining. It also has the shortest history of any of the major nonmetallics. Forty-four of the 75 years to which especial attention is devoted in these historic reviews had passed before there was a recognized potash-mining industry in the United States; and the output of that first year (1915) was less than $\frac{1}{800}$ of the record output of more than 874,000 tons (K_2O content) in 1945. Although potash production has been recognizable as an industry for only 31 years, the commodity is absolutely indispensable to the national economy. About 90 per cent of consumption is for fertilizer use, where it serves as an essential plant food.

Domestic production from mineral sources before 1915 was negligible. Potash was recovered from wood ashes in early years, particularly about 1850, when sizable shipments were made to England. The world's greatest known sources of potash were the Stassfurt salt beds of Germany, and when imports from that country became available the wood-ashes industry declined greatly. Thus, except for insignificant contributions from local sources, the United States depended entirely upon foreign supplies for many years.

With the outbreak of World War I, foreign sources were suddenly cut off; and this stringency, coupled with an increasing need of fertilizers because of the enlarged demands for food, created a very critical situation. Consumers frantically sought supplies from every source. No effort was spared to stimulate production from every possible raw material. Small quantities were obtained from such mineral sources as natural brines, alunite, cement-mill and blast-furnace dust, and (to a very small extent) silicate rocks. Supplemental sources were organic potash from kelp, distillery and sugar-mill waste, wood ashes and wool washings. The inadequacy of such sources is evidenced by the fact that consumption in 1916 was only 4 per cent of the 1935–1939 average and had reached only 20 per cent by 1920. As a result of the scarcity, prices reached fantastic heights—$436 a ton in 1916, whereas the average value (K_2O basis) in 1945 was about $36.

Intense stimulation increased production from about 1000 tons in 1915 to 45,728 tons in 1919. When foreign sources were again available, prices dropped to levels lower than they had been before the war. In consequence, imports increased substantially, and the domestic industry languished. The keen competition with imported salts kept production at a low level until 1927.

Production of potash from the natural brines of Searles Lake, California, began to attain importance about 1923. It had made rapid strides by 1927 and from that year until 1932 ranged from 50,000 to more than 60,000 tons a year.

In 1910 the German potash supplies were placed under rigid price-fixing and production control. This threat of absolute dependence upon one source of supply, and that in a foreign land, led Congress to appropriate funds to the U. S. Geological Survey in 1911 and for several years following, to carry on research work designed to determine locations geologically favorable for the occurrence of potash salts. Research was also conducted by the U. S. Department of Agriculture, and much experimental work was carried on by other organizations or by private companies on greensand, alunite, and other potash-bearing minerals.

The critical situation existent during the war years 1914–1918 stimulated more intensive search. Attention was focused on potash salts identified in drillings from oil wells sunk in the thick rock-salt formations of western Texas and southeastern New Mexico. The presence of potash salts in these wells was definitely proved, but the character, size and richness of the deposits could not be determined from the drill cuttings. As commercial possibilities were highly speculative, private capital was reluctant to undertake drill exploration. However, the potash problem had attained such national importance that in 1926 Congress appropriated funds for an exploration program to be conducted jointly by the Bureau of Mines and the Geological Survey. By October 1929, 13 wells had been completed and had established the existence of extensive beds of potash salts. The principal salt noted was polyhalite, a sulphate of lime, magnesia and potash. Although polyhalite is not regarded as the most desirable salt from a commercial standpoint the Bureau of Mines has made much progress in developing chemical processes for its successful treatment.

Contemporary with the Government drilling, core-drill exploration by a private company led to the discovery in the same general area of a large deposit of the readily soluble potassium chloride, sylvite. A mine sunk for its development near Carlsbad, N. Mex., came into production in 1931. This was the beginning of a greatly expanded potash industry. A second company sank a shaft in the same area in 1934 and a third company in 1940. Each firm operates a refinery for preparing fertilizer salts.

These mines and refineries, supplemented by salts obtained from saline lakes in California and Utah, have capacity adequate to supply all our domestic needs. By 1933 production exceeded 100,000 tons for the first time. By 1935, for the first year since 1919, production exceeded net imports. In 1941, when German imports were very small, for the first time in the history of the industry exports exceeded imports. Thus, from a state of dire dependence, the nation has developed a robust self-sufficiency in this essential product.

Nitrogen Compounds

Nitrogen is an essential plant food. Unlike potash and phosphate, the supply of which must be replenished chiefly from outside sources, a large part—roughly two thirds of the nitrogen utilized by crops—is obtained by biochemical fixation through micro-organisms. It is important, however, that the deficiency be met from outside sources if nitrogen starvation is to be avoided. Nitrogen is also an important constituent of explosives and has other industrial uses.

The United States is virtually barren with respect to natural nitrate deposits of commercial value. Cave nitrate was used in a small way to make gunpowder during the Civil War, but in 1871 there was no nitrate-producing industry in the United States. Chilean nitrate producers had a monopoly of the world's nitrogenous fertilizer markets, and the United States depended almost entirely on this source of supply in 1871 and for about 25 years thereafter.

The domestic production of nitrogenous compounds began with the recovery of sulphate of ammonia from by-product coke-oven plants, the first of which were built in 1893. The first available statistics on production from such plants covered 1897, when the "possible production" of sulphate of ammonia was 3576 tons. The output in 1910 was 22,901 tons and had grown to 66,960 tons by 1919.

Before the beginning of the twentieth century the nitrogen requirements of the soil were very small. Consumption in 1880 was only 18,817 tons. As the natural supplies were depleted by repeated cropping, demand increased rapidly. By 1900 it had reached about 72,000 tons and by 1910 it was 145,000 tons. It is evident, therefore, that material recovered from by-product coke ovens was quite inadequate to satisfy domestic needs during the era that reached to the end of the First World War. Large quantities, ranging from 112,000 tons in 1910 to 222,000 tons in 1916, were imported from Chile.

A new era in the nitrogen industry began during the First World War. Germany, which consumed about 800,000 tons of nitrates annually, was completely isolated; and, if the war was to be continued, it was absolutely essential to develop a means of producing nitrate. The cyanamide process of atmospheric nitrogen fixation was already in use in Germany, but the product of this process was entirely inadequate to meet the demand. As a result of concentrated effort, the Fritz-Haber process, which had been developed in part before the war, was placed on a commercial basis. By this process a compressed mixture of nitrogen and hydrogen is passed over a catalyst at high temperature, forming ammonia by direct synthesis. The first commercial plant was established at Oppau, Germany, in 1913, and the process was a German secret until after the war.

Both the arc and cyanamide processes had attained some degree of development in the United States during the war of 1914–1918, but no commercial production in war-built plants is recorded. According to one record, it was not until 1921 that the first synthetic-ammonia plant in the United States began operation at Syracuse, N. Y. This process now dominates the air-nitrogen industry and has attained rapidly increasing importance. By the end of World War II, 19 synthetic-ammonia plants were in operation, 10 of them Government owned. The aggregate annual production was over 1,250,000 tons of nitrogen. Thus the atmosphere surrounding the earth has become an inexhaustible reserve of an essential mineral product.

Since the First World War the demands for nitrogen compounds have grown substantially. Agricultural requirements reached 376,000 tons by 1930 and 456,000 tons in 1941. By the end of the recent war the military requirements for nitrogen were estimated at nearly 600,000 tons. Total consumption evidently approached 1½ million tons a year at the peak of war requirements.

The history of the nitrogen industry therefore falls into three definite periods: (1) before 1897, when this country depended entirely upon imported Chilean nitrates; (2) from 1897 to 1921, when imports were supplemented by by-product coke-oven sulphate of ammonia; and (3) from 1921 until the present, during which time synthetic ammonia derived from the air has become the principal source.

At the close of the war the United States had the tremendous productive capacity of 1,500,000 to possibly 1,700,000 short tons of nitrogen annually, whereas it is estimated that postwar domestic needs will not exceed 1,200,000 tons. Furthermore, a continuing importation of 100,000 to 300,000 tons annually (nitrogen basis) of Chilean nitrate is to be expected, partly because of Good Neighbor policy and partly because the Chilean product contains minor fertilizer elements desired by farmers.

CHEMICAL RAW MATERIALS

Nonmetallic minerals constitute a substantial and essential part of the raw materials required by the chemical industries, and chemical processes form the backbone of industrialism. In no nation or community can diversified manufacturing and processing industries become dominant unless chemical raw materials are available in adequate quantities at moderate prices. The United States has been richly endowed with most of these raw materials, and their abundance and availability have been decisive factors in the enormous growth of the chemical industries that has marked the past three quarters of a century.

Thus, sulphur for acid manufacture is mined in the Gulf region by unique processes and in quantities unparalleled in any other region in the globe; salt and lime for alkali manufacture are obtained from inexhaustible mineral deposits in many states; magnesium salts for many products are obtained from any one of a variety of sources, including the limitless ocean; and fluorspar, so essential to metallurgy, is derived from less abundant but adequate mineral reserves. Barite, important in oil-well drilling and in the paint and chemical industries, is mined from extensive deposits in several states. The important steps in the history of these commodities are outlined in following pages.

Sulphur and Pyrite

Production of sulphur in the United States ranged from only a few hundred to a maximum of 7443 long tons per year before 1904. Domestic requirements were satisfied chiefly with Sicilian sulphur, imports of which ranged from 88,000 to 191,000 tons a year at that time. Sicily dominated the world sulphur markets during these years. Pyrite (iron sulphide), both domestic and imported, was, however, an important and for many years the chief source of sulphur.

The most important sulphur deposits in the United States, or, in fact, in the world, are those occurring in a porous rock formation overlying salt domes in Texas and Louisiana. The most striking event in the history of sulphur mining was the application, in this region, of the process invented by Herman Frasch and known universally as the Frasch process. The basic principle involved is the injection of large volumes of superheated water into the sulphur-bearing rock formation, which liquefies the sulphur, permitting it to be pumped to the surface. The development period that began in 1890 was beset with many difficulties and disappointments, but success attained in 1904 marked the beginning of a new era in sulphur mining. The process was a commercial failure because of excessive cost of fuel until oil, discovered at Spindletop in 1901, furnished the necessary cheap fuel.

The success attained by this new process in 1904 is reflected in the remarkable output of that year—85,000 long tons compared with only 7382 tons in 1903. Still more striking was the output of 220,000 tons in 1905. As a result, imports of Sicilian sulphur immediately began to diminish, and, on the other hand, an export trade in sulphur began in 1904. Production increased enormously thereafter, exceeding a million tons in 1917, passing the 2-million mark in 1923, and reaching more than 3¾ million in 1945.

Before the First World War, pyrite, most of which was imported from Spain, was the chief source of sulphur. Native sulphur from the Gulf Coast region, however, was gradually gaining a stronger foothold; and, with paralysis of shipping due to war conditions and consequent reduction in imports from Spain, the use of sulphur for manufacture of acid increased greatly in 1917. Thus at two periods sulphur production made remarkable gains—in 1904 under the influence of the Frasch process and in 1917 when substitution of sulphur for pyrite became general, and war conditions gave increasing impetus to chemical industries requiring sulphur. At the close of the war many acid plants continued to use sulphur.

The principal use of sulphur is for making sulphuric acid, which has been designated "the old warhorse" of chemical manufacture. It is used primarily as a reagent in the fertilizer, petroleum-refining, and a host of other chemical and process industries. About three fourths of the total sulphur mined is converted into acid. The high purity of the sulphur produced in the Gulf region encourages its use in the chemical industries.

Sulphur in elemental form is used in a wide variety of products, including rubber and insecticides, and a large tonnage is oxidized for use in papermaking. Much research has been conducted during the past 15 years on new uses. A cement consisting of 40 per cent sulphur and 60 per cent silica sand is highly resistant to acids. Other types of sulphur cements are adapted for use in acid-proof masonry linings for tanks. Plasticized sulphur, made by reacting sulphur with organic sulphides, polysulphides, and polymars thereof, have exceptional qualities as jointing materials in brick pavements and sewer pipe. A process has been developed for making noncorrosive pipe, consisting of coke and a gravel or asbestos aggregate cemented with molten sulphur.

Pyrite deposits are widely distributed in the United States. They occur as lenses in schists of the Appalachian area, associated with coal and with lead and zinc ores in the Middle West, and in veins and lenses in the Rocky Mountain states and the coast ranges. The most important commercial deposits are in the Ducktown district, Tennessee. Deposits are worked also in California, Virginia, Wisconsin and New York. Total pyrite includes the primary mined product plus the pyrite, which, in quantities varying considerably from year to year, is recovered at certain coal-mining operations ("coal brasses") and that obtained in milling certain ores, together with by-product sulphur dioxide from smelters and fuel gases.

Production of pyrite in 1871 was unrecorded, but very small. It reached 12,000 tons in 1882 and exceeded 100,000 tons in 1891 and more than 200,000 tons in 1900. There were no further significant gains until the First World War, when output increased greatly, reaching nearly 483,000 tons in 1917. This figure was never reached again until 1935, when it exceeded 500,000 tons. Thereafter it continued to increase, attaining an all-time high of over 800,000 tons in 1943. For these later years by-product pyrite and pyrrhotite from zinc and copper operations are added to the mined pyrite.

As domestic production plus imports has ranged from 800,000 to over a million long tons annually during the past 10 years, it is evident that pyrite continues to be an important factor in the sulphuric acid industry.

Total sulphur consumption follows, in general, the trends in industrial activity and therefore fluctuates greatly with booms and depressions. Its use in explosives and many heavy-chemical industries promotes substantial growth in war periods. The tremendous industrialization of the United States during the past 35 years is reflected in the striking increase in total consumption of sulphur, which in 1945 was more than four times as great as in 1910. There are no substitutes for sulphur for its major uses; therefore a steady and substantial market may be expected for it, although the proportions obtained from brimstone and pyrite may fluctuate under changing circumstances.

Lime

Lime has such a multitude of uses that it cannot be assigned exclusively to any one of the major groups of the nonmetallics. It is used widely in the building trades, is employed more extensively as a chemical and industrial raw material, and is applied to soils in substantial quantities as a conditioner. As this historical record deals primarily with the growth and development of the industry as a whole, all phases are touched upon herein.

The conversion of limestone into lime under the influence of heat was known to the ancients. Lime mortar was used by the Egyptians in chambers of the pyramids and in the construction of temples as early as 2000 B.C. Lime and gypsum mortars were virtually the only masonry binders known before natural cement was invented, about 1817. The gradual replacement of lime by natural cement for masonry use was noted as early as 1886, although cement was not a serious competitor at that time.

There were evidently many widely scattered local limekilns in 1871, because the first available statistics covering 1880 show a production value exceeding $4,600,000. That figure was nearly doubled by 1889, but the value of output did not exceed $10,000,000 until 1905. Growth was gradual until the First World War, when it gained more rapidly, and immediately after the war it experienced marked prosperity, attaining in 1925 a production value of over $42,000,000, a maximum for the era preceding World War II.

The lime industry began to lose ground 5 or 6 years before the industrial depression of the early 1930s, chiefly because of the growing competition with gypsum plaster and portland cement. Following the drastic decline of the depression years, production made substantial gains owing to increasing application in the chemical and manufacturing industries. Sales attained an all-time high of over 6½ million tons, valued at $49,000,000, in 1943.

The use pattern of lime has changed greatly. For many years it was predominantly a building material; in 1906, the first year for which statistics by use are available, 83 per cent of the lime sold was used for building purposes. Thereafter the percentage declined. In 1910 it had dropped to 64, in 1920 to 39, in 1930 to 36, in 1940 to 20, in 1942 to 11, and in 1945 to only 10 per cent. Figures since 1940, however, overemphasize the trend, because building construction of a type that uses lime was at an unusually low ebb in those years.

The use of lime in the chemical and processing industries has experienced an opposite trend. From only 8 per cent applied to chemical uses in 1906, the proportion had grown to 19 in 1910, to 51 in 1920, to 54 in 1930, to 72 in 1940, to 82 in 1942, and to 84 per cent in 1945.

Agricultural lime was about 17 per cent of the total in 1910 but gradually declined to an average of about 7 per cent of the total, in 1940. This decline may be attributed to the great increase in the use of pulverized agricultural limestone, particularly since 1934.

The preceding discussion of trends in use emphasizes the outstanding growth in industrial uses. Lime, "the king of all the bases," is one of the most important chemical raw materials. It is used in making products such as alkalies, asphalts, bleaching compounds, calcium carbide, glass, and insecticides. The immense demands of war industries so stimulated consumption for industrial uses that in 1943 the quantity of lime employed in industrial plants was 2¼ times as great as the 1935–1939 average.

Lime burning was a simple process a century ago. Limestone boulders were commonly built into an arch in a hillside excavation and calcined with a cordwood fire, kept burning continuously for two or three days. Simple shaft kilns were introduced later. Pot kilns, in which stone and fuel are added in alternate layers, were widely employed for many years and are still used to some extent.

The principal fault with the early processes was the retention of the fuel ash in the lime. As the demand for pure lime grew, particularly in the chemical trades, modern shaft kilns were developed. They have fireboxes that direct the flame through the mass of stone fragments, and grates that keep the ash separate from the lime. Most of the lime now made is produced in continuous shaft kilns, to which stone is added at the top and from which lime is drawn through a cooler at the bottom. Improved heat insulation and higher fuel efficiency have gradually been attained. Modifications in kiln design have involved the use of center burners that accomplish more uniform heat distribution and permit the use of smaller stone.

A drawback in the use of ordinary shaft kilns is their inability to handle stone of the smaller sizes because of interference with draft. On this account, many thousand tons of good stone have been thrown away as waste because of the small size of the fragments. To overcome this difficulty, the Bureau of Mines experimented about 1926 with a sintering machine using a traveling grate. Such equipment has been used to a limited extent. The most popular equipment now employed to utilize the smaller sizes is the rotary kiln as employed in the cement industry. Although requiring higher capital investment and giving lower fuel efficiency than modern shaft kilns, rotary kilns are more automatic, with consequent reduction in the labor requirement. Rotary kilns are employed in many places for the entire output of lime plants.

Lime is sold either as quicklime (CaO) or as the hydrate $Ca(OH)_2$. Hydrators are important parts of the equipment of many lime plants. Hydration has been utilized for many years. As early as 1906, operation of hydrators was reported by 30 plants.

In calcining limestone approximately half of the weight is lost in the form of carbon dioxide gas. Some attempts have been made to recover part of the gas thus wasted, but little commercial success has yet been attained.

A notable trend in the lime industry is a decline in the number of the smaller plants and in the proportion of the total output obtained from them. This tendency began many years ago and has continued steadily. In 1910, when production was about 3,400,000 tons, there were 1126 active plants, whereas in 1945, when production was nearly twice as great, there were only 189.

Fluorspar

According to early records, fluorspar mining was begun at Trumbull, Conn., in 1837, when a small quantity was sold at $60 a ton, for use in smelting copper ores. It was first mined at Rosiclare, Ill., in 1842, but shipments of commercial significance from Illinois and Kentucky were contemporaneous with the establishment of the Institute, dating from 1870 or 1871. The Illinois-Kentucky area has been the chief source of supply during all subsequent years, contributing now about 88 per cent of the United States total. The remainder (12 per cent) has been furnished by Arizona, California, Colorado, Nevada, New Hampshire, New Mexico, Tennessee, Texas, Utah, Washington and Wyoming. Output was small for many years. It ranged from 4,000 to 12,400 tons a year from 1880 to 1898; but with growing appreciation of the value of this mineral in metallurgy, together with a great expansion in steel production, it increased rapidly from that date, reaching 48,000 tons in 1902 and more than 57,000 tons in 1905.

Production increased substantially in 1910, 1911 and 1912 and attained a volume of more than 116,000 tons in the last year mentioned. War demands led to a phenomenal output of nearly 264,000 tons in 1918, the peak year of that period. Thereafter, except during the depressed markets of 1921 and 1930 to 1934, production ranged from 112,000 to 187,000 tons a year until 1939. Since that time it has increased greatly under the stimulus of war demands and attained a maximum of nearly 414,000 tons in 1944.

The principal use of fluorspar is as a flux in open-hearth manufacture of steel. The second largest application is for making hydrofluoric acid, essential to aluminum metallurgy and having other important uses. The glass and enamel trades are next in importance as users, and smaller quantities are employed for many diverse products. An important use that began to attract attention about 1935 was for the manufacture of the refrigerant Freon. Steel and aluminum are classed with the capital-goods industries that are quite sensitive to booms and depressions; and, as the fluorspar industry depends for its prosperity primarily upon them, it is also in the "prince or pauper" class, fluctuating greatly under the influence of changing circumstances.

Cryolite, sodium aluminum fluoride, produced in only one locality in the world—Ivigtut, Greenland—is the only fluorine mineral beside fluorspar that occurs in commercial quantities. Supplies from Greenland are supplemented by artificial cryolite made from fluorspar. An important use is in aluminum metallurgy.

Three general methods of mining fluorspar have been followed, open-cut mining, drift mining, and shaft mining. The first fluorspar operations in the Kentucky-Illinois area consisted of small openings on surface outcrops. From these small pits the mineral was removed by hand methods. As most of such outcrops have been worked out, the open-cut method has largely disappeared.

In a few deposits, where conditions were favorable, fluorspar has been mined in drifts and tunnels, in which little hoisting or pumping has been required.

Most of the fluorspar of commerce is obtained from shaft mines. At many of the small pits opened on outcrops in early days, particularly in Kentucky, small shafts were sunk later to follow the veins downward. Few of these mines have been developed systematically, because many of them have been worked on contract under short-term leases. Production is chiefly from the larger mines, most of which are developed systematically and are planned for future operations for many years. Fluorspar generally occurs as veins in fault zones. The Rosiclare vein in Illinois, the largest yet found, extends for 4½ miles, has been developed to a depth of 720 feet, and has yielded ore bodies as long as 1500 feet and as wide as 25 to 30 feet. Several large mines are on this vein, which has been a prolific producer. A heavy flow of water has interrupted mining at times. Several large mines have been developed in Kentucky, New Mexico and Colorado. The general trend through the years has been toward operation of fewer and larger mines and toward mining lower grade material. Fluorspar deposits tend to be erratic and uncertain in extent and continuity; hence, underground mining has become complex, requiring numerous crosscuts and exploratory adits and shafts.

The adequacy of reserves has caused concern at times, but through extensive exploration the available supply has paced production.

Fluorspar pure enough for use was obtained chiefly by hand sorting in the early days of the industry. Log washers to separate clay and sand from disintegrated or residual fluorspar were introduced many years ago.

The concentration of fluorspar mined from veins is not difficult if the impurities consist of calcite or silica, which is not harmful but is merely a diluent. Concentration of such material heretofore has been generally accomplished with jigs and tables. Since December 1943, however, the ferrosilicon heavy-media concentration process has been adopted by several companies. By using this process lower grade ores can be beneficiated, treatment costs are reduced, and a better concentrate with low tailing losses is obtained. If, however, the fluorspar is associated with galena, sphalerite, or barite all of which are harmful, concentration becomes difficult. The problem remained unsolved for many years. Much research was carried on by the Bureau of Mines and by the industry, resulting in the development of a froth-flotation process that makes it possible not only to separate the harmful impurities but to concentrate them as commercial by-products. Since 1936 many improvements have been made in milling, and several modern concentration plants have been built. The success of froth flotation has led to its wide use not only to concentrate primary mine output but to re-treat accumulated tailings.

No satisfactory substitute for fluorspar has been found for most of its uses. A continuing strong demand is to be expected, but a fluctuating future history is anticipated unless circumstances can be so modified that the metallurgical industries may follow a more steady, uniform course.

Barite

The mining of barite (heavy spar) was begun in Virginia in 1845. French settlers discovered barite in Missouri in 1850 and named it "tiff." Tennessee was reported as a producer as early as 1882. Production was first recorded in Georgia in 1901, in Kentucky in 1903, and in California in 1914. Missouri has generally been the leading producer, but Arkansas led in 1944 and 1945. Substantial quantities have originated in Georgia, Tennessee, Kentucky, Virginia and California. This heavy, white, chemically inert mineral was first used as a paint pigment. For some years it was regarded merely as an adulterant of white lead, and its use was frowned upon. Thus progress of the industry was retarded by the handicap of unpopularity. During later years scientific investigation of its properties proved it to be a legitimate paint ingredient having advantageous qualities.

Virtually the entire output was sold to the paint industry as ground barite for many years. Lithopone, a mixture of zinc sulphide and barium sulphate, was first made in 1892, but its use was small for several years. About 1907 it began to assume importance, and by the end of World War I barite was employed mainly for lithopone, about two thirds of the output having been consumed thus in the late 1920s.

The manufacture of barium chemicals is a relatively young industry in the United States, except for barium hydroxide, first made in 1908. The manufacture of other barium chemicals began during the First World War, when our supplies (formerly obtained from Germany and England) were greatly reduced. The existence of four barium chemical plants in 1915 is recorded, and 11 the next year. The manufacture of chemicals has been important since that time but requires smaller quantities of barite than either lithopone or the industries using ground barite.

The most striking event in the barite industry was the utilization of this mineral as a constituent of heavy drilling muds used to prevent blowouts in gaseous and high-pressure oil wells. This application began about 1924 or 1925 and grew so rapidly that it soon became the principal use of ground barite. By 1944 more than half of all crude barite mined was employed for this purpose.

Foreign trade has exerted a marked influence on regional development of the domestic industry. Before World War I the eastern deposits in Georgia and Tennessee had difficulty in competing with low-priced German barite, and production in these states was small. When German supplies were cut off in 1916 the eastern industry flourished, but after 1928 large imports again depressed eastern production.

Production before 1915 ranged from 20,000 to 90,000 short tons a year. In 1915 it exceeded 100,000 tons and in 1916 was more than double that quantity. Thereafter output ranged from 200,000 to more than 400,000 tons and attained a maximum of 692,000 tons in 1945.

Originally barite mining was a crude and simple operation. In Missouri, where most of the output has originated, for many years it supplemented farming during slack seasons. Part of the product was shipped direct to St. Louis by the miners, but much of it was sold to local merchants, sometimes in exchange for merchandise.

Most of the deposits are of the residual type, and open-cut methods were generally used, although some shallow shafts were sunk. It was recorded in 1882 that mining was conducted with pick, shovel, wheelbarrow or dump cart. Shaking boxes were used to separate soil. The barite pebbles were hand-sorted. Some plants washed and scoured the barite in rotating cylinders. It was refined with sulphuric acid to remove iron oxide during the earliest operations because a good white color was essential for use in paint. The purified pebbles were ground in buhrmills and the product was water-floated and dried.

Barite deposits differ so greatly in character that evolution in mining and preparation has developed along different lines in different localities. Hand mining of barite-bearing clays in Missouri, Georgia and Tennessee has been gradually displaced by mechanical methods, to reduce costs. The high wages of World War I led to the introduction of steam shovels and log washers in

Georgia and Tennessee. Hand methods were displaced in part by machines in Missouri in the 1920s.

In Georgia and Tennessee the material usually is stripped with power shovels or with scrapers hauled by tractors. The barite-bearing clay, loaded into trucks with power shovels, is hauled to the bullpen, where it is washed through a railroad-rail grizzly. The slurry passes to a log washer, followed by trommel, crusher, rolls, jigs and screens. Magnetic separators may be employed to remove iron-stained material. Froth flotation is sometimes used to recover the finer products. Mechanical mining is somewhat simpler in Missouri, where overburden is thin, and milling is easier because the barite is soft.

Mining is quite different at Malvern, Ark., where the barite occurs in shale intimately mixed with quartz and other impurities. The rock, shot down in open-pit quarries and loaded into trucks with power shovels, is first crushed and then ground in ball mills. The ball-mill discharge is classified and then purified by froth flotation. The concentrate is filtered and the filter cake is dried in rotary driers. Open-pit quarrying is also employed in certain massive barite deposits in Nevada and California.

Vein barite is mined underground at one large operation in California and at smaller ones in Nevada and Tennessee. In California the rock, removed from drifts and shrinkage stopes, is crushed, jigged, wet-ground in ball mills, classified, thickened, and dried on a steam-heated drum.

A noteworthy evolution in milling is the general abandonment of the acid-leaching process widely used in early days. This change may be attributed to: (1) selective mining of high-grade barite requiring no purification, (2) improved processes of milling whereby impurities are removed mechanically, and (3) the development of important uses—for instance, for drilling muds—for which relatively impure material may be utilized.

Salt

Salt production was one of the earliest American industries. The Indians obtained it from saline springs near Syracuse, N. Y., as early as 1653. It is recorded that in 1670 and during later years the Delaware Indians sold salt to settlers in northern New York. The earliest white settlers began its manufacture from brine near Syracuse, N. Y., but it was not until many years later—about 1889—that numerous wells were drilled for the extensive salt and chemical industries centered near that city. Rock salt was discovered in Ontario County, New York, in 1865. Deposits in Michigan, Ohio and other states later attained very great importance. Salt is widely distributed in the United States, and the resources are inexhaustible. Single beds are of sufficient extent and thickness to supply the needs of the entire world for centuries.

The earliest dependable figures for salt production in the United States are those of the Tenth Census of 1880, when output was 834,548 short tons valued about $4,800,000. Production increased steadily and by 1892 was about twice as great as in 1880; but, as the price constantly declined, the value of output increased very little. Production rose to about 4,200,000 tons in 1910, to 6,800,000 tons in 1920, to 8,000,000 tons in 1930, and to 10,000,000 tons in 1940, and reached an all-time high of over 15,700,000 tons in 1944.

Table and dairy uses were the principal outlets for salt up to 1897; hence growth depended largely upon population and was moderate. From that date, however, the enlarged demands for meat packing and particularly for chemical use promoted a more rapid growth. As the refinements of civilization became higher, more salt was used per capita. Thus the per capita consumption was about 39 pounds per year in 1890; about 77 in 1900; about 92 in 1910; about 124 in 1920; about 134 in 1930, and about 151 in 1940.

Salt has become a very important chemical raw material, particularly for the manufacture of such alkalies as soda ash, bicarbonate of soda, caustic soda and chlorine. The output of the latter product has grown tremendously during recent years. It is also used for making a great variety of sodium salts, such as the acetate, benzoate, chromate, bichromate, bromide, chlorate and citrate. It is used widely in metallurgy and ceramics.

There is no definite statistical breakdown of salt used as a chemical raw material. As salt in brine is the principal source of salt used for chemical purposes, it is interesting to trace the trend in salt in brine output compared with total salt production. For five-year periods beginning with 1919, the proportion of salt in brine to total salt shows a steady increase from 38 per cent in 1919–1923 to 54 per cent in 1945.

The unit sales value of salt has always been low. From an all-time high of $4.93 a ton in 1921 it dropped to a range of $3.00 to $4.00 a ton up to 1934, but since that year the average sales value at the plant has not exceeded $2.90 a ton. In 1943, when high war prices prevailed for most commodities, the average unit sales value of salt was lower than the lowest point reached during the depression period.

Salt is obtained from three sources: (1) by mining solid beds of rock salt, (2) from wells that furnish natural or artificial brines, and (3) from sea water. All of these sources of supply have been utilized for many years. The high solubility of salt (about 35 pounds per 100 pounds of water at ordinary temperature) has encouraged the mining of by far the largest proportion of it in the form of brine, which is the most economical method. Water enters the well by gravity; and as it circulates in the salt bed it dissolves the salt. The brine thus formed is pumped or otherwise forced to the surface.

The greatest advance in mining salt by solution was the development of the Trump plan during the 1930s. Previously water carried down through pipes in drill holes dissolved the salt from the upper surface of the salt bed. As solution progressed, the collapse of shale from the ceiling damaged the piping, and the shale and mud accumulations blanketed the salt surface, retarding the rate of solubility. According to the new method, a horizontal undercut is first dissolved at the base of the salt bed. Solution then continues at the ceiling of the undercut; and, as all impurities fall to the floor, they do not impede solution. This method has reduced the cost of mining by solution very greatly.

Sea water, which contains 3 to 4 per cent of salt, is an important source where solar evaporation may be employed. Most of the salt produced in California is recovered by that method. Intake ponds are flooded at certain intervals of high tide. The salt water is pumped into secondary ponds and gradually transferred from pond to pond as the brine strength increases by evaporation.

Salt is prepared for use in three ways: (1) by evaporation of brine, (2) by processing rock salt in solid form, and (3) by preparation of a concentrated brine which is used directly in industry. Salt made in early years was rather crude. Processes of purification were greatly improved by 1902; as a consequence, imports of the more refined grades, chiefly from England, were substantially reduced. Many refinements in preparation have been developed during subsequent years. Iodized salt has attained prominence recently. General processes have not changed greatly, although progress has been made in refinements of manufacture and in the preparation of specialized products.

A marked trend is apparent toward fewer and larger producing companies; 268 salt plants reported production in 1880; 161 in 1897; 136 in 1911, and 97 in 1925. Thereafter the number has ranged from 72 to 83. At the same time, as noted previously, production has shown a large increase. The trend toward fewer plants was occasioned in part by the acquisition of some small firms by the larger chemical companies, to supply brine for their own needs.

Salt is essential to the health of man and beast and to the preparation and preservation of food products, and is required for a multitude of industrial needs for which replacement by substitute materials is impractical or impossible. A continued growth of the industry in consonance with increasing population and enlarging industrial activity is to be expected.

Magnesium Compounds

Compounds of magnesium, particularly the oxide and the carbonate, are used extensively in industry, chiefly as refractories and as building and insulating materials. The natural sources of magnesium compounds are magnesite ($MgCO_3$), brucite [$Mg(OH_2)$], dolomite (Ca,Mg,CO_3), well brines, sea water and sea-water bitterns. These various sources are more or less interchangeable, and therefore the history of manufacture of magnesium compounds is somewhat involved.

Virtually the only use for magnesite when the Institute was established in 1871 was for making "Sorel" cement, invented in 1867. Very little was so used for some years, but such application of California magnesite was mentioned in 1888. Magnesite was first used for lining furnace bottoms in 1891.

The magnesite industry has been confronted with two serious disadvantages: (1) location, (2) competition with dolomite.

California was the only producing state until 1916, when the Washington deposits were first mined. These two states were the sole producers until the Nevada deposits were exploited in 1940 and the Texas and Utah deposits in 1941. A large deposit of brucite was mined in Nevada in 1934. As all the important deposits are in the Far West and the principal markets are east of the Mississippi River, transportation costs have retarded development, particularly as imported Austrian and Greek magnesites have been available in eastern markets under peacetime conditions at moderate cost.

The second retarding factor is the keen competition with dolomite, which is substituted for it quite extensively and is easily available to eastern markets. The industry had its greatest growth during the two world wars, when foreign supplies were cut off and the markets for refractories were greatly expanded. During the Second World War output was stimulated far beyond any previous level, because to the urgent need for basic refractories was added the use of magnesite as an ore of magnesium metal, the manufacture of which attained large proportions.

Magnesite is mined by open-pit methods in Washington and Nevada and generally by underground methods in California. For many years it was concentrated simply by hand picking. Highly refined methods of beneficiation are recent developments. Froth flotation was first employed in Washington and Nevada in 1942. The ferrosilicon heavy-media concentration method was introduced after 1940.

Calcination is accomplished in rotary kilns similar to those used in the cement and lime industries. Two types of calcined products are made: (1) caustic-calcined at a relatively low temperature, for stucco, plaster products, technical carbonate, and certain industrial uses, and (2) dead-burned at a high temperature for making refractories, by far the largest use.

Dolomite, calcium-magnesium carbonate, occurs widely in the United States and is used extensively. It is employed interchangeably with high-calcium limestone for concrete aggregate, road stone and railroad ballast, in agriculture, and to some extent as a fluxing stone. The uncalcined stone is also used widely as a refractory for furnace patching. Dolomite, like magnesite, may be calcined at a moderate temperature for the manufacture of dolomite or high-magnesian lime or may be dead-burned at a high temperature for making refractories.

Manufacture of magnesian lime is an extensive industry, particularly in Ohio, where a large part of the product is marketed as a finishing lime for use as wall plaster. Dead-burned dolomite is widely used and is interchangeable to quite an extent with dead-burned magnesite, although the latter is generally preferred for building up original furnace bottoms.

Dolomite has decided market advantages because many high-grade deposits are available in the East within easy distance of the centers of consumption. The use of dolomite for furnace linings is recorded as early as 1891, the year in which magnesite was first used in that way. Dolomite is the chief mineral used for making basic magnesium carbonate, the major constituent of "85-per cent magnesia" pipe covering.

Recently dolomite has attained greater importance. In 1941 it became an ore of magnesium. Many thousand tons were used during the recent war years for making this light metal. Another recent new application is its use in conjunction with sea water for making refractory magnesia.

The most striking technical development in the magnesium-compounds industries was the introduction in 1937 of a process whereby the magnesia content of sea-water bitterns could be recovered commercially. The first shipment from such a plant was made in 1938. The product is comparable with that obtained from calcination of magnesite and can be used in the same ways. Since 1940, sea-water magnesia has been used for making metallic magnesium. Thus the ocean, which certainly has no metallic characteristics, has become the ore of a metal.

Well brines have attained importance as sources of magnesium chloride, vast quantities of which were employed in making metallic magnesium during the late war. Refractory magnesia and other compounds are also derived from brines.

The newer methods of recovering magnesia from sea water and well brines, for beneficiating magnesite, for treating dolomite alone or in conjunction with sea water, and for the conversion of the magnesia into refractories and metal and other products has involved a greater development of highly complex technique during the past few years than was known in all the previous history of the industry.

CERAMIC RAW MATERIALS

Pottery and glass products, the manufacture of which has attained remarkable growth, consist predominantly of nonmetallic minerals, most of which are obtainable in the United States in adequate quantities. China clays of various types are abundant, and feldspar supplies are derived from many sources. Flint, however, is chiefly of foreign origin. Glass and pottery sands of adequate purity are abundant in some regions, while in others, where contamination exists, the sands are purified by highly refined processes. Lime, which is also important as a glass constituent, is discussed under Chemical Raw Materials in this historical record.

The domestic pottery industry has always been faced with keen competition from foreign sources, and the strong foothold it has secured is due in large measure to careful selection of raw materials and to the development of a highly refined technique in processing them for use.

Clay

Manufacture of pottery began in America almost as early as brickmaking. The first American pottery plant was established about 1640 in New York City, then under rule of The Netherlands. Many small potteries were in existence in eastern United States and also in California before 1800. Probably they used local clays almost exclusively. East Liverpool, Ohio, became a center of pottery manufacture in 1837, and Trenton, N. J., in 1852. These localities soon became leading centers of ceramic activity and have never lost their supremacy.

The pottery industry had become widespread and diversified as early as 1860. The census of that year recorded more than 500 establishments scattered throughout 30 states and the District of Columbia. A pottery production value of over $2,700,000 in 1860 had increased to over $6,000,000 in 1870. The Onondaga pottery industry of Syracuse, N. Y., an important vitreous china industry, began contemporaneously with the Institute in 1871.

A great variety of products were made even in the early days. They included whiteware, tobacco pipes, flower pots, stoneware, earthenware and Rockingham ware. The art-pottery industry began in Ohio in 1880. The pottery industry was stimulated greatly in 1876 under the influence of the Centennial Exposition.

With development of the metallurgical industries, firebrick manufacture became increasingly important. Firebrick industries were established on a permanent basis in Pennsylvania, Missouri, Ohio, Indiana, Illinois, New Jersey and California.

Glass-pot blocks were made until the early 1860s from Stourbridge clay imported from England. Thereafter Missouri plastic clays were used for a time and later clays from Ohio, Pennsylvania and elsewhere.

The pottery and fire-clay industries in early days depended chiefly upon local clays, but a clay-mining industry independent of ceramic manufacture was gradually established. Certain companies mined and prepared clays, shipping them to the pottery-manufacturing centers. Thus the so-called "merchant clay" industry developed.

Clay mining was begun in Florida in 1766, in Delaware in 1769, and in Vermont about 1810. Albany slip clay, widely used for glazing stoneware, was mined as early as 1837. Merchant clay mining began on a large scale at Woodbridge, N. J., in 1816, when clay was shipped to Boston for manufacture of firebrick. Kaolin mining began in Missouri in 1857, in Indiana and Pennsylvania in 1874, and in North Carolina in 1888. Georgia kaolins were first mined in the 1890s. Ball-clay mining began in Missouri in 1880. Before that date all the ball clay used in America was imported from England. High-grade kaolins for both pottery and paper manufacture have attained their greatest development in Georgia, South Carolina, North Carolina and Florida. The mining of fuller's earth is an ancient industry, but the utilization of bentonites did not attract attention until after 1900.

The development of a domestic china-clay industry has been retarded by a lack of constancy in composition and properties of American compared with English china clays, on which the pottery industry has always depended greatly. Much research and experimentation have been devoted to the substitution of domestic for imported clays. Remarkable progress has been made in developing refined methods of clay purification and preparation. These processes involve the use of rake classifiers, hydroseparators, thickeners, filters, froth flotation and air separation.

In 1937 the T.V.A., in cooperation with the Federal Bureau of Mines and industry, developed methods of taking clays apart, separating harmful impurities, fractionating them according to grain size, and again combining the various clay minerals in such proportions as to provide clays suitable for wall tile and electrical porcelain. Basic information for advancement in the art of clay preparation was furnished through X-ray and other fundamental studies of the clay-family minerals. As a result of studies by various ceramic schools, Government agencies and individual companies, processes of purification and preparation had advanced so far in the late 1930s that domestic clays were winning wide acceptance in the ceramic industries, which was reflected in a substantial substitution of domestic for foreign clays.

Progress in clay technology is due in no small measure to the work of the ceramic schools, the first of which was established at Ohio State University in 1894. Improvement in practice in both the pottery and heavy-clay-products industries has been stimulated greatly by the activities of the American Ceramic Society.

The recovery of alumina from clay, that will-o'-the-wisp that has eluded investigators for the past 25 years, was a subject of intense research during the Second World War. At least five independent programs were in progress. Unsubsidized production is still in the future.

Feldspar

Feldspar is an important constituent of pottery, and as pottery manufacture was among the first industries to be established in America, attention was directed to feldspar mining a great many years ago. It is recorded that feldspar was mined by the Indians in Mitchell County, N. C., as early as 1744. It was used for wampum and ornaments and for trading with white men. In 1825 feldspar from surface exposures of numerous pegmatite dikes in Connecticut was packed in barrels and shipped to England on schooners.

The first feldspar-grinding mill in the United States, operated near Middletown, Conn., in 1850, consisted of chaser stones (edge runners) set up in an open field and rotated with a yoke of oxen. Feldspar mining was begun near Cathance, Me., between 1852 and 1860. A feldspar-grinding mill was built in Trenton, N. J., in 1865. New Jersey has never been a feldspar-producing state, but the widely known pottery industry of Trenton, which had its beginning in 1852, was becoming an important consuming center. Feldspar to supply this new mill was furnished for several years from a mine near South Glastonbury, Conn., opened in 1866. Shortly thereafter other mines were operated in Maine, Delaware, Pennsylvania, and New York. A grinding mill was established at the pottery center of East Liverpool, Ohio, in 1874.

The earliest statistical records available, those of 1880, show a production value of $60,000 in that year. In 1883 six states produced 14,100 tons, all of which was used in pottery except a small quantity from Delaware, used in making artificial teeth. Production was first recorded in Canada in 1890, when 700 tons was shipped.

An interesting sidelight on mineral reserves appears in the statistical record for 1891. Production was only 10,000 tons, but it was reported that deposits were scarce and that new discoveries were urgently needed. How assiduously our resources have been developed is evidenced by the fact that no particular difficulty is now experienced in obtaining more than 300,000 long tons a year.

Connecticut was the principal producer in 1883 and for a number of years thereafter. Pennsylvania stood second. Maryland was first recorded as a producer in 1896, but Pennsylvania took the lead in output in 1900. Virginia and Minnesota were added to the list of producers in 1907, California in 1909, North Carolina in 1911, Vermont in 1912 and Georgia in 1916.

The most notable geographical change in the industry was the remarkable growth in North Carolina. Although not recorded as a producer until 1911, the state reached first rank in 1916. Since 1921 it has dominated the industry and for some years produced from 40 to more than 60 per cent of the entire supply of the United States. South Dakota became an important producer in 1931 and since 1938 has held second place.

The early mining of feldspar was in small, irregular open pits along pegmatite dikes. The first reference to underground mining was in 1907, at a mine at Pomeroy, Pa. Other underground operations followed, some of which are extensive. Loading by hand methods is almost invariably employed, although at one open-pit quarry in North Carolina power-shovel loading was introduced in 1929.

Feldspar was first ground with buhrstones, followed by batch mills using flint grinding pebbles. The first coarse grinding was done with "chaser mills" (edge runners). In 1907 one Connecticut mill introduced a gyratory crusher, steel crushing rolls, and continuous-feed tube mills. The greatest advances in milling have been made since 1925, with the introduction of air-swept tube mills, compressed-air conveyance of ground spar, improved vibratory screens and air and magnetic separators.

For many years little progress was made toward standard specifications. Consumers designated the kind of spar they desired simply by its geographic source, such as Maine spar or Connecticut spar. In 1922 serious efforts were made toward selection by chemical composition. In 1928 a long stride was made toward technical control by employing chemical analysis, segregation of varieties according to composition, and blending. In 1929, at a conference among producers, grinders, consumers and technical advisors, a new classification was agreed upon.

Pottery has been the mainstay of the industry, but since 1896 feldspar has been an important constituent of glass. Its use as a binder in abrasive wheels dates from 1907. Other important uses are as poultry grit and as a constituent of scouring soaps, polishes and cleansers. Small quantities of high-grade "dental spar" have been used since 1883 for manufacturing artificial teeth.

A recent development of great significance in the industry is the application of froth flotation to the recovery of feldspar from rocks that are too fine grained to permit hand sorting. A new mill at Kona, N. C., which began operation in 1945, employs flotation to recover feldspar, mica and quartz from alaskite, a granitic rock low in ferromagnesian minerals. If the method proves successful enough to justify wide acceptance, it will increase our feldspar reserves enormously, for it will make available abundant, relatively fine-grained rocks, such as granites, and also feldspathic sands, whereas until recently the coarse-grained pegmatites have been regarded as the chief, if not the only, commercial source.

Flint

Although ordinary silica is used abundantly in pottery, for certain uses true flint (chalcedony) is advantageous. Although true flint pebbles are obtainable in the United States—for instance, at Columbia, Texas, and on the California coast—most of the commercial supplies are imported. Danish and other imported pebbles are unique in that they constitute both raw materials and grinding tools. The firmest well-rounded pebbles are used as grinding balls in tube mills, while the less perfect are crushed and then ground to a fine state of subdivision in the tube mills.

Glass Sand

Ordinary silica sand is an important raw material of the glass industry. The content of impurities, notably iron compounds, must be low, particularly for plate glass and other special products. Nature performed an excellent milling job when she deposited many banks of sand, for the grains were washed almost free of impurities and were sorted and segregated in beds of nearly uniform grain size. Where such beds can be utilized, glass sand can be excavated and marketed at low cost. In other localities admixed impurities must be separated in log washers or other equipment. Iron-bearing grains may be removed by magnetic separators. If iron-stained impurities adhere so firmly to the surfaces of the sand grains that they cannot be removed by washing, the sand may be useless unless a solution process can be used. Glass sand is such a low-priced product that in general it has been regarded as uneconomical to use the more complex processes of purification, such as acid leaching. However, during recent years such processes have been developed commercially, and acid-treated sands are now placed on the market at prices as low as $3.00 a ton.

As a glass industry can be developed most economically in regions where natural gas or other low-priced fuels are available, glass-sand deposits in such regions have market advantages. Thus, a relatively impure sand close to a glassmaking industry may be utilized if it can be purified effectively at a cost not exceeding that of transporting naturally pure sand from a distance.

REFRACTORIES

Refractories are very important in industry, particularly for furnace linings where high temperatures are involved. Refractories must not only be capable of standing up under high temperatures but must resist slagging effects, spalling, cracking and abrasion. The principal refractories are those made of fire clay, bauxite or diaspore, silica, magnesia and chrome. The fire-clay and magnesia products have been covered in the sections devoted to ceramic clay and magnesium compounds. Bauxite and diaspore are used for making high-alumina brick and chromite for making chrome brick. The most important silica refractory is silica brick, made of quartzite (ganister), with the addition of 1.5 to 2 per cent of lime. Natural sandstones are at times used in the same way. Special refractories, such as silicon carbide, mullite, zirconia, corundum, beryllia and thoria, find limited use.

The industries requiring refractories, in order of importance, are iron and steel, public utilities, nonferrous metals, cement and lime, glass, and oil refining, followed by miscellaneous ceramic and other industries.

Developments that pertain primarily to processes of manufacture are outside the scope of this treatise. Circumstances worthy of mention are the utilization of new types of raw materials, such as olivine for making forsterite refractories. A California deposit of andalusite was first utilized about 1924 for making spark plugs and other specialized products. Domestic kyanite has been used for refractories to some extent, but the Indian product is generally preferred. Topaz is a unique refractory raw material mined commercially in one deposit only, in South Carolina. In 1940 attention was directed to pinite (similar in composition to muscovite) as a refractory. Another recent development is the manufacture of "electrocast" refractories made by fusing mullite, alumina, magnesia or other material in an electric furnace and casting it in desired forms. The most striking recent event is the utilization of magnesia derived from sea water for making periclase refractories.

NATURAL ABRASIVE MATERIALS

Abrasive materials, used to wear down, smooth or polish surfaces, are extremely important in locating and developing mineral deposits by such processes as diamond drilling, shot drilling, and wire sawing. They are of equal or greater importance in fabricating, finishing and polishing a multitude of manufactured products. They are essential in the manufacture of precision instruments, tools and machines.

Abrasive materials fall in two classes: (1) natural mineral products and (2) manufactured products. Attention herein is centered on the first group. The principal natural abrasives are the various forms of silica, including sand, ground sandstone, quartz, flint pebbles, tripoli, diatomite, and massive sandstone fashioned into grindstones, pulpstones, millstones and other products. Silicates such as pumice and garnet are also used as abrasives. Other abrasive minerals are the diamond and the aluminum silicates, corundum and emery.

Abrasive processes range from the wearing down or smoothing of rough surfaces to administering the finest degree of polish like that found on plate glass or surgical instruments. For the rougher types of abrasion, extreme hardness in the abrading agent is desirable. The diamond, the hardest substance known, is the most important of these abrasives. To obtain a fine polish, the softer types, even those as soft as talc or lime, may be used.

The diamond as an abrasive has become increasingly important, but, except for a small, sporadic output in Arkansas, there is no diamond-producing industry in the United States.

The other natural abrasives are relatively less important than they were 75 years ago, because they have been replaced in varying degree by manufactured abrasives, such as silicon carbide and aluminum oxide. A small garnet industry is centered chiefly in Warren County, New York, where an elaborate milling process has been developed.

A small emery-producing industry, confined to the Peekskill, N. Y., district, has been active for many years. Attempts to establish a domestic corundum industry have met little success. The production of diatomite, tripoli and pumicite has attained moderate volume, but these materials have many uses, such as insulation and filtration, quite apart from their abrasive applications. The millstone, grindstone and pulpstone industries have receded because of changes in practice and substitution of manufactured abrasives. An interesting technical development in grindstone manufacture in Ohio was the introduction more than 30 years ago of the so-called "circle-cutting drill," by means of which the stones are quarried from the solid ledge in circular form.

Sand is still used extensively as an abrasive in stone sawing, sandblasting and various other ways, as it is reasonably effective and is low priced. Flint grinding pebbles and tube-mill liners or substitutes therefor were produced in the United States in moderate quantities during the war period, when foreign flint supplies were unavailable.

Natural abrasives are preferred for certain uses for which they have special adaptation, but new inventions and developments in the field of manufactured abrasives may lead to a further decline in their relative importance.

MICA

Because of its unique properties, which permit it to be split into thin, transparent sheets of high dielectric strength, mica is a very useful industrial mineral. Commercial mica mining was begun in Grafton County, New Hampshire, in 1803, and production was confined to that state until 1867. In that year North Carolina became a producer, and subsequently these two states have been the principal sources of supply. Sheet mica was obtained in

Amelia County, Virginia, before 1870, and mica was discovered in South Dakota in 1879. New Mexico first produced in 1884. Connecticut, Maine, Alabama, Idaho and Colorado have contributed to the total production. Although no statistics are available before 1880, a total sales value of nearly $128,000 in that year indicates that the industry was firmly established in 1871.

Striking changes in use have marked the history of the mica industry. The first commercial use was probably the employment of large sheets for windows, which may antedate the manufacture of glass. The earliest important use was for making transparent, fireproof windows in stove and furnace doors. Until about 1880, when electric dynamos and motors began to assume importance in industry, stove mica was by far the principal product. For about 20 years thereafter the electrical industry experienced slow growth, but by 1903 use in stoves was declining, and electrical mica had attained equal importance.

A process was developed in 1894 for making built-up mica, consisting of thin films or splittings cemented with shellac or other binder. These built-up products extended the electrical uses very greatly but were of no advantage to the domestic mica-producing industry because virtually all splittings are made in India, where labor costs are low.

The electrical uses have attained increasing importance; during recent years they have consumed at least 90 per cent of the entire supply of sheet mica. The advent of radio in the early 1920s created an extensive demand for the smaller sizes.

The domestic mica industry has grown very little during the past 35 years. From 1941 to 1943 production was relatively high, but the increased output was due to large subsidies paid by the Government to stimulate production high enough to satisfy urgent war needs. The lack of growth is attributed to several causes. Mica mining is economically hazardous because the occurrences generally lack continuity in quantity or quality. The percentage of mica in the rock is low, even in the best mines, and only a small percentage of total recovery can be classed as sheet mica. Accordingly, mining costs are high. The chief unfavorable factor, however, is competition with imported India mica, which began in 1885. India has excellent deposits, and its low-paid laborers have developed skill in making excellently prepared and closely graded products with which United States operators cannot compete on an even basis.

As the specifications for sheet mica are exacting, the percentage of scrap produced is very high. Scrap consists of trimmings or imperfect sheets or may comprise the entire output of mines producing no mica that will qualify as commercial sheet. The United States has one advantage in that it is the only country having large markets for ground mica produced from scrap. The ready sale for scrap has enabled some marginal mines to operate at a profit.

Mica-mining methods have experienced little change. The irregularity of the pegmatite veins and of the mica "books" that occur in them tend to discourage large systematic operations. Most of the production is from small mines requiring limited investment and minimum mechanical equipment. Such workings are irregular, as they follow the rich streaks from one pocket to another. These "groundhogging" or "gophering" methods have undergone little change since the earliest days of mining.

Where the small pits uncovered promising supplies of good mica more systematic methods have been developed. Air compressors, drills and pumps have been installed. In only a few places have large, well-equipped mines been developed; for instance, at Alexandria, N. H.

The future of the domestic mica-mining industry is not bright. During the recent war the United States Government, through the Colonial Mica Corporation, rented equipment to miners, supervised development, instructed miners in trimming and paid high prices for acceptable grades. Under these stimuli hundreds of new mines or pits were opened, and many of them operated profitably. At the close of the war premium payments ceased, and prices dropped to about one fourth or less of those formerly paid by the Government. Accordingly, most of the producers were forced into inactivity, and production dropped to prewar levels. The domestic industry maintains its moderate degree of activity only by virtue of a protective tariff.

TALC

Talc, a soapy hydrous magnesium silicate, is one of the softest minerals mined. It is best known popularly as the basic constituent of talcum powder, but a very small percentage of the total output is applied to this use.

The history of talc mining is confusing because the terms "talc," "soapstone," and "steatite" have had different meanings at different periods. For many years before 1899 two distinct branches of the industry were recognized —the fibrous-talc industry of New York and the soapstone industry. The fibrous talc was ground for papermaking, and part of the "soapstone" produced in several states was used in the solid form as crayons, furnace blocks, laundry tubs, and so forth, and part of it was ground. For several years after 1899 the terms "talc" and "soapstone" were used interchangeably, although the fibrous talc of New York was discussed as a separate product. Later the term "soapstone" was restricted to a massive form of impure talc used chiefly as blocks or slabs, the term "talc" was applied chiefly to the relatively pure ground product and the term "steatite" to massive, relatively pure talcs used for crayons and the so-called "lava" products. During the Second World War the term "steatite" was applied to both massive and ground talcs pure enough and suitable in physical character for making porcelain radio insulators.

The massive talcs that are sawed into crayons, lava products, etc., are still included as a part of the talc industry, but soapstone used for furnace blocks, tubs, laboratory equipment, floor tile and other building products is regarded as a part of the dimension-stone industry.

Massive talc and soapstone attained some importance between 1870 and 1880 for the manufacture of tubs, sinks and various utensils. Ground talc was first recorded for 1880, when about 4000 tons was produced, hence it is possible that a small ground-talc industry existed near Gouverneur, N. Y., in 1871. The ground talc of this region, which was used almost exclusively as paper filler, dominated the industry for many years.

For many years the chief use of ground talc was for paper filler, but since 1930 paint filler has been the leading use. Other important uses that gradually developed are as roofing and rubber filler, for an insecticide carrier, as foundry facings, and in ceramics. With expansion in uses, production increased greatly. An output of about 20,000 tons in 1885 had grown to more than 200,000 tons in 1916, and since 1940 sales have approximated 400,000 tons a year, including pyrophyllite.

Pyrophyllite, a hydrous aluminum silicate closely resembling talc, is employed for many of the same uses, and certain special uses have been developed for it.

An important use of pure, massive talc (steatite) first recorded in 1907 is for making gas tips and electrical insulators. The forms are shaped from talc in its natural state and then baked. The effect of heat is to increase the hardness greatly without appreciable distortion or shrinkage. Very little of the talc produced from domestic sources would satisfy the exacting demands of these "lava" products. During later years ground talcs of satisfactory physical and chemical properties have been molded into ceramic products. Considerable lava-grade block talc is normally imported from India, Italy or Germany, but when these sources of supply were cut off during the recent war the domestic steatite grades assumed strategic importance. Much research work was conducted on purification and on testing of natural and beneficiated products. Reserves of utilizable material from our domestic sources were thus enlarged. An increasing use of steatite in making electronic equipment is forecast.

Talc is obtained from both open pits and underground mines, generally without timbering. It is easily drilled and blasted. Hand sorting of the lump talc before crushing is generally required. Mining methods have not changed greatly for many years.

Pulverized talc was first prepared in flour-grinding mills equipped with buhrstones and silk bolting reels. Although such equipment was not well adapted for talc milling, its employment in some localities was continued for many years. The operation of a mill grinding both wheat and talc was recorded as late as 1922.

Porcelain-lined flint-pebble mills were used at Gouverneur, N. Y., as early as 1885. Before 1920 two general systems of milling had been developed. In New York, where the fibrous talc is hard, tube mills were used, first the batch type and later the continuous mills. In Vermont, and later in other states, the equipment consisted of vertical emery mills, disintegrators, pulverizers and roller mills, followed by vibrating screens for the larger sizes and air separation for the finer particles. These methods are now standard. Cosmetic talc is still bolted through cloth.

Wet grinding, which would reduce silicosis hazards, has been tested at various places. One North Carolina company has tried it commercially, but further development in this field is still in the future.

The Bureau of Mines has demonstrated that froth flotation can be applied successfully to the purification of both New York and Vermont talc. A flotation plant was built at Johnson, Vt., in 1937 and has operated successfully, but flotation has not been used commercially elsewhere.

In 1944 air tables were found to be advantageous in treating steatite mixes for ceramic use. They were employed to remove minus 100-mesh material and to control bulk density in dry-press mixtures.

For certain special uses talc must be pulverized to an extremely fine consistency, the particle size ranging from less than one micron to 8 or 10 microns. This fine state of subdivision is obtained with jet pulverizers using superheated steam or special vertical hammer mills equipped with air separators. Thus long strides have been made in the development and use of specialized equipment.

OTHER MINERALS

Quartz Crystals—Seventy-five years ago water-clear quartz crystals were of interest only as specimens for mineralogists or collectors. It was not until about 1938 that they began to assume importance as oscillator plates for radio transmitting and receiving sets, detection devices, long-distance telephone transmission equipment, and other uses essential to communication. Quartz for such uses attained enormous importance during the recent war, but domestic production of suitable crystals was insignificant; we depend upon Brazil for virtually all of this essential mineral.

Vermiculite was unknown commercially 75 years ago. When the discovery was made that it would expand up to 16 times its volume upon heating, it assumed importance as an insulating material, the production of which has grown to a volume of many thousand tons a year.

Graphite has many uses but has been produced only in limited quantities in the United States. Flake graphite for manufacture of crucibles is imported chiefly from Madagascar and amorphous graphite chiefly from Mexico. Flake graphite occurs in the United States, and recently active steps have been taken toward developing milling processes, whereby a satisfactory product can be prepared. An important date in the graphite industry was 1896, for in that year Edward G. Acheson took out a patent for manufacturing graphite in an electric furnace, using coke, sand and sawdust as raw materials. The making of electrodes from manufactured graphite is now an important industry.

Bromine—Recovery of bromine from brines is a long-established industry. More than 400,000 pounds of bromine was produced in 1880, the earliest year for which records are available. It was primarily used in medicine, photography and metallurgy, but a new era appeared for the industry when a demand overtopping all others arose for the manufacture of ethylene dibromide, used in preparing antiknock gasoline. Natural brines were inadequate to supply the greatly increasing demands for such use, and in 1933 a large plant was built at Wilmington, N. C., for recovering bromine from sea water. The recovery of this product from an extremely dilute solution (one part in 16,000) marked a long step in technology.

Boron Minerals—The United States has a virtual monopoly of boron mineral production, as it supplies about 90 per cent of the world total. Production has increased more than six fold since 1910 to supply growing needs in the glassware, enamel, metallurgical, fertilizer and other industries.

Lithium Minerals—The mining of lithium minerals began about half a century ago. Spodumene mining began about 1898, and amblygonite production about 1910, both in South Dakota. Lepidolite was first mined in California and later in New Mexico, South Dakota, Colorado and other states. To its ceramic, dehumidifying and other well-known uses certain special applications were developed during the recent war, the most important of which was the use of lithium hydride as a source of hydrogen for inflating balloons. The most important change in the technology of production of lithium salts was the shift that attained great importance in 1945 from the use of primary ores to recovery of dilithium phosphate as a by-product in the treatment of brines at Trona Lake, California. This by-product has become the chief source of lithium salts.

Strontium Minerals—The production of strontium minerals in the United

States has been largely a war-fostered industry that has little prospect of successful development under peacetime conditions because the principal high-grade strontium-bearing minerals, which occur in California, cannot compete in eastern markets with material imported from Mexico, Spain and England.

Mineral Wool—The manufacture of mineral wool was an unknown industry in 1871. The first plant for making it was operated in Cleveland, Ohio, in 1888, and another plant was built at Salem, Va., in 1890. Activity began in Indiana in 1897, and by 1928 eight plants were operating in the United States. From that time the industry developed rapidly; 51 plants produced more than one-half million tons in 1944, valued at $54,000,000. The principal use is for home insulation, but industrial insulation is attaining importance. Certain glass-wool products that have recently attracted much attention consist of extremely fine fibers made by special processes. They have remarkable strength and flexibility.

Granules—The use of slate granules for surfacing asphalt composition roofing began with a shipment of two carlots of coarse slate screening for such use in 1906. By 1920 more than 300,000 tons of slate granules were so used. Later, granules were made from other rocks, and the industry grew steadily, attaining an output of over a million tons in 1945. About 30 years ago a keen desire was apparent among architects, builders and home owners for colors on roofs, and in consequence the manufacture of granules from red, green and other colored rocks began. As supplies of such materials were inadequate, and as the popular demand for bright colors was increasing, experimental work was undertaken, and in 1914 success was first attained in coloring mineral granules artificially. Now more than half of the granules sold are the artificially colored.

Presidents of the Institute

1871–1947

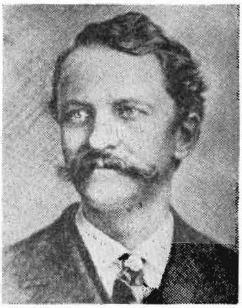
DAVID THOMAS 1871

Born November 3, 1794, Cadoxtan, Glamorganshire, South Wales. Died in 1882. Attended schools in Wales. Came to America in 1839. A.I.M.E.: Member, 1871; Honorary Member. Iron manufacturer; inventor. Built first anthracite-fired hot-blast furnace in America. Known as the "Father of the Lehigh Valley." President, Catasauqua and Fogelsville Railroad; Director, Lehigh Valley Railroad; Founder, Thomas Iron Co. and St. Luke's Hospital at Bethlehem, Pa.; Trustee, Lafayette College.

ROSSITER WORTHINGTON RAYMOND 1872–1874

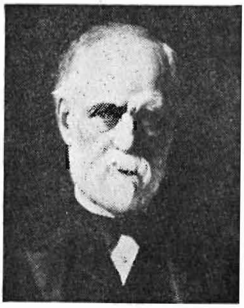
Born April 27, 1840, Cincinnati, Ohio. Died in 1918. Brooklyn Polytechnic Institute, 1857; Lafayette College, Ph.D., 1868; Lehigh University, LL.D., 1906; University of Pittsburgh, Hon. LL.D., 1915., Gold Medal, Institution of Mining and Metallurgy (London). A.I.M.E.: Founder, Member of 1871; Vice President, 1871, 1876-1877; Secretary, 1884–1911; Secretary Emeritus, 1911–1918; Honorary Member. Consulting mining engineer; practicing lawyer, sailor, soldier, writer, orator, editor, theologian, teacher, novelist, chess player. Recognized as the "Grand Old Man of the Institute."

ALEXANDER LYMAN HOLLEY 1875



Born July 20, 1832, Lakeville, Conn. Died in 1882. Brown University, 1853; Hon. LL.D., 1878. A.I.M.E.: Member, 1871; Vice President, 1874; Manager, 1877–1879. Bessemer Medal (Iron and Steel Institute, London), posthumously. Brought bessemer process to United States. A statue was erected in Washington Square in his memory and presented to the City of New York in 1889. The inscription notes: "foremost among those whose genius and energy established in America and improved throughout the world the manufacture of bessemer steel."

ABRAM STEVENS HEWITT 1876



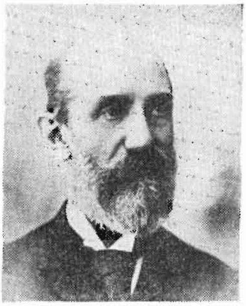
Born July 31, 1822, Haverstraw, N. Y. Died in 1903. Columbia University, 1842; Hon. LL.D., 1887. A.I.M.E.: Member, 1871; Manager, 1872–1875. Bessemer Medalist and Honorary Member, Iron and Steel Institute (London). Gold Medal, Chamber of Commerce of New York City. Philanthropist, lawyer, statesman, publicist, pioneer in the iron and steel industry. Mayor of New York City in 1887. Business partner of Peter Cooper, Executive Manager of Board of Trustees, Cooper Union, New York City.

Thomas Sterry Hunt 1877

Born September 5, 1826, Norwich, Conn. Died in 1895. Yale University (circa 1849); Hon. A.M., Harvard; LL.D., Laval (France), LL.D., University of Cambridge (London), 1881. A.I.M.E.: Member, 1871; Manager, 1873–1875; Vice President, 1888–1889. Chevalier, Legion of Honor, Order of St. Mauritius and St. Lazarus (Italy). Professor of Applied Chemistry and Mineralogy at McGill University; Professor of Geology, Massachusetts Institute of Technology; author of many scientific articles on chemistry; lecturer; first President, Royal Society of Canada.

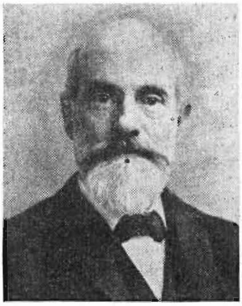
Eckley Brinton Coxe 1878 and 1879

Born June 4, 1839, Philadelphia, Pa. Died May 12, 1895. University of Pennsylvania, 1858. A.I.M.E.: Member, 1871 (Founder); Vice President, 1871–1874, 1876–1877, 1884–1885, 1889–1890. Owner and official of coal-mining companies. Helped to improve coal-mining machinery. Promoter of education, especially for sons of laboring men. Philanthropist. In April 1871, he joined R. P. Rothwell and Martin B. Coryell in issuing the circular in response to which the American Institute of Mining Engineers was organized at Wilkes-Barre, on May 16, 1871.



William Powell Shinn 1880

Born May 4, 1834, Burlington, N. J. Died May 5, 1892. Public schools of New Jersey. A.I.M.E.: Member, 1875; Vice President, 1877–1878. Declined appointment to West Point to follow a career in railroading. Managing partner, Carnegie, McCandless and Co.; President, Ashtabula, Youngstown and Pittsburgh Railroad; reorganized Vulcan Steel Co. of St. Louis; Vice President, New York Steam Co.; Vice President and General Manager, New York and New England Railroad Co. Organized U. S. Glass Co. President, American Society of Civil Engineers.



William Metcalf 1881

Born September 3, 1838, Pittsburgh, Pa. Died in 1909. Rensselaer Polytechnic Institute, 1858. A.I.M.E.: Member, 1875; Vice President, 1878–1879. Part owner of the Crescent Steel Works. Able metallurgist. Author of "Steel, a Manual for Steel Users."

RICHARD PENNEFATHER ROTHWELL 1882

Born May 1, 1837, Ingersoll, Ont., Canada. Died April 17, 1901. Rensselaer Polytechnic Institute, 1858. Attended National School of Mines and the Mining Academy of Saxony. A.I.M.E.: Member, 1871 (Founder); Manager, 1871, 1898–1900; Vice President, 1872–1873, 1875–1876. Inventor, consulting mining engineer. Editor and General Manager of *Engineering and Mining Journal.*

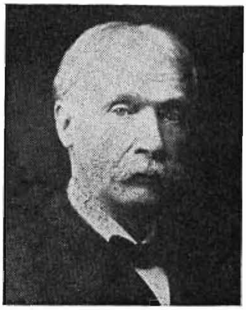
ROBERT WOOLSTON HUNT 1883

Born December 9, 1838, Fallsington, Pa. Died July 11, 1923. D. Eng., Rensselaer Polytechnic Institute. A.I.M.E.: Member, 1874; Manager, 1876–1878; Director, 1913–1917; Robert W. Hunt Medalist; Honorary Member. Captain, U. S. Military Service (Civil War). Metallurgist, developer of the modern steel rail. Established the Robert W. Hunt Co., of Chicago. Recipient Washington Award; Honorary Member and Past President, American Society of Mechanical Engineers; President, Western Society of Engineers and American Society for Testing Materials. John Fritz Medalist.

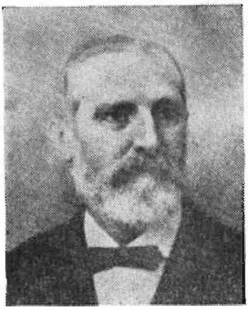
JAMES COOPER BAYLES 1884 and 1885

Born July 3, 1845, New York, N. Y. Died May 7, 1913. A.I.M.E.: Member, 1878; Manager, 1880–1882, 1891–1893; Vice President, 1888–1889. Officer in the Union Army during the Civil War. Editor of *Iron Age.* President of the Department of Health, New York City. Consulting Engineer.

ROBERT HALLOWELL RICHARDS 1886

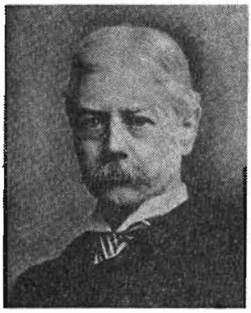


Born August 26, 1844, Gardiner, Maine. Died March 26, 1945. Massachusetts Institute of Technology, 1868. LL.D., University of Missouri, 1908. A.I.M.E.: Member, 1873; Vice President, 1879–1880; Honorary Member, 1911. Professor of Mining and Metallurgy at Massachusetts Institure of Technology. Inventor of ore-dressing equipment. Author of "Text Book of Ore Dressing," for many years the standard authority on the art. First President, M.I.T. Alumni Association, 1876–1881. Honorary Member, Canadian Institute of Mining and Metallurgy.



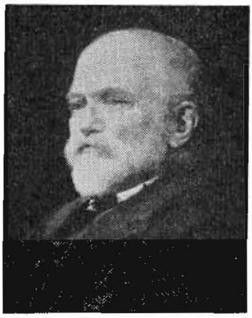
THOMAS EGLESTON 1887

Born December 9, 1832, New York, N. Y. Died January 15, 1900. A.I.M.E.: Member, 1871 (Founder); Manager, 1871; Vice President, 1872–1874; 1877–1878; 1884–1885. One of the organizers of the School of Mines at Columbia University, New York City, and professor. Commander, Legion of Honor, France. Organizer of Food Kitchens for the poor of New York City.



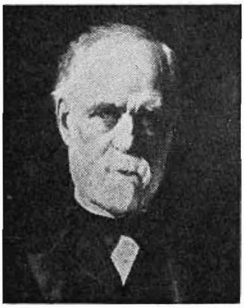
WILLIAM BLEECKER POTTER 1888

Born March 23, 1846, Schenectady, N. Y. Died July 14, 1914. Columbia University, A.B., 1868; A.M., 1869; School of Mines (Columbia), E.M., 1879. A.I.M.E.: Member, 1871; Manager, 1878–1880. Professor; first head of the Department of Mining and Metallurgy at Washington University, St. Louis, Mo. Geologist. Consulting metallurgist. Founder of the St. Louis Sampling and Testing Works. President, Engineers' Club of St. Louis.



RICHARD PEARCE 1889

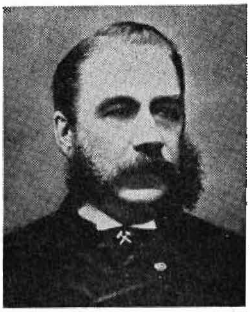
Born June 29, 1837, Camborne, England. Died May 18, 1927. Graduate of Royal School of Mines, London; Ph.D., Columbia University, 1890. A.I.M.E.: Member, 1874; Vice President, 1885–1886. Gold Medal, Royal Institution of Cornwall, 1909; Gold Medal, Institution of Mining and Metallurgy (London), 1925. Chemist, mineralogist, metallurgist, designer and builder of smelting plants. Inventor of smelter equipment.



ABRAM STEVENS HEWITT 1890

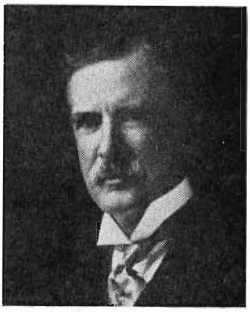
Born July 31, 1822, Haverstraw, N. Y. Died in 1903. Columbia University, 1842; Hon. LL.D., 1887. A.I.M.E.: Member, 1871; Manager, 1872–1875. Bessemer Medalist and Honorary Member, Iron and Steel Institute (London). Gold Medal, Chamber of Commerce of New York City. Philanthropist, lawyer, statesman, publicist, pioneer in the iron and steel industry. Mayor of New York City in 1887. Business partner of Peter Cooper, Executive Manager of Board of Trustees, Cooper Union, New York City.

JOHN BIRKINBINE 1891 and 1892



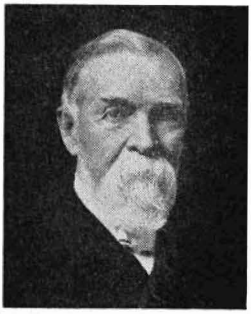
Born November 16, 1844, Berks County, Pennsylvania. Died May 14, 1915. Polytechnic College of Philadelphia. A.I.M.E.: Member, 1875; Manager, 1883–1885; Vice President, 1887–1888. Consulting engineer in the iron and steel industry. Designer and constructor of blast furnaces. Editor of *Journal of Iron Workers*.

HENRY MARION HOWE 1893



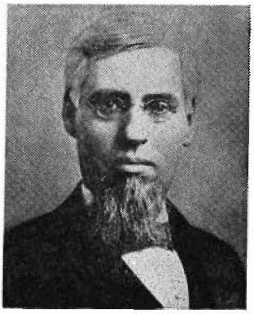
Born March 2, 1848, Boston, Mass. Died May 14, 1922. B.S., Massachusetts Institute of Technology, 1871; A.B., Harvard, 1879; Hon. A.M., Harvard, 1872, LL.D., 1905. A.I.M.E.: Member, 1871; Vice President, 1879–1880, 1890–1901, 1906–1907; Manager, 1886–1888. John Fritz Medal, 1917. Professor of metallurgy; consulting metallurgist; developer of the modern art of physical metallurgy of steel. His mother was Julia Ward Howe, author of the "Battle Hymn of the Republic." The Howe Memorial Lecture is given in his memory under the auspices of the A.I.M.E.

JOHN FRITZ 1894

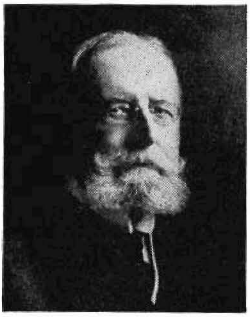


Born August 21, 1822, Londonderry, Chester Co., Pa. Died February 13, 1913. Honorary degrees: A.M., Columbia University, 1895; Sc. D., University of Pennsylvania, 1906; D. Eng., Stevens Institute of Technology, 1906; D. Sc., Temple University, 1910. A.I.M.E.: Member, 1872; Vice President, 1875. Bessemer Gold Medal, Iron and Steel Institute (London), 1893; John Fritz Medal, 1902. Honorary Member and President, American Society of Mechanical Engineers; Honorary Member, American Society of Civil Engineers. Inventor. Manufacturer of iron and steel. The John Fritz Medal (often called the premier award of engineers to engineers) was established in his honor.

JOSEPH D. WEEKS 1895



Born 1840, Lowell, Mass. Died December 26, 1896. Graduate of Wesleyan University. A.I.M.E.: Member, 1875; Vice President, 1886–1887; Manager, 1890–1902. Philanthropist, chemist, Methodist preacher, writer, Editor of *Iron Age*. Founder and Director, Pittsburgh Chamber of Commerce.

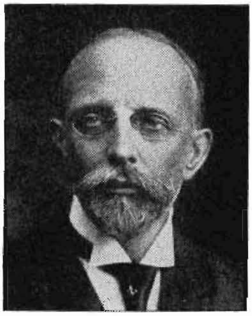


EDMUND GYBBON SPILSBURY 1896

Born 1845, London, England. Died May 28, 1920. University of Louvain, Belgium, 1862. A.I.M.E.: Member, 1873; Manager, 1885–1887; Vice President, 1893–1894. Consulting engineer, metallurgist, author, designer of metallurgical equipment. Active in International Engineering Congress, Chicago World's Fair, 1893. President, Engineers' Club, New York City, 1916–1917. Member, United Engineering Societies Library Board 1907–1913; Chairman, 1918–1920; Trustee, The Engineering Foundation Board, 1916–1920. Member of Division of Engineering, National Research Council.

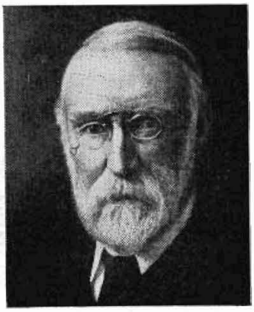
THOMAS MESSENGER DROWN 1897

Born March 19, 1842, Philadelphia, Pa. Died November 17, 1904. University of Pennsylvania, M.D., 1862; Hon. LL.D., Columbia University, 1895; Studied at Sheffield School, Yale University; Lawrence Scientific School, Harvard University; Heidelberg University, Freiberg, Saxony, Baden. A.I.M.E.: Member (founder,) 1871; Manager, 1872; Secretary, 1873–1884; Vice President, 1892–1893; Honorary Member. Analytical consulting chemist, Professor of Chemistry, President, Lehigh University, 1895–1904.



CHARLES KIRCHHOFF 1898

Born March 28, 1853, San Francisco, Calif. Graduate of Prussian Royal Mining Academy of Clausthal, 1874. A.I.M.E.: Member, 1875; Manager, 1887–1889, 1892–1894; Vice President, 1896–1897; Director, 1907–1912. Mining engineer, metallurgist, chemist, author, managing editor of *Engineering and Mining Journal;* editor-in-chief, *Iron Age*. Honorary Member, Franklin Institute of Philadelphia.



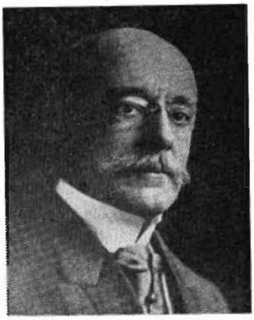
JAMES DOUGLAS 1899 and 1900

Born November 4, 1837, Quebec, Canada. Died June 25, 1918. Graduate of Queen's College, Canada, 1858; studied at University of Edinburgh; Hon. LL.D., McGill University, 1899. A.I.M.E., Member, 1889; Vice President, 1897–1898; Director, 1905–1913; Vice President, 1906–1911; Honorary Member. Industrialist, mining and metallurgical engineer. Inventor of metallurgical equipment. Author, donor of funds for the Engineering Societies Library. The James Douglas Medal (A.I.M.E.), recognizing achievement in metallurgy, was established in his honor.

EBEN ERSKINE OLCOTT 1901 and 1902

Born March 11, 1854, New York City. Died June 7, 1929. Columbia School of Mines, 1874. A.I.M.E.: Member, 1874. Chemist, engineer, manager of mines. President, Hudson River Day Line. Trustee and Vice President, Lincoln Safe Deposit Company.

ALBERT REID LEDOUX 1903



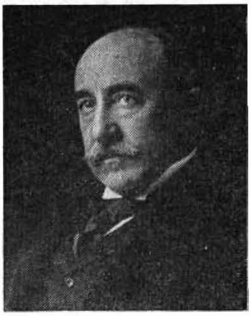
Born Nov. 2, 1852, Newport, Ky. Died October 25, 1923. North Carolina State University, M.S.; University of Göttingen, Ph.D.; Hon. D. D., University of Indiana. A.I.M.E.: Member, 1889; Manager, 1895–1897; Vice President, 1898–1899, 1919–1923; Director, 1905–1916. Consulting engineer, chemist, Founder of Ledoux and Co., New York City (analytical chemists). One of the nine incorporators of the A.I.M.E. in 1904.

JAMES GAYLEY 1904 and 1905

Born October 11, 1855, Lock Haven, Pa. Died February 25, 1920. Lafayete College, 1876. A.I.M.E.: Member, 1880; Manager, 1896–1898, Vice President, 1902–1903. Director, 1905–1913. President of A.I.M.E. (Corporation), 1905–1911. Chemist, steelmaker, engineer, inventor. First Vice President, U. S. Steel Corporation. Director, various railroads. One of the nine incorporators of the A.I.M.E. in 1904.

ROBERT WOOLSTON HUNT 1906

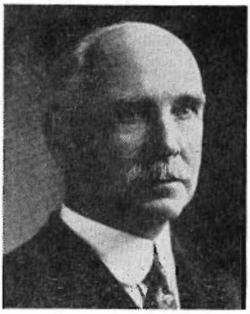
Born December 9, 1838, Fallsington, Pa. Died July 11, 1923. D. Eng., Rensselaer Polytechnic Institute. A.I.M.E.: Member, 1874; Manager, 1876–1878; Director, 1913–1917; Robert W. Hunt Medalist; Honorary Member. Captain, U. S. Military Service (Civil War). Metallurgist, developer of the modern steel rail. Established the Robert W. Hunt Co., of Chicago. Recipient Washington Award; Honorary Member and Past President, American Society of Mechanical Engineers; President, Western Society of Engineers and American Society for Testing Materials. John Fritz Medalist.



John Hays Hammond

1907 and 1908

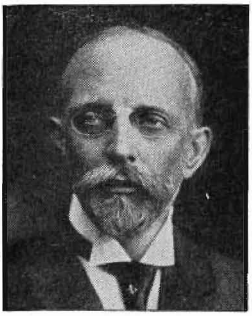
Born March 31, 1855, San Francisco, Calif. Died June 8, 1936. Sheffield Scientific School, Yale University, Ph. D., 1876. Royal School of Mines, Saxony. A.I.M.E.: Member, 1881; Vice President, 1901–1902; Honorary Member. William Lawrence Saunders Gold Medal (A.I.M.E.), 1929. Consulting mining engineer. In connection with the Jamieson raid in the Transvaal (South Africa), sentenced to death by Boer authorities, but released upon payment of fine of $125,000. Developer of mines at home and abroad. Noted for industrial leadership and public service.



David William Brunton

1909 and 1910

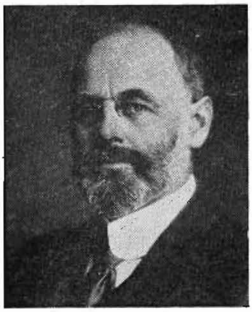
Born June 11, 1849, Ayr, Ont., Canada. Died December 20, 1927. University of Michigan, 1875. A.I.M.E.: Member, 1883; Vice President, 1897–1898. First Recipient William Lawrence Saunders Gold Medal (A.I.M.E.), 1927. Mining engineer. Outstanding citizen of Denver, Colo. Author of Book on Tunnel Driving. President, American Mining Congress; Member, Naval Consulting Board; Inventions Board, U. S. Army. Inventor of the Brunton compass.



Charles Kirchhoff

1911

Born March 28, 1853, San Francisco, Calif. Graduate of Prussian Royal Mining Academy of Clausthal, 1874. A.I.M.E.: Member, 1875; Manager, 1887–1889, 1892–1894; Vice President, 1896–1897; Director, 1907–1912.Mining engineer, metallurgist, chemist, author, managing editor of *Engineering and Mining Journal;* editor-in-chief, *Iron Age.* Honorary Member, Franklin Institute of Philadelphia.

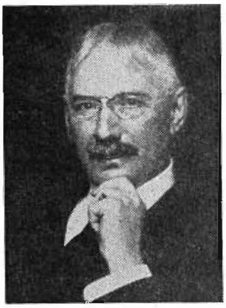


James Furman Kemp

1912

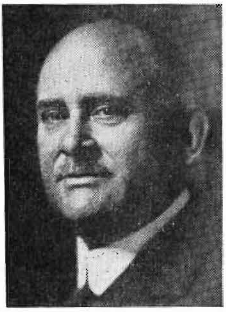
Born August 14, 1859, New York City. Died November 17, 1926. Adelphi College (Brooklyn), 1876; A.B., Amherst, 1881; E.M., School of Mines, Columbia University, 1884. Hon. Degrees: Sc.D., Amherst, 1906; LL.D., McGill University, 1913. A.I.M.E.: Member, 1891; Manager, 1896–1898; Vice President, 1903–1904; Director, 1905–1914; Honorary Member. Gold Medal, Mining and Metallurgical Society of America, 1917; President and Honorary Member. Professor of Geology at Columbia University. Consulting geologist—a recognized authority on ore deposits. Author of "Ore Deposits of U. S. and Canada" and "Handbook on Rocks." President, New York Academy of Sciences.

CHARLES FREDERIC RAND 1913



Born August 7, 1856, Canaan, Maine. Died June 21, 1927. Self-educated. A.I.M.E.: Member, 1897; Member of Council, 1910–1912; Director, 1912; 1914–1927; Treasurer, 1922–1927. Developer of mines and new processes in iron mining. President of numerous companies at home and abroad. Grand Cross of Knight Commander of Order of Isabella Catolica, 1913. Croix de Chevalier de la Légion d'Honneur, 1922 (French Government). Honorary Member, Iron and Steel Institute (Great Britain).

BENJAMIN BOWDITCH THAYER 1914



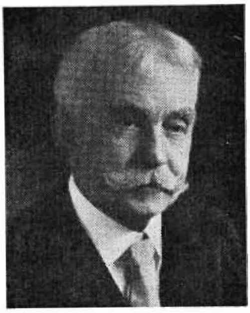
Born October 20, 1862, San Francisco, Calif. Died February 22, 1933. Lawrence Scientific School, Harvard University, 1885. A.I.M.E.: Member, 1887; Vice President, 1912–1913; 1924; Director, 1917–1918. Engineer. Mining administrator. Developer of gold and copper mines. President, Anaconda Copper Mining Co. and officer of twenty-seven different mining, railroad, and utility companies. President, New York Society of Harvard Engineers.

WILLIAM LAWRENCE SAUNDERS 1915

Born November 1, 1856, Columbus, Ga. Died June 25, 1931. University of Pennsylvania, B.S., 1876; Hon. D. Sc., 1911. A.I.M.E.; Member, 1906; Vice President, 1909–1910; 1914; Director, 1916–1917. Chairman of Board, Ingersoll-Rand Co.; Director and Deputy Chairman of Board, Federal Reserve Bank of New York; Director, numerous mining companies; President, American Manufacturers Export Association; Chairman and Representative of A.I.M.E., Naval Consulting Board; President, United Engineering Society. Established William Lawrence Saunders Gold Medal, A.I.M.E., 1926.

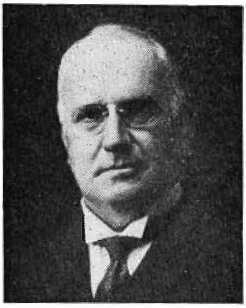
LOUIS DAVIDSON RICKETTS 1916

Born December 19, 1859, Elkton, Md. Died March 4, 1940. Princeton University, 1881; D. Sc., 1883; D. Eng., 1925; LL.D., University of Arizona, 1918. A.I.M.E.: Member, 1892; Director, 1913–1916; 1924–1926. James Douglas Medal, A.I.M.E., 1940; Gold Medal, Institution of Mining and Metallurgy (Great Britain). Engineer and metallurgist for Phelps Dodge, Inspiration Copper Co., and New Cornelia Copper Co. Designated "Arizona's Most Useful Citizen," 1915; as "Dr. Ricketts of Arizona" for development of mining in the Southwest. Trustee, Princeton University and California Institute of Technology.



PHILIP NORTH MOORE 1917

Born July 8, 1849, Connersville, Ind. Died January 19, 1930. Miami University, A.B., 1870; A.M., 1873; Hon. LL.D., 1920; School of Mines, Columbia University, 1872. A.I.M.E.: Member, 1874; Vice President, 1915–1916; Director, 1918–1919. Consulting engineer. Developer of mining properties. Founder, St. Louis Section of A.I.M.E. Active in organization of the American Engineering Council, 1917; member War Minerals Relief Commission, 1919; member Board of Managers, Missouri Geological Survey.



SIDNEY JOHNSTON JENNINGS 1918

Born August 13, 1863, Hawesville, Ky. Died November 17, 1928. Lawrence Scientific School, Harvard, 1885. A.I.M.E.: Member, 1894; Member of Council, 1912; Vice President, 1913–1918; Director, 1919–1920. Consulting engineer; mine administrator. Operated gold and diamond mines in South Africa. Developed Johannesburg's water-supply system. Vice President, U. S. Smelting, Refining and Mining Co.; President, American Mining Congress, 1922–1923.

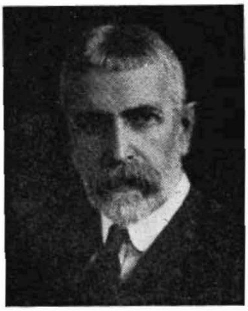
HORACE VAUGHN WINCHELL 1919

Born November 1, 1865, Galesburg, Mich. Died July 27, 1923. University of Michigan, B.S., 1889. A.I.M.E.: Member, 1892; Manager, 1901–1903; Vice President, 1909–1910; Director, 1920–1921. Consulting geologist. Organized and developed the geological department of the Anaconda Copper Mining Co.—a model for many other companies. Did exploration work in northern Europe. Authority on mining law. Author of important papers on geology of ore deposits.

HERBERT CLARK HOOVER 1920

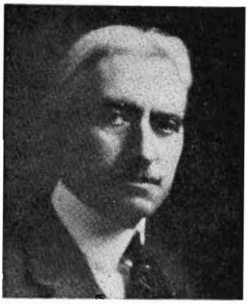
Born August 10, 1874, West Branch, Iowa. Stanford University, A.B., 1895. Hon. Degrees: Harvard, Yale, Columbia, Princeton, Johns Hopkins, Oxford, and 44 other universities. A.I.M.E.; Member, 1896; Vice President, 1914–1916; Honorary Member. Saunders Gold Medal, 1928; Gold Medal, Mining and Metallurgical Society of America; John Fritz Medal, 1929; Hoover Medal, 1930. Mining administrator. Headed European Relief, World War I. Secretary of Commerce, 1921–1928. Joint translator, with Mrs. Hoover, of Agricola's "De Re Metallica." 31st President U. S. A., 1929–1933.

EDWIN LUDLOW 1921



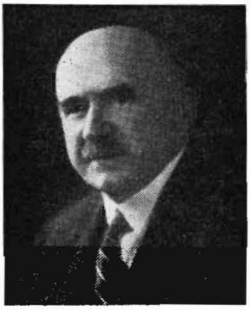
Born March 12, 1858, Oakdale, N. Y. Died February 10, 1924. School of Mines, Columbia University, E.M., 1879. A.I.M.E.: Member, 1893; Director, 1916–1919, 1922–1923; Vice President, 1919–1920. In charge of coal properties in Oklahoma and in Mexico. Vice President, General Manager, Lehigh Coal and Navigation Co. Honorary Member, Institution of Mining and Metallurgy (Great Britain); President, Alumni Association of the School of Mines, Engineering and Chemistry, Columbia University.

ARTHUR SMITH DWIGHT 1922



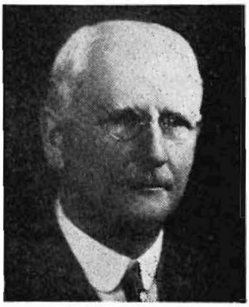
Born March 18, 1864, Taunton, Mass. Died April 1, 1946. Brooklyn Polytechnic Institute, 1882; School of Mines, Columbia University, E.M., 1885; Hon. M.Sc., 1914; D. Sc., 1927. A.I.M.E.: Member of 1885; Member of Council, 1909–1910; Director, 1920; 1923–1924; Vice President, 1921. James Douglas Medal, 1942. Egleston Medal, Engineering Alumni Association, Columbia University, 1939. Engineer and Metallurgist. Co-inventor of the Dwight-Lloyd sintering machine. President, Dwight and Lloyd Metallurgical Co. Trustee, Columbia University; Honorary Member, Institution of Mining and Metallurgy (Great Britain).

EDWARD PAYSON MATHEWSON 1923



Born October 16, 1864, Montreal, Que., Canada. McGill University, B.S., 1885; Hon. LL.D., 1922; Colorado School of Mines, Hon. D.Sc., 1920. A.I.M.E.: Member, 1889; Director, 1913–1915, 1921–1922, 1924–1925. Gold Medal, Institution of Mining and Metallurgy (London), 1911; Gold Medal, Mining and Metallurgical Society of America, 1917. Consulting metallurgist; author. Manager of various smelting works in the United States and abroad. Professor of Administration of Mineral Industries, University of Arizona.

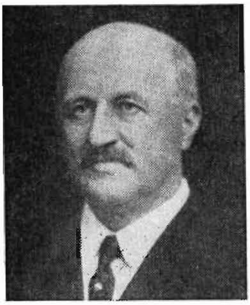
WILLIAM KELLY 1924



Born April 17, 1854, New York City. Died October 1, 1937. Yale University, A.B., 1874; Columbia University, E.M., 1877; Rensselaer Polytechnic Institute, Hon. D. Eng., 1924; Michigan College of Mining and Technology, Hon. D. Sc., 1930. A.I.M.E.: Member, 1890; Member of Council, 1910–1912; Director, 1922–1923, 1925–1926. Mining engineer; chemist. Manager of various iron and coal companies. President, Board of Examiners, Bituminous Mine Inspectors of Pennsylvania; Chairman, Board of Control, Michigan College of Mining and Technology.

JOHN VAN WICHEREN REYNDERS 1925

Born December 17, 1866, Hoboken, N. J., Died July 10, 1944. Rensselaer Polytechnic Institute, C.E., 1886; Hon. D. Eng., 1925. A.I.M.E.: Member, 1912; Director, 1919–1921, 1926; 1933–1935; Vice President, 1922–1924; Honorary Member. Consulting engineer and bridge builder. Vice President, Pennsylvania Steel Co. Built steel railway arch across the Niagara River, The Goteik Viaduct in Burma, the Queensboro and the Williamsburg bridges in New York City, Memphis River bridge in Mississippi, and the Bear Mountain bridge, New York State. Inaugurated the Open Hearth Conferences, A.I.M.E. Trustee, Bard College, Columbia University.



SAMUEL A. TAYLOR 1926

Born October 24, 1863, North Versailles Township, Allegheny County, Pa. Western University (now University of Pittsburgh), C.E., 1887; Hon. D. Sc., 1919. A.I.M.E.: Member, 1905; Director, 1915–1920, 1927–1928. Consulting coal-mining engineer. Dean, School of Mines, University of Pittsburgh. Technical Adviser to U. S. Fuel Administrator, 1917–1919. President, American Mining Congress; President, Engineers Society of Western Pennsylvania; President, Coal Mining Institute of America; Trustee, University of Pittsburgh and Western Pennsylvania School for the Deaf.

EVERETTE LEE DE GOLYER 1927

Born October 9, 1886, Greensburg, Kansas. University of Oklahoma, A.B., 1911; Colorado School of Mines, Hon. D. Sc., 1925; Southern Methodist University, Hon. D.Sc. A.I.M.E.: Member, 1914; Vice President, 1921–1926; Director, 1928–1929. Anthony F. Lucas Gold Medal, 1940; John Fritz Medal, 1942. Geologist; oil producer. President, Chairman of Board, Amerada Petroleum Corporation; Vice President, Research Corporation. Technical Adviser, NRA Oil Code, 1933. Assistant Deputy Oil Coordinator, Office of Petroleum Administration for War, 1941–1943. President and Honorary Member, American Association of Petroleum Geologists.

GEORGE OTIS SMITH 1928

Born February 22, 1871, Hodgdon, Maine. Died January 10, 1944. Colby College, A.B., 1893; A.M., 1896; Hon. LL.D., 1920; Johns Hopkins, Ph.D., 1896; Case School of Applied Science, Sc.D. A.I.M.E.: Member, 1902; Director, 1921-1926-1931; Vice President, 1927. Geologist. Director, United States Geological Survey, 1907–1930. Member, U. S. Coal Commission, 1922; Chairman, U. S. Power Commission. Director, Central Maine Power Co.; Trustee, Colby College.

FREDERICK WORTHEN BRADLEY 1929

Born February 21, 1863, Nevada City, Yuba County, Calif. Died July 6, 1933. College of Mining, University of California, 1884. A.I.M.E.: Member, 1891. William Lawrence Saunders Gold Medal, 1932. President, Bunker Hill and Sullivan Mining and Concentrating Co., Idaho; President, Alaska Juneau Gold Mining Co.; President, five Alaska gold-mining companies and officer of other companies. Director of five banks in Alaska and San Francisco; Trustee, San Francisco Chamber of Commerce.

WILLIAM HASTINGS BASSETT 1930

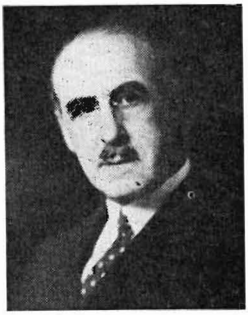
Born March 7, 1868, New Bedford, Mass. Died July 21, 1934. Massachusetts Institute of Technology, S.B., 1891. A.I.M.E.: Member, 1892; Director, 1922–1927; Vice President, 1928–1929; Chairman, Institute of Metals Division, 1920. James Douglas Medal, 1925. Pioneer metallurgist of the brass industry. Teacher. American Brass Co.: Chief chemist and metallurgist, 1903, Technical Superintendent and Metallurgist, 1912–1934. President, American Society for Testing Materials.

ROBERT EMMET TALLY 1931

Born November 5, 1877, Virginia City, Nev. Died December 14, 1936. University of Nevada, B.S., 1894; M.E., 1899. A.I.M.E.: Member, 1915; Director, 1928–1934. Mining engineer; industrialist. United Verde Copper Co., 1907–1935; promoted to the presidency in 1930. Did much to establish cordial labor relations at copper mines in Arizona. President, American Mining Congress, 1929 and 1930. Chancellor, Board of Regents, University of Arizona.

SCOTT TURNER 1932

Born July 31, 1880, Lansing, Mich. University of Michigan, A.B., 1902; D. Eng., 1930. Michigan College of Mining and Technology, B.S., E.M., 1904; D. Eng., 1932. Colorado School of Mines, D. Sc., 1930. Kenyon College, D. Sc., 1940. A.I.M.E.: Member, 1906; Vice President, 1930–1932. Mining engineer. Examined mines in U. S. A. and abroad. Director, U. S. Bureau of Mines, 1926–1934. Vice President and Director of various mining companies; Director, Belgian-American Educational Foundation; National President, Tau Beta Pi.



FREDERICK MARK BECKET 1933

Born January 11, 1875, Montreal, Que., Canada. Died December 1, 1942. McGill University, B.A., Sc.D., 1895; LL.D., 1934; Columbia University, A.M., 1899; Sc. D., 1929. A.I.M.E.: Member, 1919; Vice President, 1932–1933; Chairman, Iron and Steel Division, 1931. Howe Memorial Lecturer, 1938. Perkin Medal, 1924; Acheson Medal, 1937; Elliott Cresson Medal, 1940. Scientist, engineer, inventor, musician. President, Union Carbide and Carbon Research Labs., Inc.; Vice President, Union Carbide Co. President and Honorary Member, Electrochemical Society.

HOWARD NICHOLAS EAVENSON 1934

Born July 15, 1873, Philadelphia, Pa. Swarthmore College, B.Sc., 1892; C.E., 1895; University of Pittsburgh, D. Eng., 1928. A.I.M.E.: Member, 1900; Director, 1917–1919; Vice President, 1931–1934; Chairman, Coal Division, 1930, 1931. Consulting engineer; coal-mine executive. Designed and built 15 large coal plants in West Virginia and Kentucky. Consulting practice in Pittsburgh; senior member of Eavenson and Auchmuty. Chairman of the Board, Appalachian Coals, Inc.; President, Bituminous Coal Research, Inc. Author of "The First Century and a Quarter ot the American Coal Industry," and of "Coal through the Ages."

HENRY ANDREW BUEHLER 1935

Born May 27, 1876, Monroe, Wis. Died March 14, 1944. University of Wisconsin, A.B., 1901; University of Missouri, Hon. D. Sc., 1925. A.I.M.E.: Member, 1913; Vice President, 1929–1932; Director, 1934–1938. Geologist. Assistant to Director, Missouri Bureau of Geology and Mines, 1901. In 1908, succeeded Dr. E. R. Buckley as State Geologist and Director, to which office he was reappointed by ten consecutive Governors of Missouri. Influential in setting a pattern for the modern State Geological Survey.

JOHN MESTON LOVEJOY 1936

Born July 18, 1889, New York City. School of Mines, Columbia University, E.M., 1911; Colby College, D. Sc., 1937. A.I.M.E.: Member, 1916; Director, 1930–1938; Vice President, 1935–1936; Chairman, Petroleum Division, 1927. Petroleum engineer; executive. As geologist for the Standard Oil Company of New York discovered oil fields in the Province of Shensi, China. Captain, Field Artillery, World War I. Engaged in San Mihiel and Argonne offensives. Organizer and President, Petroleum Bond and Share Corporation; President, Seaboard Oil Co. since 1930. President, University Club, Tulsa, Okla. Member Petroleum Industry War Council, World War II.

ROLLAND CRATEN ALLEN 1937

Born May 24, 1881, Richmond, Ind. University of Wisconsin, B.A., 1905; M.A., 1908. Awarded Science Medal for graduation thesis. A.I.M.E.: Member, 1919; Director, 1930–1933; 1937–1940; Vice President, 1936–1937. Geologist; mineral economist; executive. State Geologist of Michigan; Director, Michigan Geological and Biological Survey; President, The Lake Superior Iron Ore Association, 1930; Executive Vice President, Oglebay, Norton and Co. Member, War Profits and Excess Profits Tax Board, World War I. Organizer and Chief, Division of Natural Resources, U. S. Treasury. Iron and Steel Division, War Production Board, World War II.

DANIEL COWAN JACKLING 1938

Born August 14, 1869, Appleton City, Mo. Missouri School of Mines, 1892, B.S.; D. Eng.,1933; LL. D., University of California, 1940; D.Eng., University of Southern California 1940; University of Utah, D.Sc., 1942. A.I.M.E.: Member, 1900; Director, 1914–1916; 1927–1929, 1938–1941; Honorary Member; W. L. Saunders Medal, 1930. Gold Medal, Mining and Metallurgical Society of America, 1926; John Fritz Medal, 1933; Washington Award, 1940. Developer of the first "porphyry coppers;" Utah Copper, Nevada Consolidated, Ray Consolidated, Chino. President various mining companies. Distinguished Service Medal, World War I.

DONALD BURTON GILLIES 1939

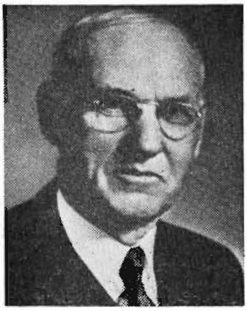
Born November 4, 1872, Bruce Mines, Ont., Canada. Michigan College of Mining and Technology, E. M., 1893; Hon. D. Eng., 1931; Hon. D. Sc., Montana School of Mines. A.I.M.E.: Member, 1922; Director, 1939–1942. First Chairman, Committee on Professional Development of Junior Engineers. Mining engineer. Manager of mines in Montana, Nevada and Mexico. Vice President, McKinney Steel Co.; President, Corrigan-McKinney Steel Co. When that company merged he became Vice President of the Republic Steel Corporation. President, The Lake Superior Iron Ore Association.

HERBERT GEORGE MOULTON 1940

Born January 16, 1883, Bellevue, Idaho. University of Oregon, B.S., 1905. A.I.M.E.: Member, 1903; Director, 1928–1934, 1940–1943; Vice President, 1937–1940. Mining engineer with Eugene Meyer, Jr. and Co., investment bankers of New York; consultant for many important companies; chief examiner for the War Finance Corporation. Special Adviser to the Reconstruction Finance Corporation. In World War II, received a commission in the U. S. Army and served as Lieutenant Colonel and later Colonel, 1943–1946.

John Robert Suman 1941

Born April 9, 1890, Daleville, Ind. University of California, B.S., 1912; Hon. D. Eng., South Dakota School of Mines, 1941. A.I.M.E.:. Member, 1917; Director, 1941—; Honorary Member; Anthony F. Lucas Gold Medal, 1943. Petroleum executive. Director and Vice President, Humble Oil and Refining Co., 1927–1933; Vice President, Standard Oil Company of New Jersey, 1945. President, Houston Geological Society; Chairman, Community Chest Commission of Houston, Texas. Known for distinguished achievement in improving the technique and practice of producing petroleum. Author of "Petroleum Production Methods."



Eugene McAuliffe 1942

Born October 3, 1866, Kent, England. Hon. D. Eng., University of Missouri, 1927. A.I.M.E.: Member, 1909; Director, 1929–1933, 1942–1945; Vice President, 1933–1935; Chairman, Coal Division, 1936. Engineer; coal-mine executive. President, Union Pacific Coal Co. Organized the International Railway Fuel Association; President, 1908–1910. World War I, Manager, Fuel Conservation Section, U. S. Railroad Administration; Special Adviser to the U. S. Coal Commission, 1923. Exponent of Mine Safety. Author of "Railway Fuel" and "Romance and Tragedy of Coal."

Champion Herbert Mathewson 1943

Born October 7, 1881, Essex, Conn. Yale University, Ph.B., 1902; University of Göttingen, Germany, Ph.D., 1906. A.I.M.E.: Member, 1918; Director, 1943–1946; Chairman, Institute of Metals Division, 1932; Institute of Metals Division Lecturer, 1928; James Douglas Medal, 1932. Professor of Metallurgy, Yale University. Translated Ruer's "Elements of Metallography." Author of "First Principles of Chemical Theory"; editor, "Modern Uses of Nonferrous Metals." Campbell Lecturer, American Society for Metals, 1943. Gold Medal, American Society for Metals. Known for his distinguished contributions to the art of working and annealing nonferrous metals.

Chester Alan Fulton 1944

Born December 18, 1883, Brooklyn, N. Y. School of Mines, Columbia University, E.M., 1906. A.I.M.E.: Member, 1907; Director, 1939–1947; Vice President, 1942–1944; Chairman, Industrial Minerals Division, 1937. Mining engineer. Served in various professional capacities in Mexico, San Salvador, Venezuela, and Cuba. President, Southern Phosphate Corporation, one of the largest producers of phosphate rock in the United States. Service as consultant to the Army Intelligence and the U. S. Navy during and after World War II, in surveying world phosphate reserves.

HARVEY SEELEY MUDD 1945

Born August 30, 1888, Leadville, Colo. Columbia University, E.M., 1912.; D. Sc., 1947; University of California, L.L.D., 1941; Loyola University, L.L.D., 1943. A.I.M.E.: Member, 1917; Director, 1928–1935, 1940–1943; 1945—. Vice President, 1937–1940; 1943–1945. Developer and administrator of the copper mines of the Islands of Cyprus. Trustee, California Institute of Technology; President, Fellows of Claremont College; Chairman, Los Angeles War Chest. Director, Southern Pacific Railroad. In 1929, in cooperation with his mother and brother, he established the Seeley W. Mudd Memorial Fund (A.I.M.E.).

LOUIS SHATTUCK CATES 1946

Born December 20, 1881, Boston, Mass. Massachusetts Institute of Technology, S.B., 1902; Michigan College of Mining and Technology, Hon. D. Eng., 1937; University of Arizona, Hon. D. Eng., 1946; Columbia University, Hon. D.Sc., 1947. A.I.M.E.: Member, 1904; Director, 1919–1921, 1931–1934, 1937–1939, 1946—; Vice President, 1934–1937; William Lawrence Saunders Gold Medal, 1939. Mining engineer. Administrator in copper mining in Arizona and Utah. First to apply "caving" on a large scale to copper mining. President of the Phelps Dodge Corporation since 1930.

CLYDE WILLIAMS 1947

Born September 8, 1893, Salt Lake City, Utah. University of Utah, B.S., Chemical Engineering, 1915; Case School of Applied Science, Hon. D.Sc., 1945; University of Utah, Hon. D.Sc., 1946. A.I.M.E.: Member, 1926; Director, 1941–1944, 1947—; Chairman, Iron and Steel Division, 1936. Director, Battelle Memorial Institute. During World War II, Chief of War Metallurgy Division of the Office of Scientific Research and Development; Chairman of War Metallurgy Committee, National Research Council, which established and supervised research throughout the United States.

Treasurers of the Institute

1871–1947

J. Pryor Williamson 1871–1872

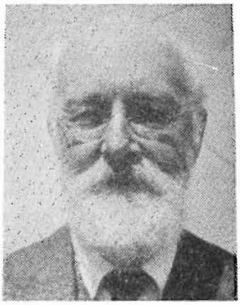
Born in 1840, Baltimore, Md. Died in October 1879. Attended schools in Baltimore, Md. Assistant to President, Baltimore Coal Co. In 1863 assisted in organizing the Wilkes-Barre Deposit and Savings Bank, of which he became treasurer. Engaged in many civic and charitable enterprises.

Theodore D. Rand 1873–1902

Born September 16, 1837, Philadelphia, Pa. Died April 24, 1903. Attended Episcopal Academy and Polytechnic College. A.I.M.E.: Member, 1873. Lawyer and scientist. Vice President, Franklin Institute of Philadelphia. Testimonial given to him at A.I.M.E. meeting at Atlantic City, February 1898, on the occasion of 25 years of "efficient, faithful, gratuitous service.

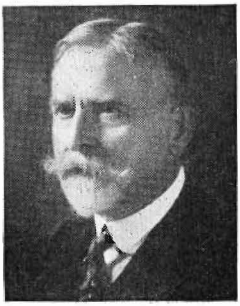
Frank Lyman 1903–1912

Born December 20, 1852, Brooklyn, N. Y. Died April 26, 1938. School of Technology, Boston; Harvary University, A.B.; Columbia School of Mines, E.M., 1878. A.I.M.E.: Member, 1877; Manager, 1897–1899; Councilor, 1905–1906; Director, 1905–1912; Member of Legion of Honor, A.I.M.E. Iron-mining executive.



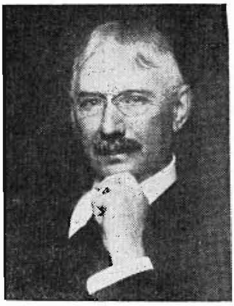
George Cameron Stone 1913–1918

Born August 6, 1859, Geneva, N. Y. Died November 18, 1935. Columbia School of Mines, Ph.B., 1879. A.I.M.E.: Member, 1880; Secretary Board of Directors, 1912; Director, 1913–1919. James Douglas Medalist, 1935. Authority on zinc metallurgy; inventor. Associated with New Jersey Zinc Co. from 1882 to 1929, as chemist, blast-furnace superintendent, superintendent and chief engineer, successively. Unofficially known as the company's "human encyclopedia." Author, "A Glossary of the Construction, Decoration, and Use of Arms and Armor."



George Davis Barron 1918–1922

Born January 20, 1860, St. Louis, Mo. Died April 1, 1947. Washington University, St. Louis, Mo. A.I.M.E.:. Member, 1901; Director, 1915–1927; Vice President, 1928–1931. Representative on The Engineering Foundation. Owned and operated mines in Mexico, having been President and General Manager of the Teziutlan Copper Co., Pueblo, Mexico. Trustee, Village of Rye and President of the United Hospital at Rye. As an officer of the A.I.M.E. Committee on Admissions for many years he was largely instrumental in maintaining the high standards of membership.



CHARLES F. RAND 1922–1927

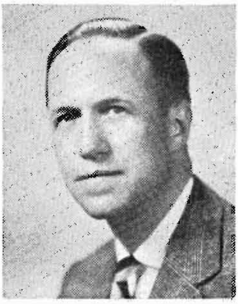
Born August 7, 1856, Canaan, Maine. Died June 21, 1927. Self-educated. A.I.M.E.: Member, 1897; Member of Council, 1910–1912; Director, 1912; 1914–1927; President, 1913. Developer of mines and new processes in iron mining. President of numerous companies at home and abroad. Grand Cross of Knight Commander of Order of Isabella Catolica, 1913. Croix de Chevalier de la Legion d'Honneur, 1922 (French Government). Honorary Member, Iron and Steel Institute (Great Britain).

KARL EILERS 1927–1941

Born November 20, 1865; Marietta, Ohio. Died August 18, 1941. Brooklyn Polytechnic Institute; Columbia School of Mines, E.M.; M.S. (Hon.) A.I.M.E.: Member, 1888; Councilor, 1909–1911; Vice President, 1912–1914; 1916–1918; 1934–1939; Director, 1927–1941; Honorary Member. Associated with his father in Colorado Smelting Plant at Pueblo, Colo.; with American Smelting and Refining Co. for many years as Director and Vice President. Constructed Garfield copper smelter, Utah. President, Lenox Hill Hospital; organizer and President of Associated Hospital Service of New York.

HARRY THOMAS HAMILTON 1941–1944

Born October 24, 1880, Groton, Conn. Died February 5, 1944. Graduate of Yale University. A.I.M.E.: Member, 1913; Director, 1936–1944. Engineer and manager for the Calumet and Arizona Mining Co. and the Phelps Dodge Corporation; Consulting practice; Industrial Department of New York Trust Co., becoming chief of Personnel Division and later Assistant to the President. During World War II with the Metals Reserve Co. as a dollar-a-year man. President, Mining and Metallurgical Society of America.

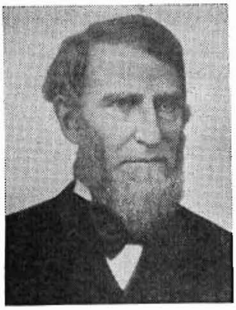


ANDREW FLETCHER 1944–

Born February 6, 1895, New York City. Sheffield Scientific School, Yale University, Ph.B., 1916. A.I.M.E.: Member, 1936, Director, 1944–1947; Vice President, 1947– . Head of W. A. Fletcher Company, ship repairers, later merged with five other shipyards into United Dry Docks, Inc. Since 1921, associated with St. Joseph Lead Co. Developed the lead and zinc resources of the Aguilar mine in the Argentine. Elected President of the St. Joseph Lead Co. in 1947. Chairman of the Board of Industrial Hygiene Foundation of America.

Secretaries of the Institute

1871–1947



MARTIN CORYELL 1871–1872

Born July 20, 1815, New Hope, Bucks County, Pa. Died November 29, 1886. Educated in the public schools of Lambertville, N. J. A.I.M.E.: Founder, having been one of the three signers of first "call" in 1871; Manager, 1873–1875. Civil and mining engineer. Associated with the construction of canals and railroads. Pioneered in the Lake Superior copper region as well as in the Pennsylvania anthracite region around Hazleton. Manager of the Warrior Run Mining Company.

THOMAS M. DROWN 1873–1884

Born March 19, 1842, Philadelphia, Pa. Died November 17, 1904. University of Pennsylvania, M.D., 1862; Hon. LL.D., Columbia University, 1895; Studied at Sheffield School, Yale University; Lawrence Scientific School, Harvard University; Heidelberg University, Freiberg, Saxony, Baden. A.I.M.E.: Founder, 1871; Manager, 1872; Secretary, 1873–1884; Vice President, 1892–1893; President, 1897; Honorary Member. Analytical consulting chemist, Professor of Chemistry, President, Lehigh University, 1895–1904.

ROSSITER W. RAYMOND 1884–1911

Born April 27, 1840, Cincinnati, Ohio. Died in 1918. Brooklyn Polytechnic Institute, 1857; Lafayette College, Ph.D., 1868; Lehigh University, LL.D., 1906; University of Pittsburgh, Hon. LL.D., 1915., Gold Medal, Institution of Mining and Metallurgy (London). A.I.M.E.: Founder, Member of 1871; President, 1872–1874; Vice President, 1871, 1876–1877; Secretary Emeritus, 1911–1918; Honorary Member. Consulting mining engineer; practicing lawyer, sailor, soldier, writer, orator, editor, theologian, teacher, novelist, chess player. Recognized as the "Grand Old Man of the Institute."

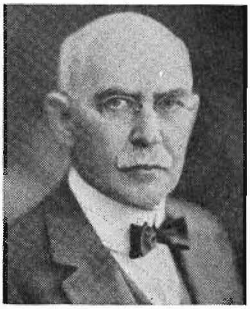
JOSEPH STRUTHERS 1911–1912

Born 1865, New York City. Died February 18, 1924. Columbia University School of Mines, Ph. B., 1885; Ph. D. 1895. A.I.M.E.: Member, 1888; Editor, 1903–1905; Assistant Secretary, 1906–1910; Assistant Treasurer, 1906–1912; Director, 1911. Instructor in Metallurgy, Columbia University. Editor, *Mineral Industry;* Field Assistant, U. S. Geological Survey; treasurer of various shipping companies. Author of "Quiz Compend of Chemistry and Physics." Trustee and Treasurer, United Engineering Society; Treasurer, The Engineering Foundation.

BRADLEY STOUGHTON 1913–1921

Born December 6, 1873, New York City. Yale, Sheffield Scientific School, Ph.B., 1893; Massachusetts Institute of Technology, B.S., 1896; Hon. D. Eng., Lehigh, 1943. A.I.M.E.: Member, 1897; Member of Legion of Honor, A.I.M.E. Instructor in metallurgy at the Columbia University School of Mines; Professor of Metallurgy at Lehigh University; Dean, College of Engineering, in 1936. Author of "The Metallurgy of Iron and Steel" and "Engineering Metallurgy." Helped establish the eight-hour day in the U. S. steel industry Awarded the Graselli Medal.

FREDERICK FRALEY SHARPLESS 1921–1925



Born January 22, 1866, West Chester, Pa. University of Michigan, B.S. Chemistry, 1888. A.I.M.E.: Member, 1889; Secretary Emeritus, 1925–1926. Following five years as a member of the Faculty of the Michigan School of Mines, he became associated with Horace V. Winchell in consulting practice in geology and mining engineering. Later, advised the Consolidated Mines Selection Company, Ltd., of London, regarding mines throughout all of the Americas, Mexico, West Africa and Turkey.

H. FOSTER BAIN 1925–1931

Born November 2, 1871, Seymour, Ind. Moores Hill College (Indiana), B.S.; graduate student, Johns Hopkins University; University of Chicago, Ph. D. A.I.M.E.: Member, 1897; Member of Legion of Honor, A.I.M.E. Director, Illinois Geological Survey; Editor, *Mining and Scientific Press;* Editor, *Mining Magazine*, London; Director, U. S. Bureau of Mines; Consultant to the Philippine Government regarding the mining industry; interned by the Japanese at Santo Tomas University camp for Americans, 1942–1944. Author, "Ores and Industry in the Far East."

ARTHUR BARRETTE PARSONS 1931–

Born November 22, 1887, Salt Lake City, Utah. Utah School of Mines, B.S., 1909; South Dakota School of Mines, Honorary Doctor of Engineering. A.I.M.E.: Member, 1914; Assistant Secretary, 1930. Superintendent, Candor Mines Co. (North Carolina); Burma Mines, Limited, India; Mining Engineer, Butte and Superior Mining Co.; Associate Editor, *Mining and Scientific Press;* Associate Editor, *Engineering and Mining Journal;* President, Mineral Research Corporation. Author of "The Porphyry Coppers," A.I.M.E. 1933, and of more than two hundred articles on technical and political phases of the mineral industries.

Seventy-five Years of Progress in Mineral Production—the Statistical Record

By Elmer W. Pehrson

ELMER W. PEHRSON

Since 1928, Mr. Pehrson has been in the Mineral Economics Branch of the United States Bureau of Mines. He is now Chief of the Branch and directs all the statistical work of the Bureau. He spent a number of years in western metal-mining districts before going to Washington and his specialty in the Bureau has been in metals. For two years he has been chairman of the A.I.M.E. Committee on Mineral Economics.

THE founding of the American Institute of Mining Engineers in 1871 came at an unusually significant moment in the life of our country. The industrial revolution, in which mineral production played a major role, was just getting underway. The iron industry, established several decades earlier, was reaching sizable proportions. In 1871 pig-iron production was approaching 2 million tons, and the industry had spread as far west as Missouri and Wisconsin. The chief sources of iron ore were Pennsylvania, New Jersey, New York, and Michigan. The age of steel was in its infancy; production had not yet reached 100,000 tons per annum.

The gold rush to California two decades earlier and the discovery of other gold and silver bonanzas in the West paved the way for the transcontinental railways, which were then being built and which contributed much to the subsequent development of the great copper, lead, and zinc districts of the Rocky Mountain area. Regular production of copper in the Michigan peninsula and of lead in Missouri and the upper Mississippi region had been established for many years but on a scale dwarfed by the quantities later required as technical progress, invention and enterprise made possible the rapid expansion of industry.

Discovery of oil in Pennsylvania in 1859, the growing recognition of the

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importance of the coal resources of Pennsylvania and its neighboring states, and the development of the Mesabi Range in Minnesota about 1890, gave further impetus to the industrial growth of the United States. Thus the Institute was born on the eve of the greatest industrial expansion in all history—an expansion that has brought to the United States a standard of living that is the envy of the world and a position in world affairs second to none.

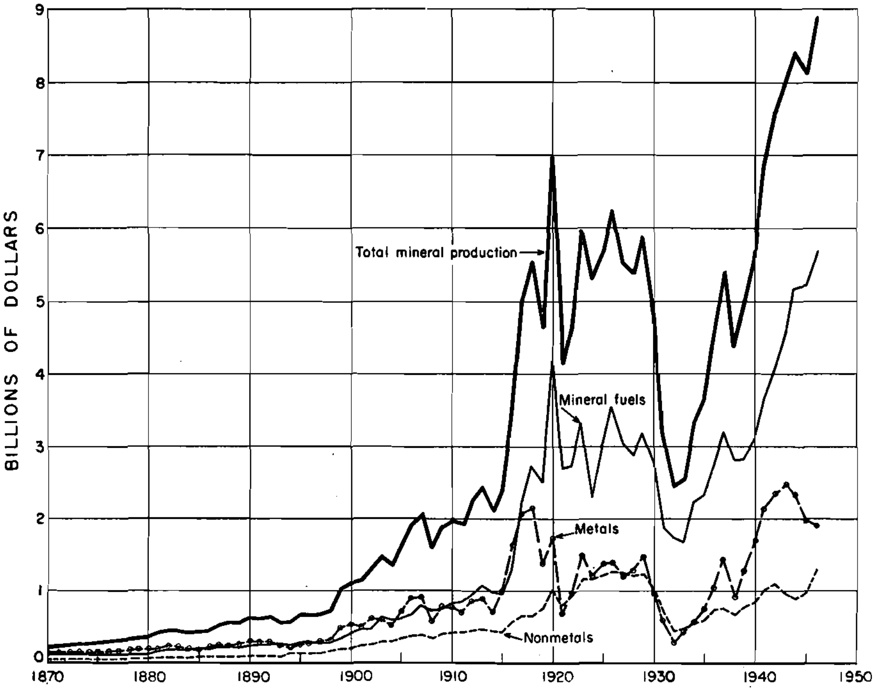


FIG. 1—*Trends in value of mineral production in the United States, 1870–1946.*

These accomplishments were possible only because nature endowed the United States with bounteous mineral wealth, which has enabled it to become the world's leading producer and consumer of minerals. Previous chapters record the contributions of our profession to the technical progress that played such an important part in this achievement; this summary presents the results of these achievements as revealed by statistics of production.

The outstanding growth of the mineral industry during the 75 years that have elapsed since the founding of the Institute is shown in Fig. 1. Data prior to 1880 are incomplete, so that the values shown for the earlier years are merely estimates. From 1870 to 1946 the annual value of mineral production rose from an estimated $240,000,000 to an all-time peak of $8,900,000,000, a 36-fold increase. Meanwhile population increased from 39.8 million to 140.8 million, only a 2½-fold increase, so that per capita production multiplied more than 10 times—from $6 to $63. Probably fewer than 200,000 persons were employed directly in the extraction and processing of minerals in 1870, compared with an estimated 750,000 in 1946; millions more now derive their livelihood in transporting and fabricating the raw materials produced by the mineral industries of the United States.

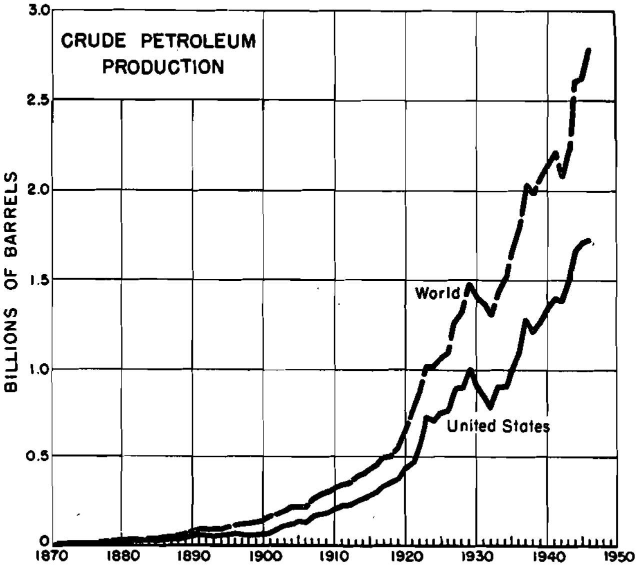


FIG. 2—*Production of crude petroleum in the United States and the world, 1870–1946.*

Fuels

The mineral fuels have occupied a preeminent position in mineral production in recent decades, having gained in relative importance at the expense of metals. In 1870 mineral fuels comprised 38 per cent of the value of all mineral products, metals 52 per cent, and the nonmetallic minerals 10 per cent. In 1946 fuels accounted for 64 per cent of the total while metals represented only 21 per cent; the value of the nonmetallic minerals other than fuels had increased to 15 per cent. This outstanding advance in the relative positions of the mineral fuels is due entirely to the rapid growth of the petroleum and natural gas industries. In 1870 crude petroleum contributed 8 per cent to the value of mineral output and there was as yet no recorded production of natural gas. In 1946 these products accounted for 39 per cent of the total. During the same period the proportion of total value contributed by coal declined from 30 to 25 per cent.

Fig. 2 compares the production of crude petroleum in the United States with that of the world from 1870 to 1946. Except from 1898 through 1901, when Russia ranked first, the United States was the leading producer throughout this period, contributing 90 per cent of the world's output in 1870 and 62 per cent in 1946. Domestic production increased from 5,261,000 barrels (42 gallons) in 1870 to a peak of 1,733,424,000 barrels in 1946, a 328-fold increase. This phenomenal rise can be attributed largely to the invention of the internal-combustion engine, which accounts for so much of today's enormous demand for liquid fuels. However, this use did not become significant until after 1900. In the earlier years petroleum was consumed principally in the manufacture of kerosene for use in lamps, lubricating oils, and waxes. Since about 1890 a substantial quantity of oil in the form of heavy crude or residual products from distillation has been used as a fuel for industrial purposes.

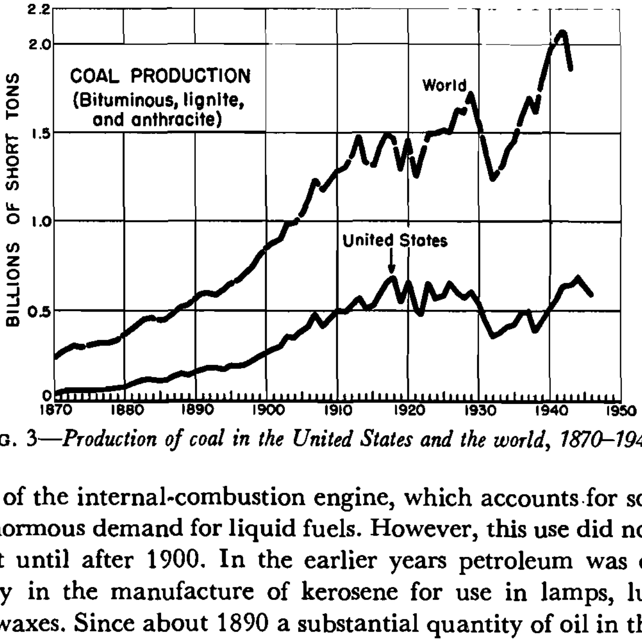


FIG. 3—*Production of coal in the United States and the world, 1870–1946.*

The increase in coal production has been less spectacular than that of petroleum (Fig. 3). The annual output increased steadily from 33,000,000 net tons in 1870 to 678,000,000 tons in 1918. Thereafter it remained relatively constant, owing largely to increased efficiency in the utilization of coal as a fuel and the inroads of oil, natural gas, and water power in the domestic fuel and power markets. The 1918 record was not exceeded until the war year 1944, and then only by a narrow margin. Meanwhile world production increased steadily as a result of industrial expansion in many parts of the world where coal suffered considerably less competition from other forms of fuel and energy. The United States' proportion of the world output rose from 14 per cent in 1870 to 46 per cent in 1918, but has declined to about 33 per cent in recent years.

Domestic production of anthracite increased from 15,664,000 net tons in 1870 to an all-time peak of 99,612,000 tons in 1917, but has since declined to 60,300,000 tons in 1946. It represented 47 per cent of the total coal output in 1870; 15 per cent in 1917, and 10 per cent in 1946. During the same period production of bituminous coal and lignite rose from 17,371,000 tons in 1870 to a World War I peak of 579,385,000 tons in 1918, and to an all-time peak of 619,576,000 tons in 1944. Failure of anthracite to maintain its position in production of solid fuel has been due chiefly to its higher cost, as a result of which it has lost markets to bituminous coal, and to the intense competition from oil and gas in its principal market—domestic heating.

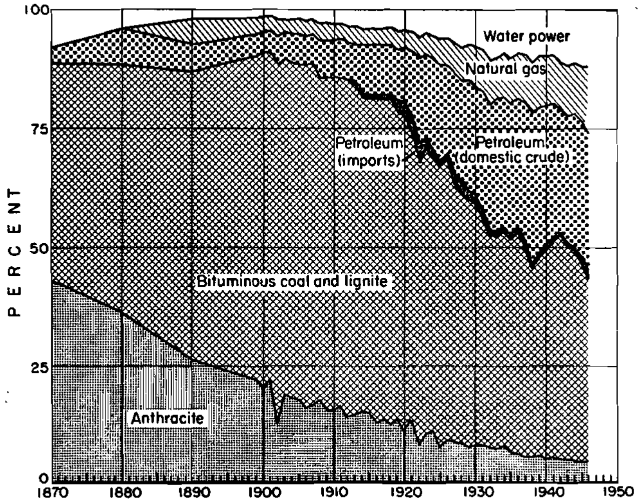


FIG. 4—*Percentage of total B.t.u. equivalent contributed by the several sources of energy in the United States, counting water power at a constant fuel equivalent, 1870–1946.*

The industrial growth of the United States is strikingly revealed by the enormous expansion in its total consumption of energy. It is estimated that the energy derived from mineral fuels and water power was 991 trillion British thermal units in 1870 and 35,977 trillion in 1946, assuming water power at a constant fuel equivalent of 4.05 pounds of coal per kilowatt-hour. This was a 35-fold increase. The per capita use of energy rose from 25 million B.t.u. to 255,000,000, a 9-fold increase. Fig. 4 shows the proportions of our energy requirements that have been derived from various sources from 1870 to 1946. There has been a substantial decline in the relative importance of anthracite throughout the period. Bituminous coal and lignite gained from 1870 to about 1910 and declined thereafter; they supplied a smaller proportion of our energy requirements in 1946 than in 1870. Petroleum and natural gas have advanced markedly, particularly since 1900. Water power declined in importance from 1870 to 1900 but subsequently has increased.

Iron and Steel

Iron ore and coal are the basic requirements for steelmaking and consequently they are indispensable in maintaining an industrial society such as ours. Fortunately the United States' resources of these vital raw materials have been equal to the demands of its ever-expanding industry. Figs. 5, 6 and 7 show United States and world production of iron ore, pig iron and steel from 1870 to 1946. Domestic production of iron ore rose steadily from 13 per cent of the world total in 1870 to 65 per cent in 1918. The tonnage produced in 1918 was not exceeded until 1941. Meanwhile the United States' share of world output dropped to 26 per cent in 1939 but rose again to an estimated 40 per cent in 1946. The trend of the domestic pig-iron industry followed a similar pattern, rising from 12 per cent of the world total in 1870 to 60 per cent in 1918, then declining to 31 per cent in 1931 and again advancing to 50 per cent in 1946. Domestic steel production shows a more persistent upward trend throughout the 76-year period, but since World War I it also has not kept pace with the advance in world output. Per capita consumption of pig iron has increased from 94 pounds in 1870 to 630 pounds

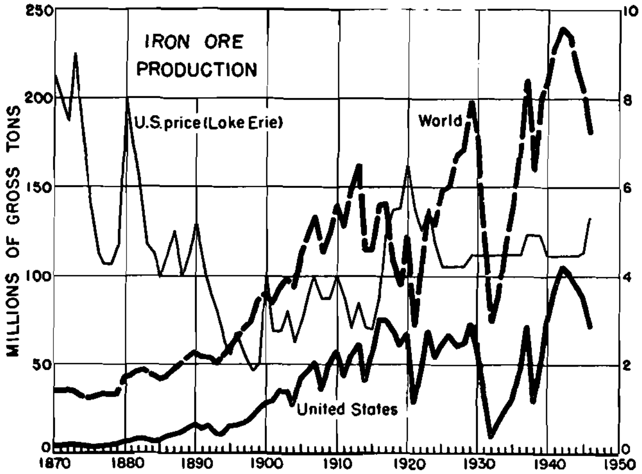


FIG. 5—*United States and world production of iron ore, and price of typical non-bessemer ores at Lake Erie ports, 1870–1946.*

in 1946. Prices of iron ore and pig iron declined sharply from 1870 to 1898, but since then the general trend has been upward.

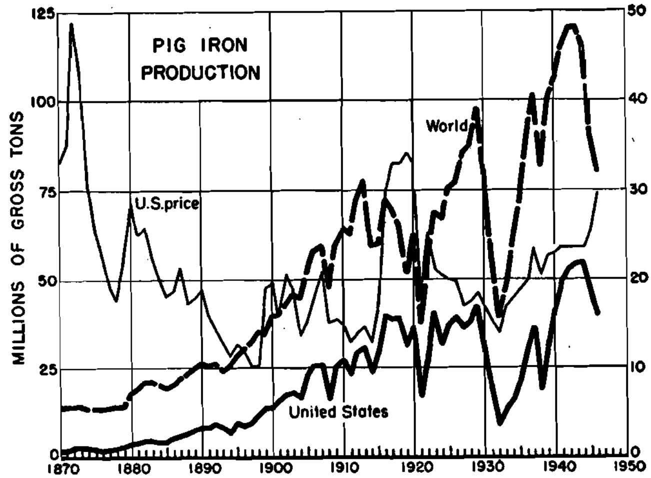


FIG. 6—*Trend in production of pig iron in the United States and the world, and in the price of standard grades of pig iron in major United States markets.*

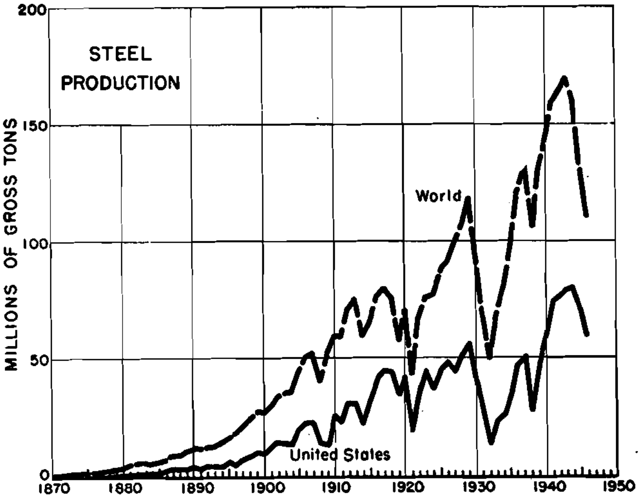


FIG. 7—*Steel production in the United States compared with that of the world, 1870–1946.*

In the light of the enormous growth of the iron and steel industry, the comment of James M. Swank, in Mineral Resources of the United States for 1882, is of interest. After citing the statistics of coal and iron production for 1860 and 1880, he stated:

> Our national pride may well be gratified with the foregoing statements. To be second only to Great Britain in the production of iron ore, coal, pig iron, and steel is itself a great fact; to have made the vast strides of the last few years in the production of these materials is another great fact; but to contribute 23 per cent of all the coal produced in the world, 19 per cent of all the iron ore, 22 per cent of all the pig iron, and 28 per cent of all the steel is a still greater fact. But the most remarkable fact of all in connection with this vast material development remains to be stated. Large as our production of iron ore, pig iron, and steel is shown to be, it is not large enough to meet our wants, and we are consequently importers in a large degree of the iron and steel products of other countries, and indirectly of the iron ore and coal which are required in their manufacture; we are also large direct importers of iron ore itself. Were it necessary to do so, statistics could readily be cited which would fully establish the fact that our country is a larger consumer of iron and steel than any other country. It is natural that we should be, as our population is greater than that of any other civilized country, Russia alone excepted, and as our railroad system, which absorbs fully one-half of all the iron and steel we produce and import, embraces a greater number of miles of track than that of all Europe.

Today we may look back on the accomplishments of 75 years with the same feeling of pride expressed by Swank over 60 years ago; but we may do so with a feeling of assurance that our exuberance will not appear as such a masterpiece of understatement 75 years hence as Swank's does today.

Nonferrous Metals

The production trend of the major nonferrous metals—copper, lead, and zinc—approximates the pattern of steel production. In this electrical age, it is not surprising that the demands for copper should advance rapidly, and Fig. 8 shows the extent to which production during the past three quarters of a century has responded to that demand. During this period the per capita use of copper has increased from 1 to 20 pounds per person. Since 1883 the United States has been the leading producer in each year except 1932 and 1934, when Chile ranked first, but its share of world output has declined from 63 per cent in 1916 to 31 per cent in 1946. The steady upward trend in domestic production ended with World War I. Since then the record indicates that we may be reaching the maximum productive capacity of our resources. The fact that Michigan and Montana recorded their peak output to date in 1916 and Arizona in 1929 lends support to this surmise. Significant features of the price curve are the sharp decline from 1870 to 1894, the pronounced rise in World War I and the moderate rise in World War II, and the low average of prices since 1930, compared with that of the previous 60 years.

In contrast to the geometric rise in production of copper from 1870 to World War I, production of lead advanced in a straight line of less spectacular slope, as shown in Fig. 9. Although the upward trend persists to 1929, production during the past 15 years has failed to even approximate predepression levels. The evidence that we have passed our peak in lead production is thus much more convincing than that in copper. Despite recent adverse trends, the United States is the leading world producer, a position

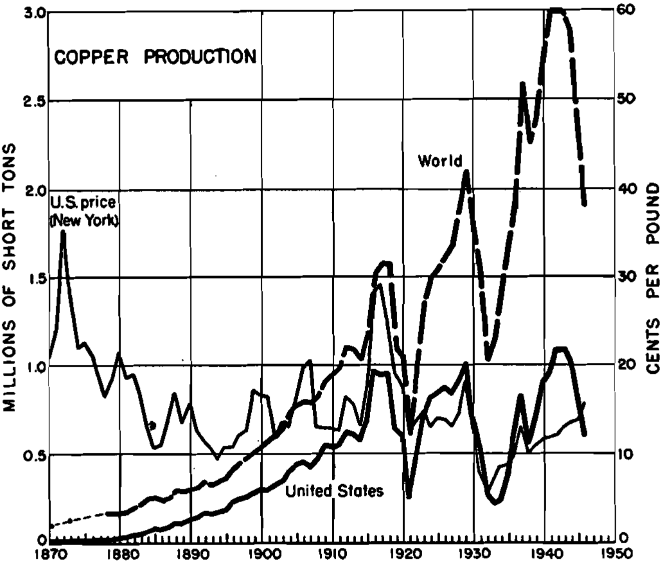


FIG. 8—*Production of copper in the United States and the world, and the New York price, 1870–1946.*

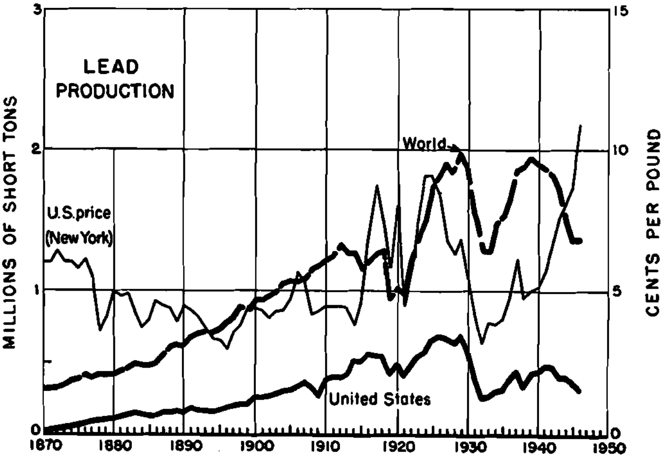


FIG. 9—*Production of lead in the United States and the world, and the New York price, 1870–1946.*

held almost every year since 1880, when she took the lead from Spain. World production has advanced more rapidly than domestic production, so that our share of the total, which rose from 6 per cent in 1870 to 47 per cent in 1920, had declined to 22 per cent in 1946. Per capita consumption of primary lead rose from less than 2 pounds per year in 1870 to more than 8 pounds in 1945. The upward trend in prices since 1896 is of interest.

While production of lead failed to establish new peaks during World War II, that of zinc did both in the world and in the United States, although the latter exceeded previous records by only a narrow margin (Fig. 10).

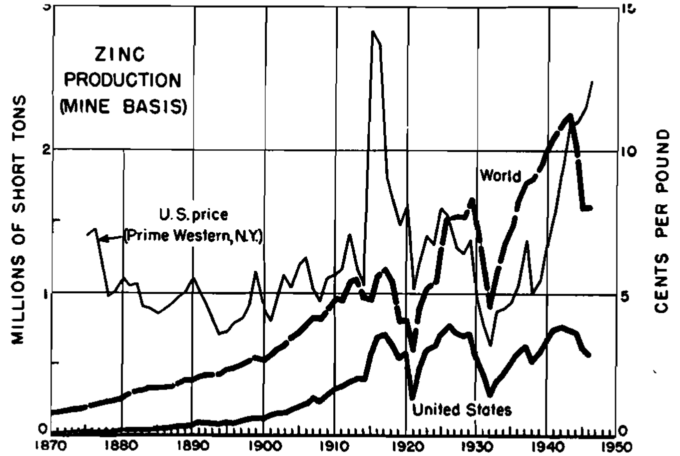


FIG. 10—*Production of zinc in the United States and the world, and the New York price, 1870–1946.*

Zinc production was well established in Europe by 1870 but was just getting underway in the United States. Progress in the domestic industry was slow for the first three decades, but by 1910 we had surpassed Germany as the leading producer. Since 1920, when we accounted for more than 70 per cent of the world's output, our share in the total has declined to 35 per cent in 1946. As with lead, there has been an upward trend in prices since 1893. Per capita consumption of primary zinc in the United States has increased from less than one pound per year in 1870 to nearly 11 pounds in 1945.

The common nonferrous metals have encountered a formidable competitor in aluminum in recent decades. The phenomenal rise in the production of this metal is shown in Fig. 11. Production began in Europe about 1873 and in the United States in 1895, but world output did not reach the 10,000-short-ton mark until 1904. But once established its uses expanded rapidly and production gained steadily. During World War II domestic production exceeded that of lead and zinc and nearly equaled that of copper. The increase in production of aluminum from 1933 to 1943 has not been matched in any 10-year period by that of any other commodity included in this review except magnesium. No less spectacular was the decline in price from $8 per pound in 1886 to $1.21 in 1891 and 15 cents at the present time. The United States produced 39 per cent of the world's aluminum in 1910 and 50 per cent in 1946. She gained first place in world production and has held that position consistently except for 1934–1935 and 1938 to 1941, when Germany took the lead.

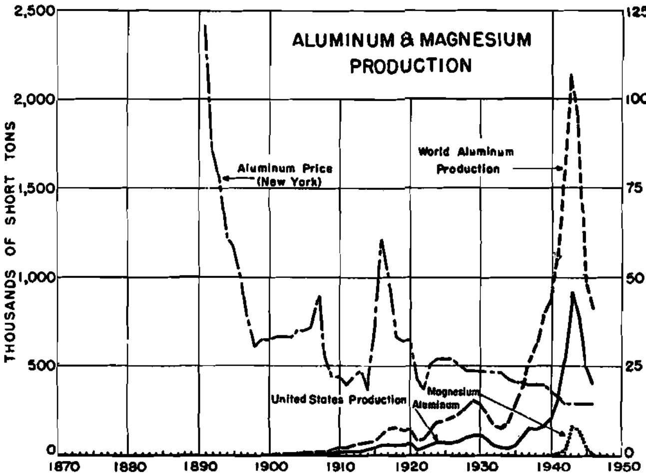
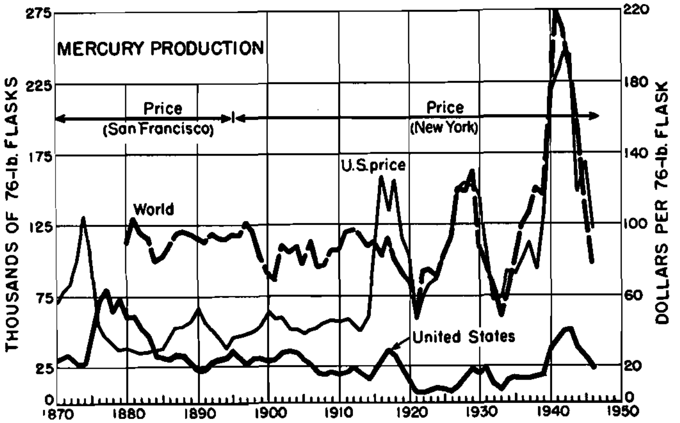


FIG. 11—*Production of aluminum in the United States 1885–1946, and in the world 1873–1946; New York price for aluminum, 1891–1946, and domestic production of magnesium 1915–1946.*

Domestic production of magnesium, also shown in Fig. 11, began in 1915, enjoyed a tremendous growth during the war, but has since declined almost to prewar levels. Germany's production of this light metal greatly exceeded ours for many years prior to World War II, but in 1942 our production surpassed Germany's. World production data are incomplete, but estimates indicate that the United States produced only about 10 per cent of the world's magnesium in 1937, 65 per cent in 1943, and 54 per cent in 1945. Domestic quotations (New York, carload lots) for magnesium also have shown a marked decline, from $5 per pound in 1915, when commercial production began, to 48 cents in 1930 and 20.5 cents in 1946.

The tremendous growth in domestic mineral production during the past 75 years did not include mercury, production of which is shown in Fig. 12. The peak for that metal was reached in 1877, when the domestic output comprised 60 per cent of the world total. Despite an upward trend in prices since then, and substantial tariff protection since 1883, production declined. Since 1910 the United States has imported a substantial part of its needs, although during World War II the highest prices on record brought out sufficient mercury to meet war needs. With the collapse of prices after the war, production returned to prewar levels. In 1945 the domestic output comprised only 23 per cent of the world's supply.

Gold and silver mining were well-established industries in the United States in 1870, contributing approximately 30 per cent of the total value of mineral production. Although the output of precious metals continued to expand, it did not keep up with the growth of other mineral production. Consequently, in 1940, when gold reached its peak output and silver was near its peak, the two metals accounted for less than 5 per cent of the total value. Gold production in 1870, as shown in Fig. 13, was trending downward from the high level established following the gold rush to California in 1849. The United States and Australia were alternately the world's leading producers. From 1875 to 1897, the United States ranked first, but in 1898 the Union of South Africa gained the lead and, except for a few years during the Boer war, has held that position by a wide margin. The record output in the United States in 1940 resulted from the revival of gold mining following the revaluation of gold in 1934. However, the 1940 level was only slightly above the output in 1915. World production reached a peak in 1940. The United States contributed 40 per cent of the world total in 1870, 21 per cent in 1915, and 12 per cent in 1940.



IG. 12—*Production of mercury in the United States and the world, and the domestic price, 1870–1946.*

World production of silver has maintained an upward trend during the past 75 years (Fig. 14). The peak output recorded in 1940 was 6.4 times that of 1870. The United States established its maximum in 1915, but thereafter production declined and in 1933 reached the lowest level since 1872. With the revival of nonferrous metal mining, where a large part of the silver is obtained as a by-product, and the discovery of rich silver deposits in the Coeur d'Alene region of Idaho, production again increased rapidly. Since

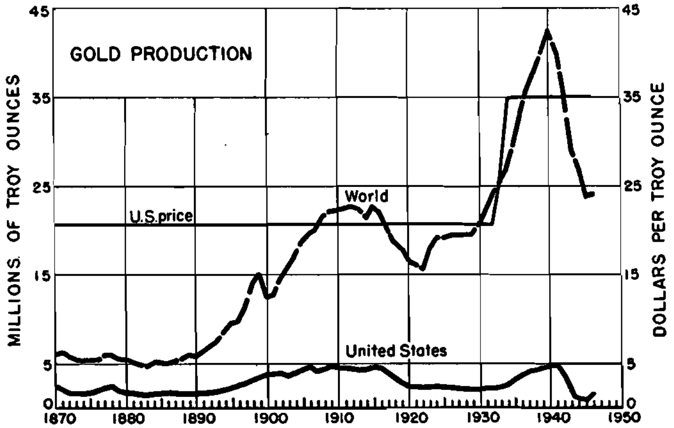


FIG. 13—*Production of gold in the United States and the world, and the domestic price, 1870–1946.*

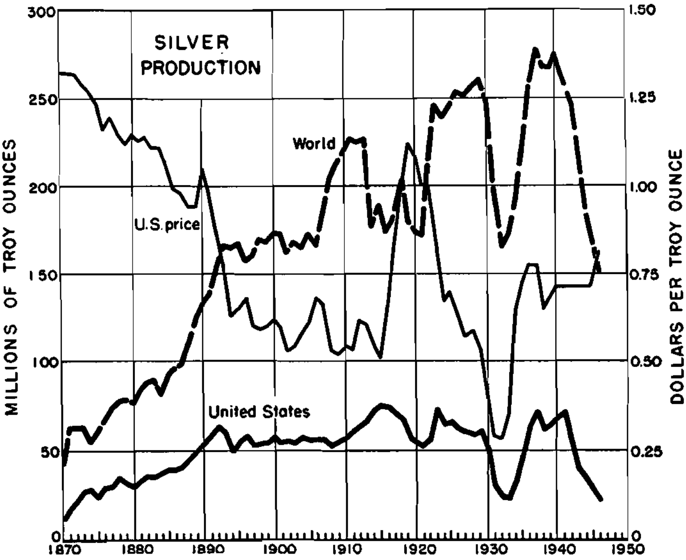


FIG. 14—*Production of silver in the United States and the world, and the domestic price, 1870–1946.*

1941, however, silver mining has been affected adversely by war conditions and other postwar factors that prevented recovery of production in 1945 and 1946. The United States contributed 29 per cent of the world's silver in 1870, 40 per cent in 1915, and 25 per cent in 1940. Prior to 1919, the United States and Mexico alternated as the world's leading producer, but since that year Mexico has ranked first, in most years by a considerable margin.

Nonmetallic Minerals

The growth in production of some of the nonmetallic minerals has been even more spectacular than that of most of the fuels and metals. For example, the annual domestic output of native sulphur, as shown in Fig. 15, increased 7700 times from 1870 to 1946, whereas that of petroleum increased only 330 times, coal 17 times, iron ore 15 times, and copper 42 times. The value of native sulphur produced in the United States in 1945 outranked that of gold, lead, silver and several other metals. In 1870 the annual production of sulphur was only about 500 long tons, an inconsequential portion of the world's output which at that time was virtually all obtained from Sicily. However, soon after the invention in 1894 of the ingenious Frasch process for extracting sulphur from the huge dome deposits of the Gulf Coast region, the domestic output began to expand. The United States became the leading producer in 1912, and in 1946 contributed more than 85 per cent of the world total. Before World War II, native sulphur supplied about 40 per cent of the world's sulphur requirements, pyrite 57 per cent, and by-product

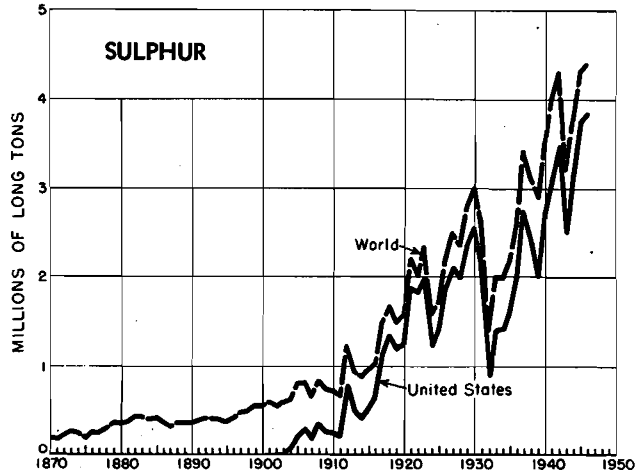


FIG. 15—*Production of native sulphur in the United States and the world, 1870–1946.*

sources about 3 per cent. In 1940 the United States accounted for less than 10 per cent of the world's production of pyrite.

The United States potash industry is another example of outstanding accomplishment during the past few decades. Before World War I the industry was virtually nonexistent and Germany was supplying most of our needs of this essential fertilizer. When the European war broke out German supplies were cut off and domestic prices soared. To meet the urgent need, attention was turned to every known source, and with prodigious effort production did increase, but only enough to meet a small part of our requirements. After the war, recovery of potash from the waters of Searles Lake, California, continued to expand, but the production from other sources ceased as prices collapsed. Search for new deposits was stimulated by the Government and in the mid-twenties the presence of potash minerals in underground beds in New Mexico was discovered. Subsequent drilling proved that the deposits were large and high grade. Production in this area began in 1931 and now it supplies more than 80 per cent of the domestic output. Largely as a result of this development, the United States has advanced from a "have-not" status to one of the world's leading potash producers. In 1946 it supplied 38 per cent of the estimated world output. Fig. 16 shows the growth of this industry since 1870.

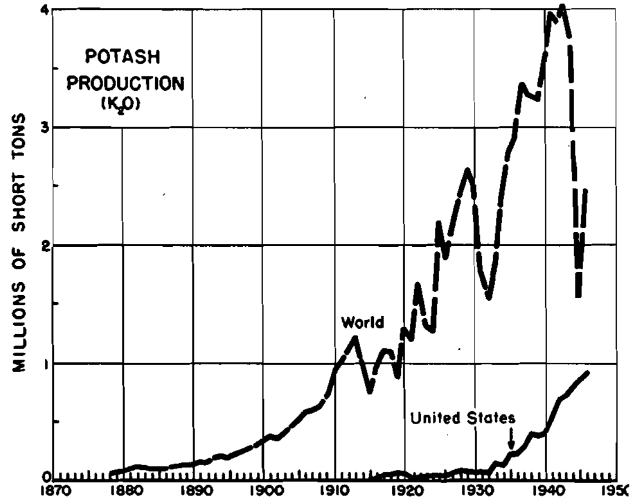


FIG. 16—*Production of potash in the United States and the world, 1870–1946.*

Fig. 17 illustrates the remarkable expansion in the production of phosphate rock during the past three quarters of a century. In 1870 the domestic industry was only a few years old but it accounted for about one third of the world output. It grew rapidly and in 1877 became the leading producer, a position the United States has since held consistently except for one year, 1890, when France ranked first. In 1946 the domestic output established a new peak, which was 57 per cent of the estimated world production. The industry began in South Carolina. Florida entered the field in 1888 and in 1894 became the leading producer. The United States has exported a large proportion of its output for over 50 years.

The United States produces no natural nitrates, the third of the three great fertilizer minerals, but substantial quantities are recovered as a by-product in coke manufacture, and since World War I synthetic nitrogen chemicals have been produced by the fixation of atmospheric nitrogen. During World War II capacity for manufacture of synthetic nitrogen was expanded greatly and, for the first time in history, the United States can now meet its needs of this commodity. In recent years she has been the world's largest producer and consumer of nitrogen products.

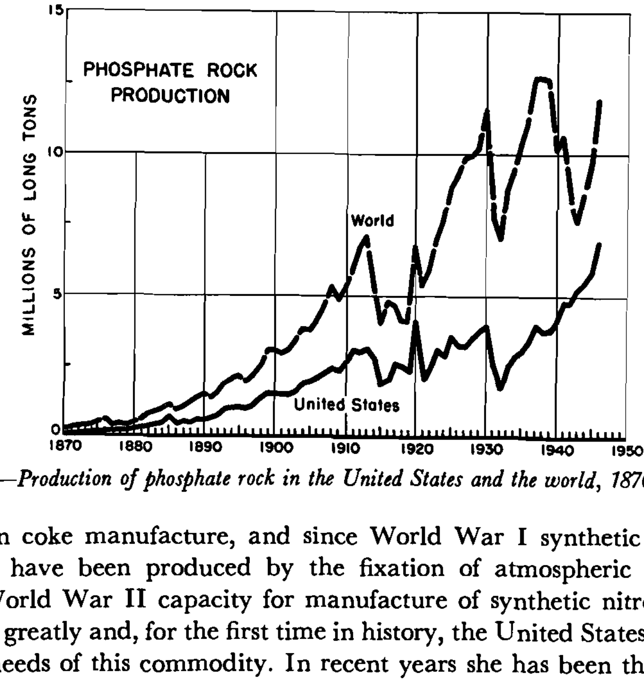


FIG. 17—*Production of phosphate rock in the United States and the world, 1870–1946.*

Increasing population and a rising standard of living have greatly increased the demand for building materials of mineral origin. Unfortunately, the statistical record for most of these minerals, as well as for many other nonmetallic products, is incomplete. Fig. 18 shows the production of cement in the United States from 1870 to date and world production since 1923. Natural cement was a well-established industry in 1870 and the manufacture of portland cement, which today comprises about 99 per cent of the total output, began shortly thereafter, in 1871. The industry has experienced a remarkable growth, in which the invention of the automobile with the consequent demand for good roads and the development of concrete construction have played major roles. Domestic production of cement reached a peak in 1942 when its value ranked sixth in total mineral output. It led all other nonmetallic products except fuels in value of production in that year. Production declined during the latter part of World War II but recovered substantially in 1945 and 1946. The United States ranks first in world output but its proportion of the total has declined from 51 per cent in 1923 to 44 per cent in 1942 and 32 per cent in 1946.

The rapid advance in production of cement has been duplicated in the domestic production of sand and gravel, statistics for which from 1902 to date are shown in Fig. 18. The growing popularity of concrete as a construction material has greatly increased also the demand for crushed stone, but it has had an adverse effect on dimension stone, production of which has declined in recent decades.

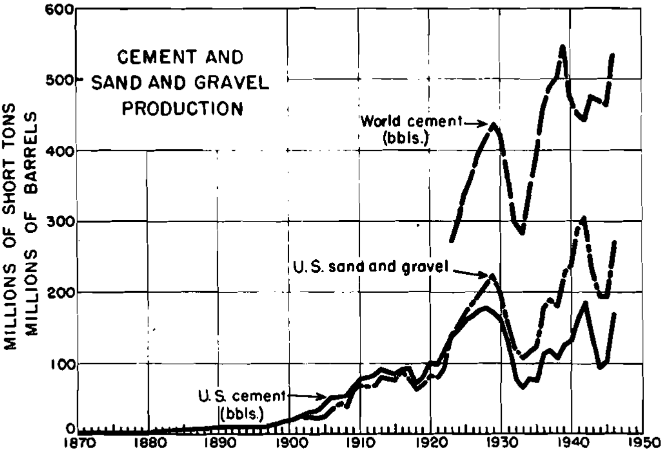


FIG. 18—*Production of cement, also sand and gravel, in the United States and world cement production, 1870–1946.*

Conclusion

The sixteen minerals whose production records are revealed in the accompanying graphs accounted for 77 per cent of the total value of mineral output in the United States in 1945. Only three of these commodities—aluminum, magnesium, and potash—were not produced in 1870. The Census of 1870 also records the production of asphalt, building stones, clay, lime, nickel, peat, salt, and slate. In addition, apparently there was some production of cobalt, chromite, grindstones, manganese, natural gas, platinum and a few other mineral products. The total list of minerals produced in 1870 probably did not exceed 35, whereas in 1945 about 90 were included in the list. Thus the contribution of mineral technology during the past 75 years includes not only the engineering achievements that have made possible vast increases in the volume and efficiency of the production of the older minerals, but also the metallurgical and chemical advances that have produced new raw materials to meet the increasing complexity of industrial needs.

Seventy-five Years of Progress in Mineral Industry Education

BY THOMAS T. READ

THOMAS T. READ

Dr. Read was Vinton Professor of Mining Engineering at Columbia School of Mines from 1929 until his death in May 1947. In 1905 and 1906, he taught mining and metallurgy at Colorado College, and from 1907 to 1910 he was Professor of Metallurgy at Pei Yang University, Tientsin, China. Thereafter he was connected with the Mining and Scientific Press, the U. S. Bureau of Mines, and with the A.I.M.E. (1926–1929) *as Assistant Secretary.*

It is natural, in reviewing the progress that has been made in mineral industry education during the three quarters of a century that has elapsed since the American Institute of Mining Engineers was organized in 1871, to seek to establish some significant correlation. Earnest endeavor along such lines, however, produces nothing more in the way of fundamental relationship than a technical economic interest in mineral production and utilization in the United States, which had been steadily increasing since 1800. This is a sound correlation, since it is unquestionable that organized and systematic mineral industry education had its origin in Germany, more than 150 years before 1871, in an economic interest in producing minerals for use with the maximum of recovery at a minimum of cost.

Mineral industry became the originator* and creator of systematic technical education because of the political and economic fact that in all European (and most other) countries, prior to 1800, precious metals belonged to the ruling power, no matter upon whose land they were discovered. The practical way of working under this system was to grant to a discoverer the right to work the deposit on payment

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* The claim, by civil engineers, that the Ecole des Pouls et Chaussées, established at Paris in 1765, represents the beginning of technical education, is erroneous. The instruction in drafting and other subjects for prospective employees of government bureaus, out of which it grew, had been in progress only a few years, whereas systematic mineral instruction began at Freiberg, Germany, in 1702, and at Nevia, Russia, in 1709.

of a "royalty" to the legal owner of the mineral. This, in turn, made it necessary for the owner to exercise some supervision over the producer, to ensure he was not being cheated of his rightful dues, either through dishonesty or honest ignorance and inefficiency, in the actual operation of the enterprise.

All other forms of productive enterprise were private and met their need for technical competence through the apprentice system, which was in general use. This provided operatives but not supervisors. The silver-lead mines of the Freiberg district of Saxony were so very profitable before 1700 that people went from all over Europe to see them and learn what they could from practice there, since it was the most advanced. This was because the operators had abundant funds to do anything that promised better returns or lowered costs, and they were less inclined than other nonmineral producers to keep their operations secret, since the differences between individual deposits are enough so that it was not practicable to simply copy the methods of another. Since there was no overproduction in that field, operators did not think of themselves as competitors. Thus the minerals industry may lay claim to originating the practice of freely sharing technical knowledge as well as for making the first systematic provision for instruction in that field.

The latter achievement was the provision in 1702, at the instance of Oberberghauptman Von Schonberg, of a series of free scholarships for natives of Saxony who would pledge themselves to enter the service of the state after completing the course of instruction provided for them at Freiberg. How this developed into Bergakademies there, at Schemnitz in Hungary, and elsewhere in Europe, has been presented[1] and need not be reviewed here. It will be noted, however, that there was no established mineral industry education in England[2] before 1851, since that may have some bearing on its failure to develop in the United States until even later.

That fact seems odd in itself, because in their attempts to form a federal union the American colonies had ceded to the federal government their conflicting claims to tracts west of their main areas, and as early as 1787 there was federal legislation providing for the taking up of these lands, including the reservation of mineral rights and the payment of royalties upon mineral production therefrom. But instead of leading to a demand for trained inspectors and supervisors of mineral enterprises on government-owned lands, the system worked so badly in practice that the mineral-lease aspects of the public land laws were repealed in 1847, and there was actually no legal way

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[1] T .T. Read: Development of Mineral Industry Education. A.I.M.E., 1941.

[2] Page 9 of reference 1.

to carry on mining operations on public lands in the United States from that time until a federal mining law was passed in 1865.

It need hardly be said that the practical conduct of mining and metallurgical operations up to that time had made little or no demand for technical instruction. Coal and iron had been the principal mineral industries of the eastern seaboard region and both depended on practical operating experience rather than technical information. Even at the time the Institute was organized, it would have been possible to get up an argument as to whether a chemist was worth his wage to a steel plant. In a country where the population was increasing through immigration, as ours then was, the skilled manpower supply was augmented through immigration quite as effectively as through apprentice training.

This being so, it is somewhat remarkable that there was as much interest in mineral industry education in the United States before 1871 as actually existed. Americans had gone to study at the Ecole des Mines, in Paris, as early as 1800, and between 1819 and 1849 there was an occasional American student at the Bergakademie at Freiberg. After the latter year American students flocked there. It is not unlikely that political conditions in Germany in 1848, which drove many educated men to seek refuge in America, and the discovery of gold in California in 1849, as well as the greater similarity of German to American mineral deposits than to those of France, was responsible for the keen interest in Germany in this period.

Early Attempts at Systematic Education

Strangely enough, the first two attempts to establish systematic mineral industry education in the United States were unsuccessful. In 1853, Alfred L. Kennedy obtained from the Pennsylvania Legislature a charter for a Polytechnic College of the State of Pennsylvania, together with an initial grant of $5000. This school offered definite two-year curricula in mining and metallurgy, and gave degrees, but aside from the initial $5000 the Legislature gave it no further aid, nor did it seem to enlist much support in Philadelphia, where it began its work at Market Street and Penn Square. Although its charter said that its objects were " . . . particularly mining, engineering, and the natural sciences," there was less interest in mining than in its other curricula. Kennedy listed himself as Professor of Metallurgy, although his own field was actually medical chemistry.

Whatever the various causes for the lack of interest in and support for this institution, it quietly went out of existence in 1890, having graduated 369 students in the 36 years of its existence, relatively few of them having taken the mining and metallurgical curricula. Many of its graduates who attained subsequent distinction in the mineral industry had graduated from other curricula.

If inability to secure sufficiently well-qualified teachers in its technical fields may be suggested as at least one reason for the failure of this Polytechnic College in Philadelphia, it certainly is not the reason for the lack of success of the next American attempt to provide metallurgical instruction. In 1855, Yale established a professorship of metallurgy, and appointed George J. Brush, one of its own graduates, to the chair. He had just completed a year of study at Freiberg, and instead of immediately returning to New Haven he spent another year studying metallurgy in London under Dr. John Percy, the most distinguished authority of the time, and afterward visited all the European metallurgical plants to which he could gain access.

Arriving in New Haven in January 1857, he gave a few popular lectures on metallurgical topics, but thereafter gradually turned into a teacher of mineralogy, as well as becoming Secretary of the Faculty. Yale did not offer any curricula in which a course in metallurgy was required, and, although Connecticut had for some time had important brass-manufacturing plants, the metallurgy of the time almost exclusively concerned itself with the production of metal from ore, in which there was no local interest. Since O.D. Allen was appointed Professor of Metallurgy and Assaying when Brush became Professor of Mineralogy, some years later, there must always have been some institutional interest at Yale in metallurgy, but there was little evidence of it in the student body before mineral industry education was re-established there a half century later. Alfred D. Rockwell was appointed Professor of Mining at Yale in 1865, and six mining degrees were given in 1868–1870, but Rockwell went to the Massachusetts Institute of Technology in 1867 and was not replaced.

Era of 1864–1871

Just why there were no further attempts* to establish mineral industry education in the United States between 1855 and 1864, the next to the last year of our Civil War, is not easy to determine, but there were none. Nor is it at all clear why there was a sudden flowering of interest in 1864. It has been widely assumed that the striking success of the School of Mines established under the auspices of Columbia College in New York in 1864 led to similar attempts elsewhere, but if that is true there is no definite evidence to support it. There is, on the contrary, reason to suppose that each of the insti-

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* The passage of an Act by the State Legislature of New York in 1858 incorporating an American School of Mines is passed over here because nothing ever came of it. See reference 1 for further details.

tutions that evinced interest in mineral industry education at that time had its own reasons for doing so.

COLUMBIA SCHOOL OF MINES

The School of Mines at Columbia was the result of the impact of Thomas Egleston on that institution, which had been established by royal charter in 1754 but was still, after more than a century, only a small college of the traditional sort. Its curriculum was loaded with Latin, Greek, logic, rhetoric and other "humanities," though it had developed vague and tenuous associations with a School of Medicine and a Law School. Its trustees had long been aware that it needed reorganization and development but seemed to find it difficult to make up their minds what to do. The head of its chemistry department was anxious to establish a School of Chemistry there, and had advertised its opening in the New York papers in the autumn of 1863, but he did not properly coordinate his activities with those of the Trustees, with the result that his "school" was swept away the next year, to his great chagrin.

Thomas Egleston, a rich man's son, had graduated in science at Yale in 1854, and remained for another year of graduate work in chemistry, under Silliman, after which he went to Paris for further study. He first registered at the Jardin des Plantes, but learning that the Ecole des Mines was a much better place for the study of mineralogy, which had by that time become his major interest, he transferred. By 1860 he had completed the full course of instruction there and received the official graduation certificate given foreign students. Returning to the United States he was appointed, in 1861, by the Smithsonian Institution, to classify and label the collections of specimens that various exploring expeditions had brought back to Washington from the West.

Either because he was independently wealthy or because his father had meanwhile died, much of this work seems to have been done either at the family home, on the then most fashionable part of Fifth Avenue, or at their summer home near Lenox, Mass. In his relatively infrequent sojourns in Washington, Egleston is believed to have made various attempts to promote the establishment of a National School of Mines there, but since his correspondence of that period has not been found and the files of the Smithsonian for the period were destroyed by fire, there is no evidence to support the belief.

Egleston was prominent in Trinity Church and knew George T. Strong, an active trustee of Columbia. Strong had a collection of minerals that he wished to give to Columbia. Egleston labeled and arranged them and took a letter of introduction, dated Jan. 10, 1863, to the President of Columbia, to arrange for the transfer of the collection to Columbia.

The next documentary evidence we have is a printed pamphlet, "Plan for a School of Mines and Metallurgy in New York City," dated March 1863, which apparently was issued at Egleston's expense. At the meeting of the Columbia Trustees on April 6, 1863, this plan was considered and a committee of three trustees was appointed to report on it. This committee made a favorable report on April 29, 1863, and by December plans were far enough advanced so that Egleston was officially appointed Professor of Metallurgy and Mineralogy in the new School. It opened to receive students on Nov. 15, 1864.

Since the organization of the School seems to have been one of the principal factors in its outstanding success, it will be described in some detail. Columbia, which was then situated between 49th and 50th Sts. and Madison and Park Avenues, had a building that could be converted to the use of the School at a cost of $3500. All the members of the faculty of Columbia College who taught subjects in the curriculum of the School of Mines were appointed to seats on the faculty of that school, some of them at higher titles than they had in the College. Thus rivalry was effectively stopped.

Only three new professors were appointed. Egleston was made Professor of Metallurgy and Mineralogy. Francis F. Vinton, a graduate of West Point, who had been a classmate of Egleston's at the Ecole des Mines, 1857–1860, and had been retired as a Brigadier General on account of wounds received in our Civil War, was made Professor of Mining, and Charles F. Chandler was brought from Union College to be Professor of Analytical Chemistry. None of these three men was given a definite salary, though Chandler was privately assured that he would not lose by the move; the other two were in a position to take a chance on the success of the venture.

Twice as many students appeared on the opening day as had been expected and by the end of the second year there were as many students in the School of Mines as Columbia College had acquired in a century of existence. Meanwhile a separate building had been provided as well as definite salaries of $3000 for the three new professors,* and John S. Newberry was also appointed Professor of Geology. By 1866 a new building had to be constructed for the School.

But the most significant event of 1866 was a report by the Faculty to the Trustees in March recommending that the degree of Engineer of Mines be given for a three-year curriculum and the Bachelor of Philosophy degree for curricula with a common core of physics, mineralogy, and geology but with options in engineering and chemical subjects. The institution, scarcely yet established as a School of Mines, was already in process of transformation

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* Chandler received $100 additional as Dean of the School.

into a School of Applied Science. The evidence is quite clear that those who were actually building it as an institution thought of it as a graduate* professional school, as contrasted with the "undergraduate" college. Many of the first students did, in fact, already have bachelor's degrees.

By 1868 this trend crystallized into five definite curricula, leading to the degrees of Engineer of Mines, Civil Engineer, and the Bachelor of Philosophy for those in Metallurgy, Chemistry, and Geology. These curricula covered four years and although the first was called a "preparatory" year it was not really so, because its studies were quite as advanced as those of the first year of the College.

By the time the A.I.M.E. was founded in 1871, this institution for mineral industry instruction was firmly established and, through its reaction on Columbia College, was a potent force in the subsequent development of Columbia into one of the great universities of the United States.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

An Institute of Technology in Boston had been suggested to W. B. Rogers by his brother Henry as early as 1846. After Rogers settled in Boston in 1853, he worked on the project, and the institution began work with 15 students in February 1865. Robert H. Richards, well known to all the older generation of mining, was one of them. Richards has described the early developments there in such interesting detail in his autobiography, and they are summarized in the reference 1 cited herein, so they need not be repeated here, though it may be interesting to note that originally he registered in the mechanical engineering course and changed to mining because he thought the professor of mechanical engineering a poor teacher.

James D. Hague was announced as Professor of Mining, but he seems never to have given any instruction, and Alfred D. Rockwell went from Yale (where he had been appointed Professor of Mining in 1865 but seems never to have given any instruction in mining) in 1867 to fill the place. J. M. Ordway taught the metallurgy for some years, though his main interest was chemistry. J. D. Runkle, a mathematics professor who succeeded Rogers as president in 1870, took much interest in the mining and metallurgical work and encouraged Richards by putting him in charge of setting up a mining laboratory. But there was so much more interest in other branches of technology at the Institute that it was not until 1878 that it graduated as many men in mining and metallurgy as it had in its first class. In 1883, Richards,

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* The report also recommended the award of the Doctor of Philosophy degree for a suitable program of advanced studies. This was the real beginning of doctoral work as we now know it in the United States, the advanced degrees granted by other institutions before that time having been essentially honorary.

who had meanwhile become Professor of Mining, was made Professor of both Mining and Metallurgy. The curriculum was known as Course V, which is perhaps an index of its relative importance in the Institute's field. The Columbia School of Mines was, in actual organization, an institute of technology too, but there the other fields of instruction were destined to remain subordinate to mineral industry education for a long time to come.

MICHIGAN SCHOOL OF MINES

Early in 1865 the faculty of the University of Michigan requested permission from the Regents to "establish a course of study to be known as the School of Mines," and it was granted March 28; but all that was done to establish a department of mining engineering was "increased provisions to assist the professor of chemistry and giving some additional labor to the professors of geology and civil engineering." A three-year curriculum was offered until 1870, when it was increased to four years. No teacher of mining or metallurgy was appointed until 1875, and then only a $750 assistant. Two men were awarded the Engineer of Mines degree in 1867, six in 1868, seven in 1869, three in 1870, and one each in 1871 and 1872, and none again until 1876. In 1879–1880 the curriculum was definitely dropped.

It seems quite clear that the failure of mineral industry education to develop in the state university at Ann Arbor was due to the wrong attitude of the administrative authorities, who supposed that adequate instruction in this field could be given by teachers of other subjects. The then president of the University of Michigan was hostile to the development of separate schools, believing in the harmonious development "under one government, and largely under the same professors, of various departments of education and culture." It was not a sound idea.

HARVARD

At Harvard, in 1865, Samuel Harper endowed a Sturgis-Harper professorship of geology with the intention that it should be a nucleus of a School of Practical Mining and Geology. J. D. Whitney was selected to fill this chair but he did not go to Harvard until 1868, when he was made Research Professor in the Museum of Comparative Zoology and took no part in undergraduate matter. He persuaded Raphael Pumpelly to give the geology lectures at Harvard until Whitney should be ready to take them on (he never did). Pumpelly, who was paid $1500 a year, had three students in 1869–1870, but resigned in the spring of 1871. William H. Pellee had been made instructor in mining in 1869 and Thomas M. Drown (later Professor of Chemistry at Lafayette and M.I.T., and President of Lehigh, and a founder member of A.I.M.E.) was made instructor in metallurgy, but they both left in 1871. There were no students in mining in 1874 and the School of Practical Mining and Geology disappeared from the Harvard catalogue after that year. No mining engineer degrees were given at Harvard between 1875 and 1906, though a curriculum leading to the B.S. in mining was established in 1894.

Obviously, one difficulty at Harvard was that there was no organization of the instruction. There were no entrance requirements, no curriculum, and the catalogue officially said, "Attendance on the lectures and recitations is voluntary." With the Institute of Technology in Boston offering a definite curriculum and practical laboratory instruction, it was not strange that instruction at Cambridge modeled on that at Athens 2000 years before did not attract many students, however much it may have stimulated a few. As a matter of fact, the Massachusetts Institute of Technology also had relatively few students in the mineral industry field.

WASHINGTON COLLEGE, LEXINGTON, VIRGINIA

The institution founded at Lexington, Va., in 1749, and later known as Washington College, was revived in 1865 with General Robert E. Lee as President, and began offering a curriculum in mining engineering, but its resources were so slender that the professor of mathematics gave the instruction in civil engineering as well as that in mining engineering. There was no real reason for offering such specialized instruction as mineral industry education in an institution that, because of its geographical location and limited support, could scarcely hope to flourish. After the land-grant college was opened in Blacksburg in 1872 there was even less reason and the course was officially dropped in 1876, having given eight mining degrees altogether.

LAFAYETTE COLLEGE

At Easton, Pa., Lafayette College, for which local people had obtained a charter in 1826, and which actually had started in a rented farmhouse in 1832, obtained much needed help from the Presbyterian synod in 1849, and received $100,000 from Ario Pardee, of Hazleton, in the early '60s, to establish a scientific course. It appointed H. S. Osborn as Professor of Mining and Metallurgy in 1865 and offered a mining and metallurgy curriculum oddly loaded with classical antiquities. Osborn, an ordained clergyman, was really a "natural scientist" in the old sense, and also a talented writer; he is best known for his Prospector Fieldbook and Guide, which he published 20 years after he left Lafayette in 1870. E. S. Moffatt was made Adjunct Professor of Mining and Metallurgy in 1868, but left in 1873. From 1871 to 1880, Thomas M. Drown was Professor of Chemistry and Rossiter W.

Raymond, formerly Mineral Commissioner of the United States, was lecturer in mining geology. During this period these men were strongly influential in guiding the early steps of the Institute. Pardee Hall, built in 1872 from gifts of Ario Pardee, was acknowledged at that time to be the most extensively equipped engineering and science laboratory in the United States. Frederick Prime, Jr., a graduate of Freiberg, became Professor of Mining and Metallurgy in 1870 and remained to 1881. I. M. Silliman, who graduated in mining engineering at Rensselaer in 1870, joined the staff at Lafayette in 1871 and held the title of Professor of Mining Engineering until he died in 1896. These men were an appreciable fraction of the total faculty of what was still a small institution.

Although there were few graduates in mining during the early years, Lafayette never abandoned its mining curriculum, and later greatly strengthened its mineral industry courses. After the first world war, in 1920, William B. Plank, a graduate under Wadsworth at Penn State, and a mining engineer of the U. S. Bureau of Mines, was appointed Markle Professor of Mining. In 1929, John Markle, an alumnus and an anthracite operator, made the first of three gifts totaling $1,000,000 for a new hall of mining, metallurgy and geology and a foundation for the support of the department of mining and metallurgy. In 1936 the separate degree curriculum in metallurgy was set up.

RENSSELEAR POLYTECHNIC INSTITUTE

Rensselaer Polytechnic Institute, which Amos Eaton had established at Troy, N. Y., in 1824, to "qualify teachers for instructing the sons and daughters of farmers and mechanics," quickly turned to teaching civil engineering to young men to qualify them for jobs on construction of the Erie canal, and thus became the first engineering school (aside from the engineering taught at West Point) in the United States. Rensselaer decided to offer mineral industry curricula in 1867 and appointed George W. Maynard, who had graduated at Columbia and taken graduate work at both Göttingen and Clausthal, Professor of Mining and Metallurgy. During the four years he was there, 23 men were graduated in mining but the curricula were discontinued when he left in 1871. Many years later metallurgical instruction was resumed, but not mining.

LEHIGH UNIVERSITY

Lehigh University, Bethlehem, Pa., began its work in the autumn of 1866, but no professors of engineering were appointed until 1871, when a half-million dollars promised by Packer became available. Benjamin W. Frazier was then made Professor of Mining and Metallurgy, and he also taught geology and mineralogy. Only six mining degrees were given before

1880. Tuition was free until 1892; many students attended but did not attain degrees. After 1881, the bachelor of metallurgy degree was also offered for an optional curriculum, and four such degrees were awarded in 1884.

NATIONAL SCHOOL OF MINES

Late in 1867, Senator Stewart, of Nevada, introduced a bill into Congress to establish a National School of Mines "west of the Rocky Mountains." It was referred to the Committee on Mines and Mining of the Senate, but was never reported out.

COLLEGE OF CALIFORNIA

The College of California, established by Congregational missionaries at Oakland in 1853, had prospered so much that by 1864 it is reported to have established a "Mining and Agricultural College" in San Francisco, with William P. Blake as its director. But no record remains of where this enterprise was, what equipment it had, or other faculty than Blake, who was also mineralogist for the State Board of Agriculture. Gardner F. Williams took his degree from the College of California in 1865. The next three years were ones of struggle as to whether this institution or a proposed State University should receive the Morrill Act land subsidy. It was settled by the trustees of the College giving to the State the tract of land in Berkeley where the University now stands and turning over the College as the academic department of the University.

Joseph LeConte was appointed Professor of Geology at the new State institution in 1869; Robert A. Fisher was Professor of Chemistry, Mining and Metallurgy. William Ashburner was appointed Professor of Mining and Metallurgy in 1874 but George F. Becker, who was lecturer in metallurgy, carried on the work of the school until 1876. After that there was no one with the title of professor of mining and metallurgy until 1885, when Samuel B. Christy, who had graduated in 1874 and was immediately appointed assistant in chemistry, was appointed to it. It might almost be said that the effective history of mineral industry instruction there begins with him.

COLORADO SCHOOL OF MINES

In Colorado, a missionary bishop of the Protestant Episcopal church secured money in Boston to establish a university, which was to include a School of Mines. Construction began at Golden in 1869, but the first building was destroyed by a storm before it was completed. In January 1870, the State Legislature appropriated $3872.45 for a brick building "for the use of a School of Mines," but mining instruction was not organized until 1873, when E. J. Mallet, Jr., became Dean and Professor of Chemistry. E. L. Berthoud taught geology and civil engineering. In 1875 Mallet resigned and tried, without success, to establish a rival School of Mines in Denver. He was succeeded at Golden by Gregory Board, then by Milton Moss, and finally, in 1880, by Albert C. Hale, who had taken his Ph.D. at Heidelberg,* and who became the first president of the school by Act of the Legislature.

During this time, although many students attended the institution, relatively few took any degree; one was given in 1882 and two in 1883. The Legislature granted ⅕ mill of the State tax to the School in 1881, and under Regis Chauvenet, who became President in 1883 and remained until 1902, there was a long period of steady growth, though the institution long suffered from the inability of the secondary schools of the region it served to provide it with students prepared to undertake work at the entrance level set by some of the eastern schools.

UNIVERSITY OF WISCONSIN

At the University of Wisconsin, Roland Duer Irving (who had taken the E.M. degree at Columbia in 1869) was appointed Professor of Geology, Mining and Metallurgy in 1870, and established instruction in mining and metallurgy there in June 1871. Few students in that field appeared and Irving's interests turned more to geology, as did those of Charles R. Van Hise, who took the E. M. degree under Irving in 1879 and who was for a while Professor of Metallurgy. When the University was reorganized into four colleges in 1889, geology and mineralogy were assigned to letters and science, while mining and metallurgy were assigned to engineering. No one was appointed to the engineering faculty to teach either subject, and instruction in both fields was not revived until after 1908.

WASHINGTON UNIVERSITY, ST. LOUIS

Washington University, St. Louis, which had been offering engineering curricula since 1854, received a grant from an alumnus of $2800 per year for five years to establish a professorship of mining and metallurgy. William B. Potter, who had taken his E.M. at Columbia in the same year as R. D. Irving, was appointed. The parent institution was then small and weak, the four mining graduates of 1883 represented all the engineering degrees given that year. After Potter, who had participated in organizing the St. Louis Sampling and Testing Works, resigned in 1888 to give his whole time to that business, he was not replaced, and no mining degrees were given after 1894.

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* Dr. Hale was head of the physics and chemistry department in the Boys High School at Brooklyn, N. Y., when the writer was a student there, 1895 to 1898.

MISSOURI SCHOOL OF MINES

When Missouri received its Morrill Act subsidy, the citizens of the southern part of the state were unwilling to have its income controlled by the curators of the State University at Columbia, and the latter reluctantly consented to the establishment of a School of Mines at Rolla, where Phelps County had made the highest bid of the rival claimants. It opened in November 1871, a few months after the A.I.M.E. was founded. It had a three-year curriculum, and quite as much difficulty as Colorado School of Mines in securing students who were qualified to undertake it; though called a School of Mines, it offered instruction in other fields of engineering and, after 1885, an academic curriculum. Its exact relationship to the State University was long a source of difficulty, finally settled by its becoming a School of the University, under a Dean.

STATUS IN 1871

It will thus be seen that when the A.I.M.E. was founded in 1871 mineral industry education had already been in progress in the United States for a number of years. Two physically separate institutions known as schools of mines had been established, though one of them offered a variety of technical curricula and neither was yet well established. Both had difficulty in securing students qualified at the collegiate level. Many more institutions east of the Mississippi offered mineral industry education than west of it, but many of them on such a basis that it did not thrive. Harvard's work in this field was not properly organized until the 1890s; Yale had appointed the first qualified professor of metallurgy in 1855 and a professor of mining in 1865, but had abandoned the field by 1871, as had Rensselaer Polytechnic, and Washington and Lee was soon to do so. The better established work at the University of Michigan dwindled for the next 10 years and was dropped in 1879–1880. The first school in the United States to offer degrees for mining and metallurgical curricula, the Polytechnic College of Pennsylvania, at Philadelphia, was meeting with only slight success, so little that it went out of existence about 1890. At the Massachusetts Institute of Technology, where mining and metallurgy was also only one of several engineering curricula offered, it always occupied a subordinate position to these others.

Only at Columbia, where the instruction had been organized as a School of Mines in what was about to develop into a great university, was mineral industry education finding any considerable demand from qualified students. Although it offered five different curricula after 1868, and later seven, the main attendance for many years was in the mining curriculum. Of the total number of mineral industry degrees given in the United States up to 1890, probably more than half were granted by the Columbia School of Mines. The precise reasons for this greater success are hard to determine. It was in a region of large population with good secondary schools to supply qualified entrants, it had a good faculty, well-organized curricula, granted appropriate degrees, and had buildings and equipment of its own, though associated with a long-established institution. It was very well adjusted to its environment at the time. The changes time brought about will be discussed later.

Instruction in 1871–1891

The organization of the A.I.M.E. in 1871 had no easily distinguishable effect on the development of mineral industry education in the United States. Instruction in mining and metallurgy continued to be organized at additional institutions, but space is lacking to describe it in as much detail as heretofore.

Illinois Industrial University, as it was then called, was established at Urbana in 1867 and offered mining instruction on a sketchy basis, with but few students, until 1892, when it was dropped, only to be revived in 1910.

Vanderbilt University, started in 1875, attempted to offer mining instruction from the start and later added metallurgy, but it gave only one mining degree prior to 1910, when chemical engineering was introduced as a curriculum.

University of Iowa announced curricula in civil, mechanical and mining engineering as early as 1871, though mining differed from mechanical engineering only by addition of quantitative analysis, metallurgical engineering, and mine surveying. It seems to have declined, to be revived in the 1890s.

Ohio State University formally opened in 1874, and a School of Mines was established there in 1877, with John A. Church as the first Professor of Mining and Metallurgy. Nathaniel W. Lord, who had taken his E.M. at Columbia in 1876, succeeded Church when he left in 1879, and was in charge of the School until his death in 1911. Lord's main interest was in analytical work and fuel testing and the school graduated fewer than 40 men in mining in the first 20 years of its existence.

Case School of Applied Science, established in 1877, offered mining instruction from the beginning but was more successful after the middle 1890s.

South Dakota established a physically separate School of Mines, at Rapid City, in 1885. It grew only slowly, in spite of having a highly qualified staff, probably because qualified students were few.

Michigan College of Mines opened at Houghton in 1886, with a good staff, and grew rapidly because it charged no tuition fees, even for students from foreign lands.

University of Nevada mentions a curriculum in mining and metallurgy in its 1886 report. R. D. Jackson was Professor of Mining from 1887 to 1901, but the first mining degree was given in 1892. In 1901, six colleges of the University were organized, among them a School of Mines, with George J. Young as Professor of Mining and Metallurgy.

University of Alabama established a School of Mining and Metallurgy in 1887. Mining instruction was under the direction of Eugene E. Smith (the State Geologist) and there were not many graduates in mining before 1900.

College of Montana, at Deer Lodge, appointed F. W. Traphagen, who had taken his Ph.D. at Columbia in 1883, Professor of Chemistry and Assaying in 1887. He at once set about trying to organize a School of Mines there and succeeded enough so that two men took their E.M. degrees in 1891. However, Traphagen went to the State College at Bozeman in 1893, and the College of Montana (which was a sectarian institution) closed for lack of support in 1899. Meanwhile the State had appropriated money for a State School of Mines at Butte, which admitted its first students in September 1900.

New Mexico State School of Mines was established at Socorro by the Legislature in 1889 and began work in 1893 with a faculty of two. A separate department was established in 1895, but the school did not grow much until it was enlarged to cover civil engineering and liberal arts, after 1902.

North Dakota—When the University of North Dakota was established in 1883, it was given 40,000 acres of public land for a School of Mines, but this school was not actually created until 1891, as the fourth college of the University. It did not flourish until after 1900, when the State Geological Survey began to stimulate interest in mining.

Utah—The University of Deseret, which had opened in 1850, was reopened in 1867. A School of Mines was recommended in 1888 and the first B.S. in mining was given in 1893; the Legislature officially established a School of Mines and Engineering in 1891.

Arizona—Although the territorial university was established at Tucson, Ariz., in 1885, the money provided was not enough to complete the building until 1890, when more was obtained. Work started in 1891 with 31 students, of whom only 9 had completed high school (this was characteristic of the early days of the western mineral industry schools). Theodore B. Comstock was Professor of Mining and Metallurgy from 1893 to 1895. William F. Blake succeeded him as Director of the School of Mines and remained until 1905. The School gave its first B.S. degree in Mining in 1899 and by 1915 had awarded 60 such degrees.

University of Tennessee announced a course in mining engineering in 1887–

1888, but apparently no one with the title of professor of mining or metallurgy was ever appointed and the curriculum disappeared from the catalogue after 1896.

Increased Interest, 1891–1901

During the decade 1891–1900, there seems to have been an increase in interest in mineral industry curricula, especially at some schools. This is interesting because in a series of articles published in *Engineering News* between March 1892 and June 1893, A. M. Wellington, its editor, had argued that mining courses were falling into "innocuous desuetude" because the usual mining curriculum was one "from which no possible student could gain any advantage." In excuse for Wellington, it must be said that his table of 14 schools offering mining curricula included five that had already dropped them or were about to do so, and every school that had given such degrees in the 1880s had given fewer in 1890. He was wrong in his deductions from such data, because the Society for the Promotion of Engineering Education was organized at Chicago in the autumn of 1893 and, while the mineral industry educators were not at first at all active in it, their field did share in growth that resulted from it. Registration at the University of California increased threefold in the decade 1893–1903, increasing from 3 per cent of the total university enrollment in the former year to 11 per cent in 1903.

University of Idaho offered a curriculum leading to the degree of bachelor of mining engineering in 1896–1897 and the work grew steadily, until in 1917 a School of Mines was established.

Washington State College, at Pullman, offered a curriculum in mining engineering before its near-by rival did, but did not acquire a qualified teacher of mining until 1899. In 1909 it offered curricula in coal mining, coal washing, and metallurgy, as well as metalliferous mining. In 1917 a School of Mines was organized there.

University of Minnesota organized a School of Mines in 1892, at first as a subdivision of the College of Engineering and Mechanic Arts, but as an independent school after 1897. William R. Appleby was the first Professor of Mining and Metallurgy and Dean of the School. He continued as the head of the School until his retirement as Dean in 1935. Four-year curricula were established and the first mining degree was given in 1894; the first metallurgical degree in 1901. During Dean Appleby's incumbency, it was always maintained as a separate school, but after 1935 it was merged with the colleges of engineering, architecture, and chemistry to form an Institute of Technology.

At *Pennsylvania State College* mining engineering instruction was authorized in 1890 and actually began in 1893, and the School of Mines there became a distinct unit in 1896. Its steady growth into a School of the Mineral Industries will be mentioned later.

At the *University of Washington*, Seattle, a School of Mining had been authorized in 1893, and H. M. Landis began to give courses in assaying and mining after 1895. By 1898, three curricula, in mining, metallurgy, and geological engineering, were offered, and by 1900 the School had a faculty of 20. In spite of this it developed slowly and the first B.S. in metallurgy was awarded in 1912. Later it grew more rapidly.

At *Harvard*, H. L. Smyth was appointed Professor of Mining and Metallurgy in 1893 and a four-year curriculum leading to a B.S. degree was offered in mining and metallurgy, following the general reorganization of Harvard in 1890. Under the new arrangement the student enrollment in the Lawrence Scientific School increased rapidly until 1903, when the curriculum was changed and mining and metallurgical engineer degrees were awarded only for a fifth year of study by men who had already taken the B.S. degree. Subsequent developments can best be read in a book on Development of Harvard University, 1869–1929, by S. E. Morison. It may be enough to say here that Harvard now grants the M.S. and Ph.D. degrees for graduate work only in mining and metallurgy.

At the *University of Pittsburgh* (then in Alleghany) mining instruction was provided for by the Legislature in 1895. W. G. Wilkins and S. M. Taylor were its first professors of mining engineering. It moved to its present site in 1906, M. E. Wadsworth, former President of Michigan College of Mines and then Dean at Penn State, was brought on as Dean. Between 1914 and 1923, the University grew so rapidly that the mining work was squeezed out into temporary war buildings, and did not get back into permanent quarters until 1935. Meanwhile E. A. Holbrook, from the Pennsylvania State College, became Dean of both the School of Mines and the College of Engineering. The development of petroleum engineering or refining courses will be mentioned later.

Stanford—Academic work began at Stanford University in October 1891, with the understanding that a professor of mining would be needed within a year or two. Actually almost 20 years elapsed before one was appointed, because at first instruction in mining and metallurgy was given by young men attached to the geology department, of which John C. Branner was the head. J. F. McClelland taught mining 1908–1910 and was made the first full Professor of Mining in the latter year. How Stanford shortly thereafter became one of the three institutions that put engineering on a graduate basis will be related later.

At the *University of Kansas*, a four-year curriculum leading to the B.S. degree in mining engineering was established in 1898, and a little later the

B.S. in metallurgy was given as an option in the chemical engineering curriculum. Between 1900 and 1941 the university granted 165 degrees in mining and metallurgy.

Oregon State Agricultural College at Corvallis established on paper a School of Mines a little before 1900, and in 1908 appointed H. M. Parks Professor of Mining. He and his successors built up the work there and it continued until 1932, when the State Board of Higher Education abolished the School of Mines for political reasons.

At the *University of Kentucky*, C. J. Norwood organized a College of Mining Engineering in 1901; in 1917 it was merged with the Sumter colleges of civil and electrical engineering into a single engineering college. At times mining and metallurgy have been separate departments, at other and at present they are united.

University of Texas, at Austin, announced a mining curriculum in 1900–1901, and when William B. Phillips went there the following year it was called a School of Mines. After Phillips left, in 1907, interest decreased and the mining curriculum was dropped in 1913, when the Legislature created a School of Mines as a branch of the University at El Paso. This absorbed the El Paso Junior College in 1927 and now gives two years of work toward a degree in any other State institution in various fields, including education and medicine. It also grants the B.S. degree in a variety of fields.

Period from 1900 to 1914

The period between 1900 and the outbreak of the First World War in 1914 was one of rapid growth of enrollments in engineering schools, with the result that numerous institutions that had not previously offered mineral industry curricula began to do so, while some others that had dropped mining curricula reestablished them.

Yale.—John Hays Hammond gave Yale a mining and metallurgical laboratory building in 1903 (completed 1906); L. D. Huntoon was made Professor of Mining and Metallurgy in 1908. Two years later J. F. McClelland was made Professor of Mining and C. H. Mathewson was appointed Assistant Professor of Metallurgy the next year. Before the First World War there was considerable interest in the mining engineering curriculum, but afterward it shifted to metallurgy, and when B. B. Gottsberger resigned as Professor of Mining in 1931 his position was not filled, and the mining curriculum was dropped in 1933. The metallurgical work continued to flourish, so that, more than a half century after it appointed the first well-qualified professor of metallurgy in the United States, Yale had achieved one of the most outstanding metallurgical departments in this country.

At the *University of West Virginia* a department of mining engineering was established in 1906. Some mining work had been offered for 20 years, but with no separate staff member to teach it. The work grew steadily and especial success was attained in extension instruction for working miners. In 1930, the mineral industry instruction work was set off as a separate School of Mines, with C. E. Lawall (E.M. Lehigh, 1914) as Dean; in 1939 Lawall became President of the University. The Mineral Industries building at the University of West Virginia, housing Chemical Engineering also, is the outstanding one of the United States, and instruction in the mineral industry field there occupies a larger place in the total work of the institution than in any other State university.

Virginia Polytechnic Institute, at Blacksburg, began to offer a curriculum in applied geology in 1905, one leading to the B.S. in metallurgy in 1907, and another the following year in mining. The work flourished, with the steady building up of separate departments, including one in ceramic engineering in 1928.

University of Oklahoma established a School of Mines in 1902–1903 but later it was merged into a School of Engineering, which now offers a variety of curricula, with emphasis on petroleum engineering, geology and refining.

A *subcollegiate Wisconsin Mining School*, established at Platteville in 1907, furnished the incentive for the reestablishment in 1908, of mineral industry education at the State University, where it had been dropped since 1890. Qualified teachers of mining and metallurgy were appointed in the School of Engineering. After 1921 the department also offered a curriculum leading to the B.S. degree in metallurgical engineering. Owing to the increase in metallurgical and manufacturing industry in Wisconsin, and the relative decline of mining, the trend at Wisconsin seems to be similar to that at Yale, though the mining curriculum is still offered at Wisconsin.

University of Notre Dame organized a department of mining engineering in 1908, and in 1933 a separate department of metallurgy was established. In 1940, the department of mining and the curriculum in mining was dropped.

Carnegie Institute of Technology, at Pittsburgh, Pa., established a department of mining and metallurgy in 1909. After 1919 there was a separate department of mining, which paid especial attention to cooperation with the coal-mining industry, providing a night lecture course; a four-weeks summer course for miners; a two-year curriculum, with a diploma, to qualify miners for executive positions. Cooperative technological bulletins, totaling 45, were published. This work, which started off bravely, afterward declined; the summer course was dropped in the mid-twenties, the two-year course and other cooperative activities withered away, and the four-year curriculum leading to the B.S. in mining was officially dropped in 1936, the professor of mining engineering having left in 1928. The metallurgical department built up its work along advanced technological lines, especially in the field of physical metallurgy, in which it had published 132 papers by 1941. Its work flourished, it built up its staff, and now offers evening as well as day instruction, both for the B.S. and advanced degrees, the greatest interest being in the latter.

At the *University of Illinois*, mineral industry education, moribund since 1892, was revived in 1909, because of increased interests in fuels, with the appointment of H. H. Stoek as head of a mining department. Stoek's major interest was in a two-year extension course offered at mining centers to qualify men for certificates as firemen, inspectors and hoisting engineers, short courses at the University, unit courses given in mining districts, evening classes, local miners' institutes, and so forth. This work was discontinued in 1915 but formal academic instruction in mining continued, and up to the time of Stoek's death (1933) he had had associated with him a large number of younger men who later attained much distinction in the field of mineral industry education. Illinois still offers curricula leading to the B.S. degree in both mining and metallurgy, as well as graduate work in those fields, but in recent years metallurgy, which was subordinate in Stoek's time, seems to be increasing in importance, while mining has relatively declined.

PLANS THAT NEVER MATURED

Five schools that offered mining and metallurgical curricula in this period eventually dropped them.

At the *University of Wyoming*, where the professor of geology had offered some instruction since 1893, there was a succession of qualified teachers of mining and metallurgy who, coping with the problem of too few students adequately prepared, were never able to put mining and metallurgy on a permanent basis, except that the last of them (who left in 1933) introduced instruction in petroleum engineering and refining, which still continues.

Colorado College, Colorado Springs, decided to offer engineering instruction, and appointed Fred Crabtree Professor of Mining and Metallurgy in 1904. He was succeeded by T. T. Read in 1906 and Clyde Griswold in 1907, but when Griswold left in 1911 no further appointments were made, it having become evident that it was useless to attempt to maintain mineral industry education in a college so near the State School of Mines at Golden.

At *Cornell University*, E. J. McCausland, instructor in civil engineering, had been offering an elective course in mining engineering before 1902. Made assistant professor of mining engineering and surveying in 1903, he drew up a four-year curriculum leading to the degree of Engineer of Mines, but the

Board of Trustees never put it into effect and after he left for the University of Alabama in 1907 no mineral industry instruction was offered at Cornell.

At *Northwestern University* the head of the department of geology was much interested in mining, and H. M. Parks was made Assistant Professor of Mining in 1906, but when he left in 1907 to become Dean of the Oregon School of Mines no subsequent appointment in mining or metallurgy was made. Some courses in those subjects were listed in the catalogue as offered in alternate years by the staff of the department of geology.

Armour Institute, also in Chicago, appears to have offered mining and metallurgical instruction as early as 1893, but no details are available. When it was consolidated with Lewis Institute, in 1940, to form the Illinois Institute of Technology, it had for some time been offering metallurgical instruction but no curriculum leading to a degree in that field. Plans for erecting metallurgical laboratories and establishing such curricula were held up by World War II.

Between World Wars

Three significant developments of the period between the first and second world wars, which have not been adequately covered must now be discussed. These are graduate study and ceramics and petroleum engineering.

GRADUATE STUDY

At Harvard after 1903, the mining engineer and metallurgical engineer degrees were awarded only for a fifth year of study after the B.S. degree had been attained. At Columbia it had been possible, since 1896, for a student to enter the College, transfer to the School of Mines after two years, receive the A.B. degree at the end of five years, and an engineering degree at the end of six. For a detailed discussion of the circumstances that led up to the adoption, and application to the class that entered in the autumn of 1914, of a curriculum providing three years to be spent in the College, the receipt of the A.B. after one year in the School of Mines and the E.M. and Met. E. degrees for two more years work, see pages 175 to 183 of reference 1. It would require entirely too much space here to set them forth, as well as to speculate what effect World War I, with its temporary stoppage of engineering education, had on the result.

Columbia School of Mines had had its name changed, in 1896, to Schools of Mines, Engineering, Chemistry, and Architecture* because students in the field of mineral industry had for some time constituted only one fifth of its total student body, and the other departments thought their development

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* Architecture was transferred to the Faculty of Fine Arts in 1902. During the '30s the name was again changed to School of Engineering.

was hampered by being included in a School of Mines. The effect of the new curricula was that in 1920–1921 the registration in these schools was down to little more than one third of what it had been 10 years earlier. What was much more serious was the change in distribution of students in the various curricula. In 1910–1911, mineral industry students numbered more than one third of the total registration and in 1920–1921 only one sixth of the total registration. In later years they further declined, coming finally to represent only a minor fraction in the school they had so long dominated.

At Harvard after 1934, a bachelor's degree was required for admission to the Engineering School and it has already been noted that at Stanford this had been adopted as early as 1925. The Dean of Engineering at Harvard later characterized its policy of dropping the four-year engineering curricula as a "costly mistake." The effect on mineral industry registration does not seem to have been as immediately serious at Stanford as at Columbia, but eventually it was. At Columbia, the effects were so severe on the whole engineering school that requirements were progressively so modified that an adequately prepared student can now attain a B.S. degree in an engineering field in four years and the engineer degree in five. Even with this liberalization, the mineral industry undergraduate registration has never recovered from the blow dealt it, and the major interest of the mining and metallurgical department has become graduate work.

Until recently, no mining department has offered work really of graduate caliber. If a student worked for a doctor's degree it would usually be found, on examination, that his research was actually in the field of economic geology, metallurgy, ore dressing, or some broad problem perhaps involving all three, rather than actual mining. Until Prof. P. B. Bucky (at Columbia) put barodynamics upon a sound theoretical and experimental basis, it was not practicable for a graduate mining student to work for a doctor's degree on any other basis, nor would any mining company consider that the possession of such a degree by an employee enhanced his business value to the company. There was thus neither incentive for young mining engineers to engage in general graduate study, nor facilities at most institutions for doing so. This situation is now in process of being corrected, and the graduate from a mining curriculum will no longer be open to the charge of having a broad knowledge of the whole engineering field rather than an advanced knowledge of his own field.

What is, even yet, insufficiently appreciated is that the mining engineer is the only kind of engineer that has an adequate knowledge of the material composition and structure of the earth. The failure to maintain close liaison between the geology and mining departments at the University of Wisconsin led, as described, to the lapsing of the mining curriculum for a considerable period of years. At Stanford mineral industry instruction flourished while it was merely a subsidiary of the geological department but declined when it was transferred to a graduate engineering school. While this was being written, it was announced that Stanford has formed a new School of Mineral Sciences, combining the departments of mining and geology. This is a commendable development and may well indicate a pattern for other institutions to follow. Pennsylvania State College was the first institution to rename its School of Mines the School of Mineral Industries, in 1929. It included geography as well as geology departments and this logical form of academic organization has met with notable success.

CERAMICS

Ceramics is both an art and a technology of ancient lineage, but its affiliations with the mineral industry field have only recently become self-evident, possibly because its mineral raw materials are of little value in the raw state, thus focusing attention on the processes of their fabrication for use rather than on their production. But the growth of knowledge of ceramic technology emphasizes its kinship with general mineral technology. As early as 1894 the efforts of Edward Orton, Jr., a graduate mining engineer, to put technical ceramic engineering on a sound basis at Ohio State University was rewarded by the establishment of such a department there. In 1900, New York established a State College of Ceramics and Clayworking at Alfred, but this pattern of separate institutions did not prevail (New York has no State University) and the departments established at Rutgers in 1902, at Illinois and Iowa in 1905, North Dakota in 1910 and Washington in 1928 were all established and existing state institutions. A dozen more institutions have since either established ceramics departments or have arranged for courses in either ceramics technology or ceramics engineering to be given accessory to some other department. Ceramics is now an important and well-recognized part of the field of mineral technology education.

PETROLEUM ENGINEERING

Petroleum production engineering has developed more in the past two decades than any other subdivision of mineral industry education. The production of commercial products from crude petroleum at first required only some simple special development of distillation, while the production of the crude involved only development of brine-well drilling procedure. But soon after the first well was drilled in Pennsylvania, geologists began correlating geological structure with petroleum occurrence.

The production of petroleum increased so rapidly after 1895 that there began to develop a commercial demand for men with an adequate knowledge of petroleum geology. The effects of this on the curricula offered at the

University of Pittsburgh, Missouri School of Mines, University of California, University of West Virginia, Stanford, and M.I.T. are related on pages 191 to 194 of reference 1 and are too diverse to repeat here. But men who had had academic training of this sort soon attained positions of administrative importance in connection with petroleum production, and many of them, notably John R. Suman, recognized that technical training in addition to that in geology was of value in the industry, and began to train young graduates of mineral industry schools.

This promptly reacted to cause additional institutions, especially those in petroleum-producing areas, to offer curricula in the petroleum field, and to modify their curricula so that they are now predominantly engineering in character rather than geological. By 1936–1937, one third of all mineral industry students were enrolled in such curricula. It will be interesting to see whether this trend persists in the postwar period. Petroleum production engineering curricula probably have enough general educational value so that young men who have graduated from them but subsequently find their vocation in some other field will be as adequately prepared for life as college graduates usually are.

Subcollegiate Work

A word must be said about mineral industry education on a subcollegiate level. A separate chapter is devoted to this in the book already cited, and all that is needed here, probably, is to point out that while it developed early in Europe it has never flourished in the United States except as a mere minor phase of general vocational education. The American attitude seems to be that if an institution announces itself as one of limited objectives it loses educational appeal and is driven into either offering curricula that lead to a B.S. degree or reconciling itself to limited growth. It is possible that this is the weakest sector in the field of mineral industry education in the United States, but attempts toward development in this field seem to indicate a prevailing lack of interest.

A rival claim to be the weakest sector would be the typical provisions in the mineral industry for the professional development of technical graduates after becoming employed. The writer has already discussed this at some length in the TRANSACTIONS, and can add nothing except that subsequent experience has served only to convince him of the soundness of the views there expressed.

Conclusion

The conclusion of this review of 75 years in the development of mineral industry education is that the latter is a dynamic thing, which will always be in process of development to continuously adapt itself to the needs of the time and the place. Just as the original concept of a distinction between military and civil engineering did not prove a useful one in the academic field, so the concept of a physically separate school of mines to prepare young men only for the technical work in the mineral industry has not proved well adapted to general educational development. Montana and Colorado alone among the 48 states still maintain such institutions.

Elsewhere in state institutions, mineral industry education is typically a subdivision of an engineering school, though a number of western institutions have a school of mines organized on a coequal basis with an engineering school. Where the geology department is included in the school of mines, this is sound organization and typically produces good results, but where mineral industry instruction is included in an engineering school and divorced from geology, conditions are unfavorable. This is probably the main reason why two important eastern institutions have dropped their mining curricula, though another point of importance is that mineral industry education flourished best in areas where there is a strong local demand, both because of the lower cost of attending a local institution and because of the visible opportunity for employment in that field. When graduates of western institutions apply at mineral industry enterprises in the eastern area for employment there is lessened incentive for eastern students to elect that field as a vocation.

Some earlier aspects have disappeared, never to return. The difficulty, before 1900, of securing entrants adequately prepared now exists only at state institutions, which are obliged to accept for admission the diploma of any high school in that state. No institution would now, as some did earlier, designate a member of the staff to teach say, mining or metallurgy, regardless of whether he was qualified to undertake it or not. Nor would it offer a curriculum, leading to a degree in this field, consisting of general engineering subjects and generally lacking in mineral industry topics. Curricula and educational facilities in mineral industry schools now differ about as much as different makes of automobiles. Both the automobiles and the schools give excellent value for what they cost.

Finally, mineral industry education has shown the ability as well as the necessity to conform to the needs of the time and place. In areas as widely separated as Michigan, South Dakota, and Texas, schools that originally were organized as schools of mines have transformed themselves into general technology schools, and have thus secured for themselves a future of enlarged usefulness. As long as mineral raw materials continue to be so important in the maintenance and improvement of the conditions of human life, and their utilization in that way is so dependent on an increasingly thorough and accurate understanding of all phases of technology, it seems assured that mineral industry education will continue to develop.

Vice Presidents, Directors, Managers and Councilors of the Institute

1871–1947

John L. Agnew*
Vice President, 1925–1927

Walter H. Aldridge
Director, 1915–1917, 1921–1925

John S. Alexander*
Manager, 1874–1876, 1881–1883

E. A. Anderson
Director, 1946–

L. K. Armstrong*
Director, 1926–1928

C. A. Ashburner*
Manager, 1885–1887

George Asmus*
Manager, 1878–1880

D. H. Bacon*
Manager, 1900–1902

Raymond F. Baker
Director, 1945–1947

Sydney H. Ball
Director, 1924–1927

Herbert F. Beardmore
Director, 1946

Herman C. Bellinger*
Director, 1928–1931

C. Harry Benedict
Director, 1945–

Arthur J. Blair
Director, 1947–

Thomas S. Blair*
Manager, 1874–1876

William P. Blake*
Vice President, 1871–1874, 1876–1877, 1905–1906

John F. Blandy*
Vice President, 1871–1873, 1878–1879

Selwyn G. Blaylock*
Director, 1936–1939

A. A. Blow*
Councilor, 1905–1907

John M. Boutwell
Director, 1937–1943

A. J. Bowie, Jr.*
Vice President, 1893–1894

Oliver Bowles
Director, 1947–

J. H. Bramwell*
Manager, 1889–1891

T. T. Brewster*
Vice President, 1923–1925

William E. Brewster
Director, 1946–

Reginald W. Brock*
Director, 1914–1916

Thomas B. Brooks*
Manager, 1872

Holcombe J. Brown
Director, 1940–1946; Vice President, 1946–

Stuart M. Buck*
Manager, 1883–1885

Albert Burch*
Vice President, 1921–1923

James A. Burden*
Vice President, 1880–1881

B. C. Burgess
Director, 1945

William Burnham*
Manager, 1882–1884

P. B. Butler
Director, 1924–1926

J. M. Callow*
Director, 1925–1927

H. H. Campbell*
Manager, 1893–1895

Charles Camsell
Director, 1939–1945

Albert E. Carlton*
Councilor, 1911–1912

W. A. Carlyle*
Director, 1920–1921

R. M. Catlin*
Director, 1920–1922

H. S. Chamberlain*
Vice President, 1896–1897

J. Parke Channing*
Vice President, 1908–1909

John L. Christie
Director, 1936–1939; Vice President, 1944–1947

S. B. Christy*
Vice President, 1891–1892, 1907–1908, 1911–1912

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* Deceased.

* Deceased.

John A. Church*
Manager, 1879–1881, 1894–1896; Vice President, 1907–1908
Galen H. Clevenger
Director, 1920–1925
W. B. Cogswell*
Vice President, 1874–1875, 1886–1887
Thomas F. Cole*
Vice President, 1905–1906
Eli T. Conner*
Director, 1933–1938
Edgar S. Cook*
Manager, 1884–1886
C. R. Corning*
Councilor, 1908–1909
William M. Corse*
Director, 1920–1922
F. G. Cottrell
Director, 1918–1920
E. T. Cox*
Manager, 1877–1879
William E. C. Coxe*
Manager, 1879–1881, 1885–1887
Frank H. Crockard
Director, 1927–1929
G. A. Crocker*
Manager, 1901–1903
J. R. Cudworth
Director, 1946–
W. B. Daly*
Director, 1937–1938
Erle V. Daveler
Director, 1929–1940; Vice President, 1940–
D. T. Day*
Vice President, 1892–1893; 1900–1901
C. F. DeLandero*
Vice President, 1902
Frederick W. Denton*
Vice President, 1908–1909; 1913–1915
A. B. DeSaulles*
Manager, 1887–1879
W. B. Devereux*
Manager, 1898–1900
A. N. Diehl*
Director, 1923–1925

E. V. D'Invilliers*
Vice President, 1894–1895; Manager, 1900–1902
J. V. N. Dorr
Director, 1918–1919
Henry S. Drinker*
Manager, 1877–1879; Vice President, 1918–1920
J. Terry Duce
Director, 1941–1944
Charles B. Dudley*
Vice President, 1880–1881
Theodore Dwight*
Director, 1906–1911; Councilor, 1906–1908
Stanly A. Easton
Director, 1919–1921
Anton Eilers*
Manager, 1875–1877, 1882–1884; Vice President, 1896–1897
S. R. Elliott
Director, 1931–1934
E. E. Ellis*
Director, 1935–1936
James O. Elton
Director, 1927–1929
T. N. Ely*
Vice President, 1882–1883
S. F. Emmons*
Vice President, 1883–1884, 1890–1901, 1902–1903
W. E. C. Eustis*
Vice President, 1897–1898
Cadwallader Evans, Jr.
Director, 1930–1933
Evan Evans
Director, 1947–
B. F. Fackenthal, Jr.*
Manager, 1887–1889; Councilor, 1907–1909
John B. Farish*
Vice President, 1908–1909
L. P. Feustman*
Vice President, 1898–1899
Milton H. Fies
Director, 1944–1947

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* Deceased.

* Deceased.

John Wellington Finch
Director, 1913–1915
Frank Firmstone*
Manager, 1873, 1884–1886, 1889–1891; Vice President, 1875–1876
F. Julius Fohs
Vice President, 1927–1929
Robert Forsyth*
Manager, 1888–1890
L. W. Francis
Director, 1920
B. W. Frazer*
Manager, 1874–1876, 1878–1880
Persifor Frazer*
Vice President, 1880–1881, 1907–1908
John Fulton*
Vice President, 1885–1886
Carroll A. Garner
Director, 1941–1945
E. Gaujot*
Manager, 1871–1872
J. L. Gillson
Director, 1947–
William Glenn*
Manager, 1899–1901
George W. Goetz*
Manager, 1892–1894; Vice President, 1901
C. W. Goodale*
Manager, 1897–1899; Director, 1916; Vice President, 1917–1919
F. L. Grammer*
Manager, 1904; Councilor, 1905–1906
J. B. Grant*
Vice President, 1906–1907
J. C. Greenway*
Director, 1921–1923
H. A. Guess*
Director, 1926–1929; Vice President, 1930–1934
James D. Hague*
Vice President, 1906–1907
M. L. Haider
Director, 1945
J. E. Hardman*
Vice President, 1901–1902
Joseph Hartshorne*
Manager, 1904. Councilor, 1905–1906

Henry F. Hebley
Director, 1946
Oswald J. Heinrich*
Manager, 1875–1877
William B. Heroy
Director, 1935–1939; Vice President, 1939–1942; Director, 1942–1945
Charles H. Herty, Jr.
Director, 1943–1946
E. G. Hill
Director, 1945
H. O. Hofman*
Manager, 1894–1896; Councilor, 1907–1909
E. A. Holbrook
Director, 1945
Levi Holbrook*
Manager, 1895–1897
H. L. Hollis*
Manager, 1892–1894
J. F. Holloway*
Vice President, 1887–1888, 1894–1895
Joseph A. Holmes*
Director, 1913–1914
A. C. Humphreys*
Councilor, 1909–1911
A. E. Hunt*
Vice President, 1888–1889
W. Spencer Hutchinson
Director, 1926–1928
W. R. Ingalls
Councilor, 1907–1909
John H. Janeway, Jr.*
Councilor, 1912; Director, 1913–1915
Hennen Jennings*
Councilor, 1912; Director, 1915–1919
Robert E. Jennings*
Councilor, 1910–1912
A. B. Jessup*
Director, 1938–1941
J. E. Johnson*
Manager, 1886–1888, 1901
J. E. Johnson, Jr.*
Director, 1917–1919
Oscar H. Johnson
Director, 1943–1946
Clemens C. Jones*
Manager, 1902–1903

* Deceased.

* Deceased.

Ira B. Joralemon
    Director, 1941–1944
Wilber Judson
    Director, 1935–1938, 1942–1945; Vice President, 1945–1946
L. W. Kempf*
    Director, 1946
J. Kennedy*
    Vice President, 1904–1905
Joseph C. Kent*
    Vice President, 1874–1876
William Kent*
    Manager, 1900–1902
W. C. Kerr*
    Vice President, 1883
W. S. Keyes*
    Manager, 1880–1882; Vice President, 1884
J. P. Kimball*
    Vice President, 1881–1882
J. C. Kinnear
    Director, 1944–1947
A. B. Kinzel
    Director, 1946–
E. B. Kirby*
    Vice President, 1912; Director, 1913–1914
Frank Klepetko*
    Manager, 1903–1904; Councilor, 1905; Director, 1905–1906
Philip Kraft
    Director, 1946–
Henry Krumb
    Vice President, 1928–1942; Director, 1942–1943
W. B. Kunhardt*
    Vice President, 1895–1896
George F. Kunz*
    Vice President, 1899–1901
Frederick Laist
    Vice President, 1920–1922
William A Lathrop*
    Vice President, 1911–1912
B. B. Lawrence*
    Manager, 1903–1904; Councilor, 1905; Vice President, 1910–1911
Robert G. Leckie*
    Vice President, 1893–1894

* Deceased.

J. H. Lee*
    Vice President, 1902–1903
Thomas H. Leggett*
    Vice President, 1913–1915
C. K. Leith
    Director, 1935–1938
J. P. Lesley*
    Manager, 1872–1874
David Levinger
    Director, 1927–1929
James F. Lewis*
    Manager, 1879–1881; Vice President, 1886–1887, 1895–1896
Waldemar Lindgren*
    Vice President, 1912–1913
B. S. Lyman*
    Manager, 1896–1898
Charles MacDonald*
    Vice President, 1882–1883, 1889–1890
James T. MacKenzie
    Director, 1939–1942
J. B. Mackintosh*
    Manager, 1891
James MacNaughton
    Vice President, 1916–1918
Birch O. Mahaffey
    Vice President, 1926–1928
John Markle*
    Vice President, 1903–1904
W. G. Mather
    Director, 1921–1923
John A. Mathews*
    Director, 1930–1933
George W. Maynard*
    Manager, 1871–1874, 1885–1886; Vice President, 1904–1905
Walter E. McCourt*
    Director, 1938–1941
Andrew S. McCreath*
    Manager, 1882–1884
Donald H. McLaughlin
    Vice President, 1945–
T. S. McNair*
    Manager, 1871; 1884
William W. Mein, Sr.
    Director, 1947–
C. A. Meissner*
    Vice President, 1926–1928

* Deceased.

Paul D. Merica
Vice President, 1932–1944

Charles W. Merrill
Director, 1914–1916; Vice President, 1924–1926

Willet G. Miller*
Councilor, 1909–1911; Director, 1917–1919

C. V. Millikan
Director, 1947–

Philip W. Moen*
Vice President, 1903–1904

D. D. Moffat
Director, 1946–

E. S. Moffat*
Manager, 1883, 1885; Vice President, 1887, 1889

Robert H. Morris
Director, 1945–

Seeley W. Mudd*
Vice President, 1920–1922; Director, 1923–1926

H. S. Munroe*
Manager, 1881–1884; Vice President, 1890–1891

Charles B. Murray*
Director, 1934–1937

James W. Neill*
Manager, 1902–1904

W. G. Neilson*
Manager, 1886–1888

J. S. Newberry*
Manager, 1876–1878

J. C. Nicholls
Director, 1945–

R. V. Norris*
Councilor, 1908–1910; Vice President, 1911–1912; Director, 1920–1926

W. J. Olcott*
Manager, 1898–1900; Councilor, 1911–1912; Director, 1913

W. N. Page*
Vice President, 1899–1900

Francis W. Paine*
Director, 1929–1932

Hugh Park
Director, 1933–1936

E. W. Parker*
Manager, 1902–1904

Russell B. Paul
Director, 1943–

John B. Pearse*
Vice President, 1877–1878

E. C. Pechin*
Manager, 1872; Vice President, 1873, 1875–1876, 1885, 1891–1892

W. M. Peirce
Director, 1937–1940; Vice President, 1940–1943

E. D. Peters, Jr.*
Vice President, 1898–1899

Richard Peters, Jr.*
Director, 1927–1929

Thomas Petherick*
Manager, 1871–1872; Vice President, 1884

William H. Pettee*
Manager, 1873, 1889–1891; Vice President, 1881–1883

William B. Plank
Director, 1946–

J. C. Platt*
Vice President, 1894–1895

J. A. Porter*
Manager, 1891–1893

E. C. Potter*
Vice President, 1899–1900

J. W. Powell*
Vice President, 1882–1883

Wallace E. Pratt
Director, 1944–1945

Fred Prime, Jr.*
Manager, 1871–1873

Raphael Pumpelly*
Manager, 1871

Howard C. Pyle
Director, 1947–

Bertram D. Quarrie
Director, 1924–1926

Oliver C. Ralston
Director, 1946

W. C. Ralston*
Vice President, 1900–1901, 1909–1910

Erskine Ramsay
Director, 1936–1938

* Deceased.

* Deceased.

J. B. Randol*
Vice President, 1900–1901
J. C. F. Randolph*
Manager, 1881–1883; Vice President, 1891–1892
Robert M. Raymond*
Director, 1917–1918; Vice President, 1918–1920
Leo F. Reinartz
Director, 1942–1945; Vice President, 1945–
Mark L. Requa*
Vice President, 1917–1919
Joseph W. Richards*
Vice President, 1910–1911; Councilor, 1912; Director, 1913–1915; Vice President, 1916–1917
Brent N. Rickard
Director, 1934–1940
Edgar Rickard
Vice President, 1929–1936
T. A. Rickard
Manager, 1894–1896; Director, 1905; Councilor, 1905–1906
Heinrich Ries
Manager, 1903–1904; Councilor, 1905
Milnor Roberts
Director, 1930–1936
Percival Roberts, Jr.*
Manager, 1880–1882; Vice President, 1889–1890
Kenneth Robertson*
Manager, 1888–1890
William F. Robertson*
Councilor, 1906–1908
C. S. Robinson*
Director, 1913
Allen H. Rogers*
Director, 1917–1919
C. M. Rolker*
Manager, 1888–1890
R. M. Roosevelt
Director, 1935–1938
Reno H. Sales
Director, 1923–1928
LeRoy Salsich
Director, 1938–1941; Vice President, 1941–1944
Albert Sauveur*
Vice President, 1910–1911
Earle E. Schumacher
Director, 1945–
W. L. Sheafer*
Manager, 1893–1895
L. A. Shipman
Director, 1945
William H. Shockley*
Councilor, 1908–1910
A. M. Shook*
Manager, 1893–1895
Frank L. Sizer*
Director, 1933–1939
Frank M. Smith*
Vice President, 1923–1925
H. DeWitt Smith
Director, 1941–1942
John C. Smock*
Manager, 1875–1877; 1891–1893
Henry L. Smyth*
Director, 1914–1916
Charles H. Snow
Manager, 1904; Councilor, 1905–1906; Director, 1905–1910
F. McM. Stanton*
Manager, 1897–1899
John Stanton*
Vice President, 1892–1893
I. A. Stearns*
Vice President, 1905–1906
T. B. Stearns*
Director, 1916–1918, 1922–1924
C. A. Stetefeldt*
Vice President, 1885–1886, 1895–1896
Ralph H. Sweetser
Vice President, 1925–1927
J. H. Swoyer*
Vice President, 1871
Wilfred Sykes
Director, 1935–1936; Vice President, 1936–1941
W. R. Symons*
Vice President, 1871–1872; Manager, 1873–1874
W. J. Taylor*
Manager, 1890–1892, 1898–1901

* Deceased.

* Deceased.

Arthur Thacher*
Director, 1918–1920
Robert W. Thomas
Director, 1944–1947; Vice President, 1947–
Samuel Thomas*
Vice President, 1879–1880
Charles O. Thompson*
Vice President, 1881–1882
Francis A. Thomson
Director, 1939–1945
Robert H. Thurston*
Vice President, 1878–1879
Joseph B. Umpleby
Director, 1932–1935
M. D. Valentine*
Manager, 1902–1904
J. R. Van Pelt, Jr.
Director, 1941–1944; Vice President, 1944–1947
C. D. Walcott*
Vice President, 1904–1905
Arthur L. Walker
Director, 1911
H. Y. Walker
Director, 1938–1944; Vice President, 1944–1945
W. R. Walker*
Director, 1919
Frank A. Wardlaw, Jr.
Director, 1940–1946
T. S. Washburn
Director, 1947–
George B. Waterhouse
Director, 1934–1940
William R. Webster*
Manager, 1895–1897

* Deceased.

Clyde E. Weed
Director, 1945–
S. T. Wellman*
Vice President, 1883–1884; Manager, 1890–1892
Eugene A. White
Director, 1945–
Charles C. Whittier
Director, 1932–1935
H. D. Wilde
Director, 1938–1941
Gardner F. Williams*
Vice President, 1911–1912
T. M. Williams*
Manager, 1871
A. Winslow*
Manager, 1899–1901
Thomas F. Witherbee*
Manager, 1876–1878
Walter C. Wood*
Councilor, 1906–1908
Felix E. Wormser
Director, 1940–1946
William Wraith
Director, 1931–1937, 1938–1941
W. E. Wrather
Director, 1921–1923, 1945–
William R. Wright
Director, 1929–1932
Edward L. Young*
Councilor, 1911–1912; Director, 1913–1914
L. E. Young
Director, 1937–1942; Vice President, 1942–1945

* Deceased.

Proceedings of Meeting and World Conference on Mineral Resources

Seventy-fifth Anniversary Celebration and World Conference on Mineral Resources

At the meeting of the Board of Directors in March 1945, plans were discussed for a special General Meeting to commemorate, in an appropriate way, the founding of the Institute at Wilkes-Barre, Pennsylvania, in 1871. It was decided that seventy-five years of growth, progress, and achievement; of service to the profession, to the mineral industry in all its branches, and to society at large should be fittingly celebrated. Harvey S. Mudd, then President of the Institute, was authorized to appoint a General Committee on Arrangements as well as necessary working committees.

On June 6, 1946, Louis S. Cates, as President, at a special meeting of the Pennsylvania-Anthracite Section at Wilkes-Barre, officially announced plans for a three-day meeting to be held at The Waldorf-Astoria, in New York City, September 16–18, 1946. Four major sessions to be addressed by eminent speakers had been planned in some detail to constitute a "World Conference on Mineral Resources." The U. S. Department of State had dispatched a 1500-word airgram to all its diplomatic posts giving worldwide publicity to the scope and importance of the meeting; and formal invitations had been issued to more than 150 institutions in 40 foreign countries to send official delegates. These included scientific and engineering societies, educational institutions, and sundry government agencies connected with the mineral industry.

However, about a month later it was found necessary to postpone the celebration. The reason was an unforeseen expansion in the requirements of the United Nations for hotel living space in New York to accommodate delegates to the meeting scheduled to start September 3; and, of course, U.N. delegates would be given priority. It was decided to postpone the Celebration-Conference to the week beginning March 17, 1947; to devote the first three days primarily to the Celebration; and to follow it with the technical sessions, committee meetings, and other functions, that are regular features of the Annual Meeting. To accommodate the combined "show" it would be necessary to hold some of the Annual Meeting sessions at another hotel;

The Waldorf-Astoria Hotel

and the Pennsylvania, in New York, was selected for the purpose. The present report will be confined, however, to the proceedings of the Celebration-Conference, all of which were held at the Waldorf-Astoria on Monday, Tuesday and Wednesday, March 17, 18 and 19, 1947.

Three thousand people, including eight hundred women, participated in the proceedings in one way or another. Twenty-five foreign countries were represented, some of them by five or six individuals (see p. 799). Likewise, official representatives were named by 50 institutions of higher learning in the United States. All of the eight main sessions and functions were held in the Grand Ballroom of the Waldorf. The principal addresses are published in full in the pages following this review, and only brief notes will appear here.

Opening Luncheon

MONDAY, MARCH 17, 1947

Louis S. Cates, as President of the Institute, opened the proceedings by welcoming the 850 guests, and reviewing briefly the history of the Institute, noting the part it had played in the industrial growth of the country and outlining the program for the Conference. He explained the reason for the unavoidable absence of the Honorable Thomas E. Dewey, Governor of New York, who was to have welcomed the visitors; and then introduced those delegates at the speakers' table "who have come a long way from overseas to be here."

He then introduced Cornelius F. Kelley, Chairman of the Anaconda Copper Mining Co., to deliver the keynote address: "Seventy-five Years of Achievement by the A.I.M.E. in the Mineral Industry." The text of Mr. Kelley's remarks is published in full starting on page 545.

World Mineral Resources

MONDAY AFTERNOON, MARCH 17, 1947

Donald H. McLaughlin, Chairman of the General Committee for the Celebration-Conference and President of the Homestake Mining Co., presided at the Monday afternoon session, his associate chairmen being William E. Wrather, Director of the United States Geological Survey, and Chester A. Fulton, Consulting Engineer. To an audience that filled the ballroom, Dr. McLaughlin emphasized the extent to which the industrial civilization of the world—"One World"—depends on metals and fuels; and promised a discussion of "the world's resources of these vital minerals by four distinguished speakers who come before you clothed with prestige and authority." The Honorable Julius A. Krug, Secretary of the Interior, spoke on "Mineral Resources of the United States"; Charles McElroy White, President of the Republic Steel Corporation, on "Iron Ore and the Steel Industry"; and Sir William Fraser, Chairman Anglo-Iranian Oil Co., Ltd., on "International Aspects of the Petroleum Industry." In the unavoidable absence of Clinton H. Crane, President of the St. Joseph Lead Co., Andrew Fletcher, Vice President of that company, read Mr. Crane's paper: "Copper, Lead and Zinc Mining in the Future."

World Mineral Economics

TUESDAY MORNING, MARCH 18, 1947

John M. Lovejoy, Past President of the Institute and President of the Seaboard Oil Co., presided at the Tuesday morning session, his associate chairmen being Eugene McAuliffe, Chairman of the Union Pacific Coal Co., and Wilfred Sykes, President of the Inland Steel Co. Mr. Lovejoy made the observation that "even if economists are often wrong, they are always interesting"; and noted that on the program, in addition to one "real" economist, were "three engineers, and engineers have no inhibitions when they get into the realm of economics."

In the absence of Peter M. Anderson, of South Africa, H. DeWitt Smith presented Mr. Anderson's paper, "The Future of Gold in the World Economy." Wilfred Sykes introduced Dr. Willard L. Thorp, who delivered his address, "not as an economist but as a representative of that branch of our government concerned with foreign policy." His subject was "Tariffs, Cartels, and the Mineral Industry."

Pedro Beltran, Mr. Lovejoy explained, had prepared his address, "Latin American Minerals in the Future World Economy," but had been prevented at the last minute from leaving Peru. The paper was not read, but it is published in full in this volume. Mr. McAuliffe, with characteristic deftness, introduced C. Augustus Carlow, of Fife, Scotland, as his "fellow countryman" and friend, and Mr. Carlow abstracted his remarkably comprehensive and scholarly paper on "Coal Resources of the World."

Second General Luncheon

TUESDAY, MARCH 18, 1947

Harvey S. Mudd, junior Past President of the Institute, presided at the Tuesday luncheon and opened the proceedings by thanking Mr. Cates in behalf of the 700 persons present for the exceedingly useful bronze souvenirs that had been distributed with the compliments of the Phelps Dodge Corporation. After introducing a number of delegates from foreign countries at the speakers' table, he asked for informal remarks from the following:

C. Augustus Carlow, who concluded by reading and handing to Mr.

Cates, as President of the Institute, a scroll bearing an official greeting from the Institution of Mining Engineers, dated in London, December 31, 1946.

Charles Camsell, who conveyed congratulations, in his usual urbane way, from the Canadian Institute of Mining and Metallurgy and from the Engineering Institute of Canada.

Manuel B. Llosa, Professor of Mining at the Escuela Nacional de Ingenieros in Peru, who represented that institution and also the Sociedad de Ingenieros del Peru.

P. Y. Hu, who represented the Ministry of Economic Affairs of the National Government of China, and the Tangshan Engineering College, Nan Yang University, Shanghai, China.

Mineral Industry and Atomic Energy

TUESDAY AFTERNOON, MARCH 18, 1947

Ira B. Joralemon, Consulting Engineer of San Francisco, presided at the session on Tuesday afternoon, with J. R. Van Pelt, Jr., of Battelle Memorial Institute, as associate chairman. Mr. Joralemon explained that he was officiating because of the absence in Europe of Fred Searls, Jr., one of the close associates of "elder statesman" Bernard Baruch, while he was head of the United States Delegation of the United Nations Atomic Commission. The three speakers were all present and each delivered his address in person: John M. Hancock, Partner, Lehman Brothers, "Control of Atomic Energy"; P. C. Keith, President, Hydrocarbon Research, Inc., "Role of Engineers in Atomic Development"; and Harry A. Winne, Vice President, General Electric Co., "Application of Atomic Energy to Industry."

Forecast of Mineral Technology

WEDNESDAY MORNING, MARCH 19, 1947

H. DeWitt Smith, Chairman of the Program Committee for the Celebration and Vice President of the Newmont Mining Corporation, presided at the Wednesday morning session, his associate chairmen being Leo F. Reinartz, Manager of Operations for the American Rolling Mill Co., and C. H. Mathewson, Professor of Metallurgy at Yale University—and, incidentally, past president of A.I.M.E.

Mr. Smith observed that many of the addresses thus far had stressed the shrinkage in resources of mineral commodities and remarked that "the most effective answer to the present inadequacy of reserves is improvement in technology, as to methods both of production and of utilization." He introduced Dr. Robert E. Wilson, who delivered his address, "Petroleum and Natural Gas—Uses and Possible Replacements."

Dr. Mathewson introduced his esteemed co-worker, Dr. Zay Jeffries, whose subject was "Metals and Alloys of the Future."

The last address was the collaborative product of Louis S. Cates and Howland Bancroft; but as each of the principals was suffering from throat ailments —minor but irritating—Donald H. McLaughlin, whose voice was unimpaired, had been drafted to abstract the manuscript, which he did with éclat. The subject was "Techniques of Mineral Exploitation of the Future."

Third General Luncheon

Wednesday, March 19, 1947

Clyde Williams, President of the Institute for 1947, and Director of Battelle Memorial Institute, presided at the Wednesday luncheon, at which there were present 650 members and guests. He first read a congratulatory telegram from Essington Lewis, Honorary Member of the Institute, and head of Australia's leading industrial organization, the Broken Hill Proprietary, Ltd.

After introducing several of the speakers on the Wednesday morning program and sundry official delegates, Mr. Williams asked for informal remarks from the following:

Jean M. Goguel of France, Professor at the École Nationale Supérieure des Mines de Paris, who in addition to representing that institution, represented officially the Société Géologique de France.

K. L. Hj. Nylander, Consul General for Sweden in New York, who, as representative for the Royal Board of Trade in Stockholm, spoke appreciatively in behalf of several other organizations in his country that had designated other official delegates.

S. A. Falconer, delegate from the University of British Columbia—Canada's youngest university—who read a formal message of greeting, dated in Vancouver on February 24, 1947, and presented a scroll to Mr. Cates, as President of the Institute.

Jenaro Gonzalez Reina, of Mexico City, who spoke in behalf of the Department of Mineral Resources (Mexico) and the Instituto de Geológia.

Before adjourning the luncheon, Mr. Williams thanked the speakers from other countries, including those on earlier programs, for their expressions of friendship to the United States and asked them, on their return home, to convey to their respective institutions assurances that this friendship was warmly reciprocated. He complimented the speakers at the four major sessions and commended highly those who had planned and organized the Celebration-Conference.

75th A.I.M.E. Anniversary Banquet

WEDNESDAY EVENING, MARCH 19, 1947

Both the first and second balconies of the Waldorf Ballroom were required to seat the overflow of 1450 diners at the climactic event: the Anniversary Banquet on Wednesday evening. As at the other formal functions, the official delegates to the Celebration and the Local Section delegates were guests of the Institute. One variation from the usual program at Annual Meeting banquets was the omission of a ball following the post-prandial proceedings. This arrangement provided time for the unhurried presentation of medals and awards and the delivery of special addresses by the Hon. Spruille Braden, U. S. Assistant Secretary of State, and Virgil Jordan. The Honorable Herbert Hoover had expected to be present but was prevented by urgent business in Washington, following an important official mission in Europe from which he had only recently returned. He sent the following telegram, which was read by the presiding officer, Mr. Cates:

> *I greatly regret that a call to Washington on important matters prevents my attendance at the Annual Dinner of my fellow engineers. I had hoped to convey again the transcendent importance of the engineering profession in these times when the world so critically needs production and more production. That is the engineer's function, and it underlies our hopes not only of economic reconstruction but of world peace. I trust you will extend my greetings and my regrets to your colleagues.*

In other respects the proceedings, guided by the firm hand of President Cates, followed the program exactly as scheduled and as set forth in the following pages.

Program

SEVENTY-FIFTH A.I.M.E. ANNIVERSARY BANQUET
At the Waldorf-Astoria, New York
March 19, 1947

LOUIS SHATTUCK CATES
Chairman and Toastmaster
President of the Institute for 1946

Presentation of the J. E. Johnson, Jr. Award
To KURT NEUSTAETTER

Presentation of the Anthony F. Lucas Medal
To WILLIAM NOBLE LACEY

Presentation of the William Saunders Medal
To LEROY SALSICH

Presentation of the Insignia of the Legion of Honor
To MEMBERS OF THE CLASS OF 1897

Presentation of the Robert W. Hunt Medal
To HARRY K. IHRIG

Presentation of Certificates of Honorary Membership
To CHARLES CAMSELL CECIL H. DESCH
C. AUGUSTUS CARLOW SIR WILLIAM FRASER

Presentation of the Rossiter W. Raymond Award
To WILLIAM A. JOHNSON

Presentation of the Charles F. Rand Medal
To GEORGE MAGOFFIN HUMPHREY

Address by THE HONORABLE SPRUILLE BRADEN

Address by VIRGIL JORDAN

Message from the HONORABLE HERBERT HOOVER

Induction of CLYDE WILLIAMS as President of the Institute for 1947

Speakers Table

FRONT TABLE *Left to Right from the Audience*

CHAMPION HERBERT MATHEWSON
Past President of the Institute, Marshal for the Banquet

HOWARD N. EAVENSON
Past President of the Institute

R. R. SAYERS
Director of the United States Bureau of Mines

CHESTER ALAN FULTON
Past President of the Institute

HENRY KRUMB
Honorary Member of the Institute

ZAY JEFFRIES
Anniversary Speaker

HOWARD I. YOUNG
President of the American Mining Congress

EUGENE W. O'BRIEN
President of the American Society of Mechanical Engineers

R. M. ATWATER, JR. HERMAN A. PROSSER
H. FOSTER BAIN BRADLEY STOUGHTON
Members of the Legion of Honor—Class of 1897

HERBERT G. MOULTON
Past President of the Institute

WILLIAM O. HOTCHKISS
President of the Society of Economic Geologists

HARRY A. WINNE
Anniversary Speaker

P. C. KEITH
Anniversary Speaker

WILLIAM EMBRY WRATHER
Director of the United States Geological Survey

DONALD B. GILLIES
Past President of the Institute, Marshal for the Banquet

Speakers Table

REAR TABLE *Left to Right from the Audience*

SCOTT TURNER
Past President of the Institute, Marshal for the Banquet

ROBERT E. WILSON
Anniversary Speaker

WILLIAM NOBLE LACEY
Anthony F. Lucas Petroleum Medalist for 1947

KURT NEUSTAETTER
Recipient of the J. E. Johnson, Jr. Award for 1947

CHARLES CAMSELL
New Honorary Member of the Institute
President of the Canadian Institute of Mining and Metallurgy

SIR WILLIAM FRASER
New Honorary Member of the Institute, Anniversary Speaker

CORNELIUS F. KELLEY
Anniversary Speaker

VIRGIL JORDAN
Anniversary Banquet Speaker

GEORGE MAGOFFIN HUMPHREY
Charles F. Rand Memorial Medalist for 1947

LOUIS SHATTUCK CATES
President of the Institute for 1946

CLYDE WILLIAMS
President of the Institute for 1947

LEROY SALSICH
William Lawrence Saunders Mining Medalist for 1947

THE HONORABLE SPRUILLE BRADEN
Assistant Secretary of State, Anniversary Banquet Speaker

WILLIAM A. JOHNSON
Recipient of the Rossiter W. Raymond Memorial Award for 1947

C. AUGUSTUS CARLOW
New Honorary Member of the Institute, Anniversary Speaker

HARVEY S. MUDD
Past President of the Institute

CECIL H. DESCH
New Honorary Member of the Institute

HARRY K. IHRIG
Robert W. Hunt Medalist for 1947

EUGENE McAULIFFE
Past President of the Institute, Marshal for the Banquet

Social Events of the Celebration-Conference

Following adjournment of the Monday afternoon session on World Mineral Resources, all and sundry were invited to a complimentary cocktail party sponsored by the General Committee on Arrangements under the chairmanship of M. Butler Gentry. Virtually all the room on the Waldorf's spacious ballroom floor (except the ballroom itself) was crowded, thereby indicating that the invitation was accepted with alacrity.

In the meantime, the ballroom was being converted to accommodate a fashion show sponsored by the Woman's Auxiliary. Jinx Falkenberg and Tex McCrary, of current radio fame, acted jointly as masters of ceremony, and a dozen models—all tall, slender, and beauteous—acted as manikins for a succession of gorgeous costumes that ran from bathing suits to fur coats. Though dependable statistics are not at hand, it appeared that the men in the audience, strangely enough, outnumbered the women by a wide margin! At any rate, the ballroom was crowded and the performance was a huge success. A bow to the Woman's Auxiliary!

After an interlude of a couple of hours for dinner and a change to formal clothes, members and guests again congregated in the ballroom for the President's reception, followed by dancing, a midnight supper, and still more dancing, to the small hours of Tuesday morning.

The next day, Tuesday, from 5 to 7 p.m. was devoted to a special reception to the A.I.M.E. group at the American Museum of Natural History. Among the exhibits that attracted particular attention were the mineral collection, said to be one of the finest in the world. Ores from mines long exhausted were of special interest to many, as was the collection of gems and precious stones. Refreshments were served before the visitors left the Museum.

The Woman's Auxiliary, with notable resourcefulness and foresight, had acquired some months in advance more than 300 tickets to choice shows, and many of the ladies—and some husbands—spent Tuesday evening at the theater.

Meanwhile 200 official delegates and guests joined the Directors and the Section Delegates at the University Club, where dinner was followed by a business meeting for the organization of the new Board of Directors, at which Clyde Williams functioned as President for the first time and Louis Cates sat on the side lines.

Contributing in no small measure to the success of the Celebration was a special Anniversary Fund of substantial proportions that was donated, thanks to Cleveland Dodge, by corporations engaged in all branches of the mineral industry. The social program was subsidized from this fund; the delegates were supplied with complimentary tickets to official functions through it;

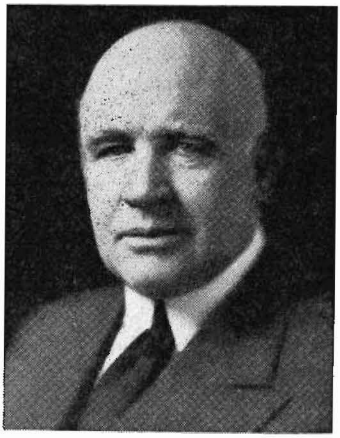
and the publication of this Anniversary Volume is made possible by an appropriation from the Fund.

Six corporations, prompted by James L. Head, secretary of the Committees on Arrangements, supplied attractive and useful souvenirs for complimentary distribution at various functions. Those attending the opening luncheon were given a set of four bronze coasters, embellished with the seal of the Institute, through the generosity of the Anaconda Copper Mining Co. At the supper dance on Monday the ladies were presented with a case containing a nail file of Inconel metal and a comb trimmed with that same excellent metal, and the gentlemen, a pocket knife of Inconel, all with the compliments, as one might guess, of the International Nickel Co. The souvenir at the Tuesday luncheon was a handsome bottle opener of bronze—large enough and strong enough to last forever—with the compliments of the Phelps Dodge Corporation. Stainless-steel ash trays contributed by the Eastern Stainless Steel Co. were distributed at the Wednesday luncheon.The Banquet programs on Wednesday evening were attractively bound in aluminum-coated covers supplied by the Aluminum Company of America, and each diner was presented with a heavy bronze letter opener with the compliments of the Ingersoll-Rand Co. The latter, like the A.I.M.E., was founded in 1871 and consequently the handsome souvenir was doubly appropriate.

Most of the burden of time and energy expended in planning and organizing the Celebration and in executing the plans fell to some 16 special committees appointed early in 1946; and to the Ladies Entertainment Committee. The roster of these committees is published on page 804 as a significant part of the record. A.B.P.

Seventy-five Years of Achievement by the A.I.M.E. in the Mineral Industry

By Cornelius F. Kelley



CORNELIUS F. KELLEY

Born near Eureka, one of Nevada's famous mining camps, where his father was a mine superintendent, Cornelius F. Kelley has a mining background. After an apprenticeship as a surveyor for the Anaconda Copper Mining Company at Butte, he studied law at Michigan. Upon graduation in 1901 *he entered Anaconda's legal department. He is now Chairman of the Anaconda board and is a dominant figure in the group of associated companies, including the Andes Copper Mining Company, Chile Copper Company, American Brass Company, and others.*

SEVENTY-FIVE years ago, in Wilkes-Barre, Pennsylvania, 22 men of vision banded together to initiate this great organization. Ideals and emotions mingled and united in the declaration of a twofold purpose: first, the more economic production of minerals and metals, and second, the promotion of greater safety and welfare for each man so employed—tacit recognition of the inseparability of humanitarian and utilitarian concepts of world progress.

The members and honorary members then, as now, were mining engineers and associates from allied walks of life. Under the able guidance of David Thomas, our first president and outstanding ironmaster of the time, there were elected 46 members and associates, and the foundations of the Institute were laid.

Conceived in a turbulent postwar era, the problems then faced had some similarity to those we face in this time of war-bashed uncertainty. With a Civil War behind them and once again dedicated to a spirit of national endeavor, they surveyed the landscape, then surged ahead toward a beckoning industrial horizon. That effort has never been relaxed.

Poised upon the threshold of a new century, rancher, banker, engineer and businessman paused to contemplate and evaluate his natural endowments. Surrounded by immeasurable God-given wealth, necessity inspired his inventive genius, and determination to succeed resulted in the miracle that transpired. Steadfastly he set about to erase obstacles. Railroads laboriously followed the covered wagon to the West; merchantmen hoisted their flags and sailed the seven seas to develop world markets. Geographically and geologically, knowledge in its practical application was advanced. The simply fashioned tools, manipulated first by hand, grew in complexity and utility as we drew heavily upon a regular pattern of mechanical progress which never failed. We became good merchants, for our products sold around the civilized world.

Thus, when in 1897, Thomas M. Drown convened the meeting that marked the twenty-fifth year of the Institute, he found himself surrounded by a group of engineers, all pioneers in their own fields, whose names have gone down in the annals of industrial and mineral development, not only of this country but wherever the story of mining is known. James Douglas, Waldemar W. Lindgren, Robert H. Richards, James F. Kemp, James Clark, Jr., J. D. Silliman, Henry S. Morrow and Roland D. Irving are but a few of the then 2500 members who, aided by personal contacts and friendships formed by Institute associations, were able to accomplish the gigantic tasks that had faced them.

Copper as Index of Accomplishment

What were those accomplishments? May we be permitted to use copper as an index, for experience has shown there is no better one for basic activity?

The completion of the rail link between the East and West had opened the Rocky Mountain area to mineral development. Theretofore, Calumet and Hecla were producing the greater part of the country's output of copper from rich native copper ores at costs per pound not too far out of line with costs in the middle '30s. Montana's placers, rich in gold in the '60s, led to silver mining in the early '70s, and the extraordinary copper strikes of '81 and '82. Bisbee, with its oxidized silver-copper ores, was gradually assuming prominence in the Southwest. These early developments possessed one economic fact in common. The mines had to be practically self-sustaining from the grass roots, with the extent of day to day development dependent upon the proceeds of metals recovered. The mines developed soundly on this basis. Although faced with aggressive prices slashing to 10 cents in 1886, the Butte operations produced more copper during the following year than all of Michigan combined. High-grade native copper bowed to the inevitable, with mining cost-price relationships taking on new significance in the West.

Mining techniques were improved. Square-set timbering replaced open stopes; mechanized pumps enabled shafts to be sunk below water level;

adequate mine ventilation became a necessity; compressed-air drills succeeded the single jack and double hammer and hand-turned drill; dynamite replaced black powder; and the miner became a craftsman, adept at selective mining, under the guidance of cost-conscious engineers.

Contemporaneously, as the changes in technique were being realized underground, improved milling practice late in the century made possible mass mining through mill selection of ores rather than tedious and costly miner-sorting at the source. Great savings in costs were effected through the increased volume of lower grade ores handled, no doubt planting the seed for the age of large-scale production yet to come.

This triumph of technical progress was repeated again and again in practically every industrial endeavor through this peace-blessed era. The role of the engineer was established through sheer necessity. Results became the measuring stick of progress.

Markets for the copper fabricators, grouped in the Naugatuck Valley in Connecticut, were limited in 1872 to manufacturers of clocks, oil lamps, pins, household utensils and cartridge cases, and they consumed an overall production of 14,000 tons of copper that year. It is important to note that the father-to-son knowledge of the foundrymen and pot casters was at this time a controlling factor in the production of fabricated materials of brass and copper. This century-old custom soon gave way to technical control as the infant electrical industry began to assert itself, and the application of electrical energy to innumerable domestic and industrial uses gave birth to the modern copper-fabricating industry. The electrical industry, which quickly found in copper the basically indispensable properties it required, was almost entirely responsible for a production increase to 247,000 tons by 1897, a seventeen-fold increase over the year 1872 and a true measure of industrial advancement in these 25 years.

Growth of Industrial Era

The nineteenth century may be considered to have initiated the industrial era. The twentieth century was to witness the amazing increase of its industrial growth. Organization and integration heralded mass-production techniques. A changed outlook on capital investment, preliminary financing, coordination and cooperation—all possibly dreamed of by the 22 visionaries in 1871—were molding contemporary necessities from early twentieth-century luxuries.

It has been said that "the best single measure of an industry's growth is the advance in its physical output." At the turn of the century, the automobile industry came into its own with rapidly increasing demands for copper, lead, zinc, steel, oil and gasoline. The petroleum industry, led by such brilliant engineers as Walter Teagle and Everette de Golyer, prospered with the automobile. The transition from kerosene for lamps and oil for lubrication to an unprecedented demand for gasoline required a versatility of action by the industry that was met in every respect. The rapid location of new oil reserves may well have set a pattern for the development of metal reserves in the years to come. The ironmasters, John Fritz, Robert W. Hunt and Henry M. Howe, also faced with an unexpected demand for steel for car and truck chassis, met this new demand with rapid integration of mine production and plant expansion.

During this same period, the electrical industry increased its output fortyfold. It is interesting to note that because of this growing demand between the years 1900 and 1910 as much copper was produced as in the last half of the preceding century.

This constantly increasing demand for copper naturally led to the exploitation of the low-grade porphyries of the West, long before known but hitherto impractical to develop. The method of mining adopted, when later combined with the flotation process of concentration, inaugurated what might be termed a practical revolution in mass-production techniques. Widely recognized are the contributions of such men as D. C. Jackling and L. D. Ricketts—unceasing in their efforts toward production in bulk of low-grade ores. Simultaneously the Mesabi iron-ore range embraced new and similar mining practices to keep pace with steel requirements.

How forcibly was World War I to illustrate a nation's dependence upon mineral sufficiency! The by-products of war, while they cannot temper or justify the accompanying disasters, record at least material advancement. National ingenuity, having been taxed to the utmost, rebounded with energetic zest to a peacetime application of strategic war lessons. Radio, the airplane, automobiles, talking pictures, were perfected and assembled by the thousands. Distinguished A.I.M.E. past presidents—Edwin Ludlow, Eugene McAuliffe—we proudly associate with those tremendous years.

Perhaps few of those who met with Colonel Arthur S. Dwight at the Institute session in 1922 realized that 25 years later we should be contemplating the future of a war-ravished world—resolved as we then were that such misery and suffering should never again be the fate of humanity.

What costly lessons have been brought before us in this last quarter century, and at what a price! We have tasted the fruits of uninhibited prosperity. Our profession met the challenge of as diversified a peacetime demand for goods and services as a people's imagination could conjure—and just as surely suffered bitterly in the depression years that followed. Here, another type of ingenuity was called forth—that of providing the barest livelihood for the mass of our employees. I am proud to say that our profession performed as splendidly in adversity as in the preceding prosperity. These were the deeds of a free economy so well personified by our distinguished fellow member and past president of the United States, Herbert Hoover. We must all agree that his strength of will and economic foresight proved a source of constant inspiration to us through the enterprise-stifling, controlled-thinking decade of the '30s.

A resounding tribute to the forthright soundness and direction of our engineering and industrial leaders was the victorious conclusion of World War II—a contest between the technological abilities of ourselves and of our enemies; abilities worthless without the aid of mineral resources—quartz crystal, zirconium, beryllium, industrial diamonds, the base metals—a veritable foundation to the pyramid of better production.

In this consideration let us not forget the real assistance of our neighbors to the north and the south. Without their mineral resources, the fate of our hemisphere would probably be different from what today we hope it will be. An indispensable factor to our success was the mastery that had been attained in the mass production of low-grade ores, for a quick glance at production statistics shows a steady decline in grade of copper in the ores beneficiated over the years, from 10 per cent copper in 1890 to 0.94 per cent copper in 1944. What better proof of mining and metallurgical achievement, though geared to war, could we have than this?

Modern Economics

But we, as producers and consumers of metals now for the peacetime markets, must be mindful of the ever-present cost-price ratio and of the serious consideration that this factor must be given in the light of a free economy, if we are to achieve normally that much sought after balance between production and demand.

How different the economics of mining today! Compare the self-sustaining mine of 75 years ago with the tremendous initial investment required for the opening of a new property in 1947. Progress? Seventy-five years of achievement! Achievements measured by real accomplishment! Here are a few.

Between 1870 and 1943, the banner year in metal production, the United States magnified her production of copper 76 times, of lead 24 times and of zinc 137 times. Production of iron ore increased 29 times, of coal, 18 times; while oil production increased 285 times. Apply this pattern of progress the world over—Rhodesia, the Congo, Chile—achievement knows no boundary. This is Measurable Economic Strength!

Factors in Successful Engineering

In recounting the achievements of this organization, it would be an unpardonable omission did we not pay tribute to our sister organization, the Woman's Auxiliary. In the development of the economic strength to which we have referred, it should never be forgotten that wherever mining camps have been established and engineers located, they were accompanied by the loyal and steadfast helpmates who shared their hardships and faced with courage the vicissitudes of a pioneer engineer's life. Ladies, we salute you!

It is fitting that we should have as Chairman here today, and as President of the organization, Mr. Louis S. Cates, who played an important part in the pioneering of the mass production of metals to which we have referred, and whose career encompassed not only that of a fine engineer but of a successful operator and industrialist as well.

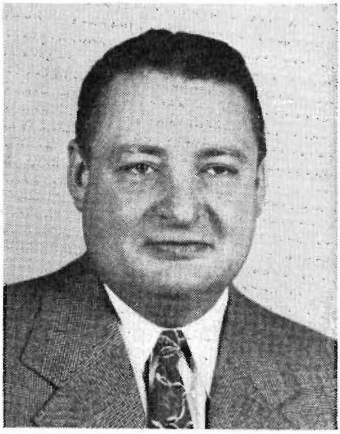
It is also, I believe, fitting and symbolic to have our President-elect, Mr. Clyde Williams, ready to take over the helm for the all-important first lap of the Institute's voyage into the uncharted future.

Fellow members, here is to the continuing fulfillment of the miner's dream! His faith, hope and vision are indelibly inscribed upon the pages of our history. It is a great heritage that has come to us, and one that we hope our successors will continue to fulfill.

The Mineral Position of the United States

By J. A. Krug

In the field of mineral resources, today's problems and those we can reasonably expect in the future are so vast that nothing less than world-wide thinking and world-wide planning will suffice. I can imagine nothing more useful for the Institute to do in celebration of its seventy-fifth anniversary than to hold this conference on world mineral resources.



JULIUS ALBERT KRUG

Ten years in responsible public service preceded Mr. Krug's appointment as Secretary of the Interior. He was with the Federal Communications Commission, and the Tennessee Valley Authority as chief engineer and manager of power. In 1941, he was appointed to the War Production Board; and in 1944 became chairman. Although not an authority on minerals at first hand, he has access to the best thinking in the U. S. Bureau of Mines and the U. S. Geological Survey.

Mineral resources are the basis of any nation's industrial production. Without expanding industrial production, the high standard of living found in the United States could not exist. Without such a standard of living it would be most unlikely that we should have a high level of culture. The hope of the world, as I see it, depends very largely on a general rise in living standards everywhere, and in the general increase of the levels of culture including a sympathetic understanding of the problems of other nations. For this reason, the proper use of the world's remaining mineral resources must be taken into account in any plans to safeguard the peace of the world.

Being as exasperatingly human as human beings always seem to be, we usually wait until almost too late to begin our plans to stave off an impending disaster. We do this as individuals, as components of particular States or Governments, and as citizens of the world. We waited, if not too late, certainly a very long time in getting started on the job of world-wide conservation of mineral resources, a job that, whether we like the prospect or not, must be done.

Whether we like it or not, we are standing on the threshold of a new world. All of us hope that the phrase "new world" will have the adjective "brave" before it, but brave or not, it will be a changed world. Perhaps I should say, it *is* a changed world.

In less than a dozen months, we have witnessed a revolutionary change in the colonial system of the world, a change that will substantially affect the mineral industries, as it will other industries. We have seen hundreds of millions of peoples assert their right to be free, and either obtain it or move much nearer that goal than in many years of their history. The colonial system, based largely on the desire of industrial nations for cheap raw materials, which in most cases meant a desire for cheap labor, and based on a desire for protected export markets, may not soon be as dead as a dodo, but surely in the lifetime of those present will become as rare as the whooping crane. I think that, rather soon, we shall see the time when no significant community of people in the world will be living as colonials.

With greater freedom will inevitably come demands on the part of these former colonials for a greater participation in the profits derived from the exploitation of their natural resources and their labor. They will demand, and sooner or later they will get, suitable industry of their own with which to lift their standard of living. This is bound to create greater pressure on the remaining mineral resources of the world, while at the same time creating new markets and stimulating world trade.

Effect of Atomic Fission

I cite that as an example of the changes that have taken place since the conclusion of the war and of which we have not all taken full account. There is another instance of change in the world mineral picture. Even with all its fame—or notoriety, whichever you prefer—I am not sure we have yet digested the effect of the discovery of controlled atomic fission. The future use of uranium-bearing ores, no matter where they are found—and I think we may take it for granted that a good many people are searching for them—is of deep concern not only to statesmen, and the members of the engineering profession, but to everyone sufficiently civilized to understand the potentialities of atomic energy. We should probably be concerned as well with fissionable materials other than uranium, and with presently nonfissionable materials which may be made fissionable by the physicist and the chemist.

Can the world achieve control for peaceful means of these fateful minerals? Certainly we shall not answer that question without getting our minds above the immediate horizon and letting them look to the highest and best answer for the welfare of mankind.

Equitable Distribution of Raw Materials Part of World Economy

This may seem to be a strange beginning for a speech entitled "The Mineral Position of the United States," but I do not think it is. As richly endowed with minerals as the people of this country have been, and are, we have clearly come to the point where, willy-nilly, we must seek outside sources for an increasingly important group of minerals. These minerals are essential to our industry and therefore essential to our power as a stabilizing force in the world. From a more selfish point of view they are essential to our standard of living. Neither the United States nor any other nation that is, or hopes to be, industrialized can long remain isolationist, either economically or politically. We have all become citizens of the world, and we must think and plan as citizens of the world.

In the United States, as in many other nations, we are faced with difficult problems in properly adjusting our mineral, agricultural, and industrial economy to the dislocations of the war and of the strongly nationalistic tendencies of the past few decades. The experience of our generation has shown all too plainly that the peoples of the world cannot live in peace without an equitable distribution of raw materials and that every nation must consider its economy as part of the world's economy.

In the past 40 years of great industrial expansion, the world has spent more of its mineral wealth than in all preceding history. During this period of industrial expansion, we have gained a fairly clear idea of the volume and geographic distribution of the world's mineral resources. It is evident that because of the world's need for further industrial expansion and for the rebuilding of devastated regions, competition will again become extreme in a struggle for the control of these mineral resources. The methods of world political and economic reconstruction *must* be successfully adjusted to alleviate this situation.

The problems are immensely complicated. The world's assets of minerals are not equitably distributed in accordance with political boundaries. In the United States the resources of many of the more important industrial minerals and metals, in proportion to population needs, were originally from three to eight times those known in all of the rest of the world together. This situation has changed. With our rapid expansion in population, and with industrialization, our mineral assets have been consumed at an extraordinary rate. The difference between our present position with respect to many mineral resources and that of other nations is not great, although the world's known supplies of some of these resources may outlast our own for a few decades, because of our greater rate of consumption.

The nations of the world have tried various methods of international control to ensure an adequate flow of minerals in world trade. As yet none of these trials has proved really effective. Attempts to become self-sufficient have invariably failed, whether in time of war or peace. The diversity in kind and distribution of valuable mineral commodities is such that all nations, even the most favored, can profitably engage in trade in them. Political and commercial arrangements to accomplish these ends may involve complex factors such as trade barriers, world monopolies, cartels, and trade agreements between different nations. Whether or not a successful international solution to these perplexing problems can be found in the critical years ahead remains to be seen. The first steps must necessarily depend upon our knowledge of the present world mineral situation.

Mineral Resources of United States

It is my main purpose today to discuss the mineral resources situation of the United States. I want also to outline the measures by which the Interior Department hopes to meet the Government's obligations in promoting the welfare of the domestic mineral industry. Industry and Government, working together, can develop a sound domestic and foreign economic policy which will ensure an adequate supply of all minerals essential to our Nation's peacetime growth and future security.

If governments, like private corporations or even individuals, are to look ahead and plan wisely, they must have at hand a fair appraisal of their material resources and their capacity to produce goods. Even in peacetime many internal problems such as the imposition or removal of tariffs, and many external problems, such as those involved in reciprocal trade treaties, can be solved wisely only if dependable information is available concerning the distribution, extent and grade of domestic resources.

Industrial expansion based upon the scientific and technical achievements of the past 30 years has demonstrated that our mineral resources are exhaustible in a very real sense. Their rapid depletion liquidates the very basis upon which this country's industrial and military might is supported. Their depletion, therefore, is a matter of national concern.

The fact that our mineral resources are not as extensive as popularly believed, and that certain extremely critical minerals are not found in ore deposits in this country, was evident at the time of the First World War. But it was not until the advent of World War II, when the threat of cessation of foreign supplies became acute, that the true situation was vividly impressed upon us. During the past few years it has become increasingly obvious that for the first time in our history our demand for many minerals and metals exceeds our supply, and that the rate of mineral discovery in the United States is being exceeded by the rate of depletion.

Before World War II the possibility of shortages of petroleum, metals and metal-bearing ores was regarded, at least by most Americans, as a matter of academic rather than practical concern. Then came the feverish search both at home and abroad during the war, and the many strict controls on production and distribution that were necessary to ensure proper availability to run our industrial war machine. These made it evident that even the United States, though it contains perhaps the best endowed area of the earth within its continental borders, still lacks many mineral resources vital to its economy, and has abundant supplies of only a few.

Production of many of our minerals has not been matched by discovery for a number of decades. In fact, relatively few metallic ore discoveries of major importance have been made in the past 40 years. Almost without exception the deposits now being worked in our principal metal-mining districts were known, even if not fully appreciated, at the beginning of the century, and for all their traditional importance and size, we have at last come to realize that they are exhaustible.

The tradition of fabulous and inexhaustible mineral deposits merely awaiting discovery and development is so firmly rooted in American thinking that this change in view is extremely painful to many. However, the facts of the situation must be faced. There is little doubt among the well informed that the era of plenty has rapidly given way to an era of insufficiency. I hesitate to use the term deficiency, or concede defeat by the more extreme designation that we have become a "have-not" nation, before a complete and exhaustive inventory is taken of our national wealth.

CATEGORIES OF MINERAL SUPPLIES IN U. S.

Before considering the policies that might best be followed to meet the shortage of ores that sooner or later will almost inevitably occur, it may be well to review briefly the present known status of our mineral resources. In anticipation of a preliminary mineral inventory, and without becoming involved in a controversy regarding individual metals or minerals, it is clear that our mineral supplies fall into three categories: (1) those that are available in abundance; (2) those that are lacking entirely, (3) those that have been abundant, but now are becoming depleted.

The first group includes those metals or minerals that are sufficiently abundant to supply all possible needs. Magnesium, nitrogen, bituminous coal and lignite, rock salt, phosphate rock, and molybdenum are included in this group. Possibly iron and aluminum should also be included because, although high-grade iron and bauxite deposits may become exhausted, these elements are sufficiently abundant in the earth's crust, or in low-grade deposits, to be available through metallurgical improvements at only slightly higher cost.

In the second, or "have-not," group are tin, nickel, platinum, industrial diamonds, flake graphite and quartz crystals. Unfortunately, sizable economic deposits of these materials have not yet been found in the United States, and it has always been necessary for us to look abroad for our industrial supplies. Of course, there is no basis for apprehension that deposits of these will not be found in the United States, and it would be unwise to adopt a defeatist attitude concerning any one of them. In this connection it is well to recall the history of American potash development, which is probably familiar to you all. During and prior to World War I, the American supply came from Germany, and there were no known economic deposits within our borders. As a result of drilling and exploration in the Southwest following World War I, we now have an adequate supply of this important substance.

The third, or depleted, group includes a large number of metals and minerals which have been found in varying degrees of abundance and which are being produced at an accelerating rate. Copper, lead, zinc, antimony, tungsten, manganese, vanadium, chromium, mercury, gold, silver, fluorspar and bauxite are a few of the items in this large group. Petroleum might likewise be included. It is around this group that most of the controversy centers—as to whether we are a "have" or a "have-not" nation.

Known ores, available under present economic and technical conditions, have been mined at an unequaled rate during the past six years. Also, mine development, exploration and discovery of new ore bodies and even oil fields, have failed to replace depleted reserves. Present reserves of many metals and minerals *are* critically low, but it remains to be seen whether or not this condition is permanent. To meet this situation we must take united action along two lines: first of all, serious detailed study should be made to determine the extent of our natural resources. Then, steps should be taken to improve the situation. To a large extent the present apparent decrease in ore reserves is due not so much to the high rate of depletion as to the postponement of exploration and development work, the shortage of equipment and labor, and to numerous operating problems.

POLICIES INDICATED

In order to meet the shortage of ores that has necessarily occurred, it seems to me that three policies are indicated:

1. A more intensive and extensive search for minerals within our own

borders and a corresponding effort to improve our mining, producing, and refining techniques.

2. The acquisition from outside sources of such metals and minerals as we lack. Through mutually favorable trade agreements, foreign countries will be provided with much needed American dollars or American-manufactured goods, and we will obtain the tin, industrial diamonds, nickel and other commodities necessary for our economy. It may be desirable to export some of our more abundant mineral supplies, such as coal, phosphates, and molybdenum, in return for those that are needed for our industrial machine.

3. The accumulation of properly safeguarded stock piles of ores, concentrates or metals by import; or preferably, and if economically feasible, by purchases from domestic mines.

Aside from economic and political considerations, two important technical factors, which I have already mentioned, can and will go a long way toward ameliorating our insufficient supply. The first of these is continuation of improvement in producing, refining, and metallurgical techniques. More efficient, lower-cost, producing methods are continually being developed, and there is no evidence of thought stagnation in this sphere. Improvements in metallurgy and mining undoubtedly have added more tonnage to our nonferrous metal ore reserves since 1900 than has any other line of endeavor.

The second technical factor in the ore-reserve picture is the increased and improved use of scientific techniques in the intensive search for ore. The time of easy discovery of ore has passed; although undoubtedly some new ore bodies will be found by further applications of the old methods and tools that have been used for exploration. But the discovery of new districts and, to a considerable extent, the discovery of *major* new ore bodies in the environs of old districts, will, in my opinion, require the utmost use of the sciences of geology and geophysics. The war provided us with a spectacular demonstration of the value of an intelligent and intensive concentration of science on the problems of warfare. I am convinced that a similar application to the field of ore finding will be equally successful.

I am impressed with the magnitude of the job facing us. The single task of appraising the mineral resources of the United States, for example, is staggering in its ramifications. When one considers the many thousands of mineral deposits—ranging from gold and silver to fluorspar and phosphate rock—and the many hundreds of oil and gas pools, one cannot help but be overwhelmed by the tremendous detail and the immensity of the problems involved. It would be a real contribution to the national welfare if, in the major mineral industries, the operators periodically assembled the data necessary to determine the known or proved national reserves of their respective commodities and made these data available in a manner similar to the practice of the American Petroleum Institute and the American Gas Association.

Policy of Department of Interior

In conclusion, I would like to emphasize that the general policy of the Department of the Interior is to assure a healthy domestic mining industry. Opinions may vary as to exactly what steps should be taken to get the best results, and what policies should be followed concerning tariffs, prices, labor problems, tax laws, and financing regulations; but so far as this Department is concerned, I am satisfied that our greatest responsibility and opportunity for service to the mineral industry is to continue our fact-finding and research functions. We hope to expand our facilities for appropriate research, fact finding and interpretation, so that private industry will have access to the basic information it needs for following through with discovery and commercial development. I believe that Government has a large and continuing responsibility in these fields, but it must be apparent that the greater part of the job must still be done by industry itself—working in a free economy.

Iron Ore and the Steel Industry

By C. M. White

CHARLES MC ELROY WHITE

As President of the Republic Steel Corporation, Mr. White ranks as one of America's leading steel executives. Educated as a mechanical engineer, he entered the industry in 1913 as a millwright's helper for the American Bridge Company. Later, he joined the Jones and Laughlin Steel Corporation, and went to Republic in 1930. In 1937 Mr. White was awarded the medal of the American Iron and Steel Institute for distinguished service to the industry.

It is indeed an honor to have been asked to participate in the program which celebrates the seventy-fifth birthday of the American Institute of Mining and Metallurgical Engineers.

This great organization has occupied an important place in the professional and industrial life of this country—of the world. Its members have explored the far reaches of our globe and have played a great part in the discovery, extraction and utilization of the mineral resources upon which our civilization so largely depends. These engineers, together with the restless prospectors, on the one hand, and the scientists, on the other, have literally been the advance scouts of our modern way of life. As such, we owe them a deep and lasting debt of gratitude.

May I, therefore, wish many happy returns to the American Institute of Mining and Metallurgical Engineers and express the hope that it may long continue to be of great service, as it has been in the past.

The subject assigned to me—Iron Ore and the Steel Industry—is, indeed, important, as one considers the future of our world. I shall give as few figures as possible. Pertinent statistical data are included in the tables in this chapter, which, I think, will prove interesting. Many studies of iron-ore reserves have been published and are available; hence I shall limit myself mainly to an interpretation of these figures.

The statistics data are from standard sources, including the Lake Superior Iron Ore Association, the American Iron and Steel Institute, the United States Bureau of Mines, the United States Geological Survey, the United

States Tariff Commission, and the Mines Experimental Station of Minnesota; and from other sources named in the appended tables.

I wish also to give credit for ideas incorporated in this talk, for the assembly and the interpretation of figures, and for other information, to D. B. Gillies, W. O. Hotchkiss, M. D. Harbaugh, R. C. Allen, A. H. Hubbell, Evan Just, Harry Mikami, C. K. Leith, and to other friends and associates in the iron and steel industry. To all of these I gratefully acknowledge a very real debt.

Iron-ore Reserves

Because the iron and steel industry is dependent upon iron ore, and iron ore is of value essentially because of this industry, I shall present, first, an opinion as to the probable demand for steel in the years to come, and then discuss the estimates of the world reserves of actual ore and of potential ore.

My impressions are based on current, but necessarily incomplete, statistical data, on the knowledge we now have of the utilization of iron ore, and on speculation as to what may constitute usable iron ore in the future.

Although we cannot foresee the size or location of new iron-ore supplies which may be discovered in the future, it is considered unlikely that any great new deposits of high-grade ores, such as another Mesabi Range, will be uncovered in either the United States or western Europe, as both areas are geologically well known. However, deposits of importance may be found in other parts of the world not so well explored.

Our domestic iron-ore resources were drawn upon heavily by both world wars. During World War II, serious shortage of manpower prevented normal continuation of exploration and development work. As a result, the enormous war demands ate more deeply into our resources of higher grade ores than new development could possibly replace. This, however, does not mean that we have now become a "have not" nation with respect to iron ores, as some people appear to think.

Fortunately, we are no longer largely dependent upon surface exposures and visual means in our search for ores. New methods, utilizing physical and chemical properties of ore deposits, are constantly being developed and undoubtedly will be of increasing aid in future exploration. These developments are an important forward step in helping us maintain our position as to mineral resources. Furthermore, improvements undoubtedly will continue to be made in the technology of mining and ore concentration, which will result in longer life of the known reserves.

The Foundations of Our Civilization

While each of you has a very definite and lively appreciation of the part that iron ore and coal play in our economy, their importance is, nevertheless, sufficiently great so that it may, with profit, be stated over and over again. Without these two natural resources, our modern civilization could not exist.

In answer to some who may think of petroleum as perhaps the most important natural resource, let me point out that without coal and iron ore there would be no steel tubing, hence our oil reserves doubtless would continue to lie untouched, as they did for geologic ages, unobtainable and unusable.

Despite the increasing utilization of the light metals, aluminum and magnesium, both of which are abundant in the earth's crust, without the products made from iron ore and coal we would have no railroads, ships, automobiles or airplanes. There would be no machine tools. Farm production would be scanty, and there would be little market for any possible agricultural surplus. Life would certainly revert to the primitive.

Fortunately for humanity, such an imaginary catastrophe cannot come to pass. It is inconceivable that our need for iron and steel will not somehow be met for an indefinite period ahead. As known iron-ore reserves become exhausted, man will be forced either to discover others of usable grade or to develop technology which will make lower grade, potential ores usable, though the cost may be large and it may involve even some relocation of the iron and steel industry.

Need to Look Ahead

Nevertheless, it is well worth while to make frequent honest surveys of current conditions as to our basic natural resources; to lift our eyes from the immediate problems of sales, production and costs (I should also add "labor relations"—that great consumer of executives' time), and try to look ahead ten, twenty, or a hundred years, and focus our best judgment on the problems of the future and their solution.

In the period immediately preceding the recent war, approximately 140 million net tons of steel per year were required to meet world needs, some 100 million tons of which came from iron ore and 40 million from scrap. On the average, each inhabitant of the world had 130 pounds available for his use, but this amount was not evenly distributed. The production of the United Kingdom provided its people with an average of 585 pounds; of Germany, 625 pounds; of France, 385 pounds; of Russia, 230 pounds. In contrast, we in the United States were provided an average of 740 pounds per capita.

It is natural that the wealth and power of the United States should be envied by all other nations. This wealth and power is due to the high efficiency in our productive and distributive industries, which, in turn, has been made possible by our high per capita use of iron and steel.

Steel—Basis of Wealth and Power

The power of the United States was demonstrated most effectively by our industrial performance during the war. No doubt every other nation would like to be as well supplied as we are with productive machines for agriculture, manufacture and transport, although not all of them would now be capable of creating and producing these things even if they possessed the raw materials.

Even though the people of other nations have not only the desire but the will, energy and ability to raise their living standards to approximate ours, obviously it will be a long process, not accomplished in several generations. Nevertheless, this desire of other peoples to live as well as we do must be recognized as a significant factor in the future. And even though all the rest of the world can never be expected to achieve the same per capita use of steel as the United States (on the prewar basis this would mean that world requirements would be multiplied by more than six), we must still anticipate that the rate of consumption of the iron ore is likely to accelerate for a long time to come. This does not preclude the increased utilization also of substitutes for iron and steel, both in this country and elsewhere, nor the increased recirculation of scrap.

World's Steel Capacity and Demand

Before discussing iron-ore reserves, I should like to consider with you the capacity of the steel industry that is utilizing these reserves, together with the probable demands for steel in the near future.

The war did incalculable damage in much of Continental Europe, China, and Japan. In England, damage was serious but not so complete. The rehabilitation of these affected countries, as they set about rebuilding destroyed facilities, will, in my judgment, mean a steel consumption greater than we have ever seen in peacetime. This is true, even though we merely restore that which has been destroyed.

But there will be a second great demand for steel. Countries that suffered no direct war damage suffered indirect damage through inability to maintain and replace their facilities in a normal way. Upkeep of railroads, of highways, construction of all types, the normal retooling of peacetime industries, together with the year-by-year expansion, were all stopped.

In this country, we need only to contemplate the unprecedented demands for automobiles, building construction, agricultural machinery, railroad equipment, domestic durable goods, and the many other items entirely dependent upon steel for their manufacture. Together these needs all indicate that the steel industry unquestionably faces a busy future.

It is of interest to note, in this connection, that the wartime *expansion* of the steel capacity of the United States, from Jan. 1, 1941, to Jan. 1, 1945, was 11,353,000 net tons, or nearly as much as the entire capacity of the United Kingdom. Total steel capacity of the United States in 1946 was 92 million net tons or 82 million long tons. This is below the wartime maximum of 95.5 million net tons because of elimination of some obsolete plants.

Annual production of steel in the various countries of the world (Tables 9 and 10) may be taken as at least indicative of relative capacities, except as changed recently by the effects of war.

It is to be doubted whether the steel production of Germany and Japan will reach prewar peaks for many years to come. Deservedly harsh peace terms will limit steel production in the Axis countries to the filling of their domestic requirements. Even these normal requirements will remain unfilled until war damage has been largely repaired.

We may expect the steel plants in allied territories in western Europe and in Russia to resume prewar rates of production within a relatively few years. But the requirements for repair and replacement of facilities there are so great that they will tax the local capacity for years to come, leaving little for export.

This will probably be true even in Russia, which has announced its purpose to expand steel capacity to 60 million tons by 1960—an increase from about 22 million net tons in 1940. Should these plans reach fulfillment, I still doubt that there will be much Russian steel available for export for many years.

United States—World's Principal Source of Steel

The logical conclusion is that the steel industry of the United States, supplemented to some extent by that of Great Britain, must be the main source of supply for the excess needs of the rest of the world. The limited contribution the United Kingdom may be expected to make to these excess needs is indicated by the fact that it exported but 3 million tons in 1946, compared with less than 4 million tons in 1929, though every effort was made to increase exports in order to build up favorable trade balances abroad.

The United States, therefore, must be regarded as the principal source from which excess world steel demands will be met. Thus, the future demands on the United States steel industry, for home consumption and for export, are likely to far exceed the production of 56.6 million net tons in 1937—our peak prewar year.

The likelihood of a continued rise in the rate of steel production in the United States for a long time seems clearly indicated except for the uncertainties of future wage rates and the productivity of labor. Excessive wages, or declining productivity of workers, and resumption of strikes such as have demoralized production in this country since the war, can either drive costs so high that we are priced out of the market, or by enforced idleness can dry up the purchasing power of the people of this country whose savings are a vital factor in maintaining the demand for steel products.

It now seems apparent that existing labor laws will be rewritten to prevent possible control and disruption of our economy by irresponsible labor leaders. I have hopes that the inherent common sense of the American people will bring about conditions of law and order and thrift which will give this country a long period of stable and orderly prosperity, instead of the "boom and bust" periods that largely accompanied the development of our railroads, utilities and street railways, and of our automobile, bus, truck, highway, radio, farm and home equipment industries—all great consumers of steel.

More Steel for Better Living

The change of our mode of living, from small town and community life to a mass basis—i.e., mass production, mass selling and distribution—has been accomplished during these "boom and bust" years, for which industry is so frequently blamed but without being given the credit for bringing to this country a standard of living for the mill and factory worker, as well as others, far superior to that possible 50 years ago in this country or any other country today.

It is my personal conviction that the increase in our steel production that has characterized the past years of this century will continue for many decades. Not only is our population steadily increasing, but the wants of the individual are also increasing. Thus, the curve of steel production of the United States will be likely neither to turn down nor to flatten out, but will continue to rise. It may not rise as rapidly as in the past, but I believe that when the statisticians in the year 2000 look back they will find a generally upward curve for the century.

Based on this analysis of the outlook both for this country and the rest of the world, the conclusion is inescapable that the normal demand for iron ore during the years to come will be materially greater, both in the United States and in the rest of the world, than it has been in the past.

Total World Iron-ore Reserves

It would, of course, be impossible and presumptive on my part to attempt estimates of world iron-ore reserves. Many such estimates or summaries of estimates have been made by mineral specialists, and their figures will be used in this discussion.

In 1910, the International Geological Congress estimated a reserve of 22.5 billion tons of actual ore and 123 billion tons of potential ore.

In 1926, in *Engineering and Mining Journal*, Olin R. Kuhn estimated 57.8 billion tons of actual ore and 167.7 billion tons of potential ore.

In 1944, Harry Mikami published in *Economic Geology* a summary of reserve estimates showing 35.2 billion tons of actual ore and 164.8 billion tons of potential ore.

In this discussion, I am using Mikami's figures, with a few additions, as the most recent and probably the most accurate. To make them comparable, the computed tons of metal in the ore are shown also. (See Appendix.)

World Reserves of Potential Iron Ore

What is potential iron ore? I shall define it as ore that we are unable to utilize today in competition with ores now supplying the market. Potential ores cannot compete with actual ores for one or more reasons. They are too low in iron content, too high in undesirable constituents, or they are inaccessible to steel plants or markets by reason of cost or distance.

The Mikami table indicates that the great reserves of potential ores are to be found in North America, France, Great Britain, Russia, South Africa, India, Brazil and Mexico. These countries contain 84 per cent of the total ore tonnage and 82 per cent of the total iron content.

Vast Tonnages of Potential Ore

As is the case with all such estimates, these tonnage estimates of potential iron ores are significant chiefly because they show that there are vast quantities of presently undesirable iron-bearing material for which we may find anl economic use as need presses.

One of the greatest reserves of such potential iron ore is to be found in the Lake Superior district, which will be discussed later. The facts relating to the Lake Superior potential estimate give us a basis for understanding how estimates of the other great reserves of the world must be interpreted.

The main iron-bearing formations, the potential reserves, of Russia, Brazil, South Africa and India are geologically similar to those of Lake Superior. Their total tonnage, however, is less definitely known than is that of the Lake Superior reserves, because we know relatively little about them. They present, in general, unsolved problems as to their utilization in our present steelmaking processes, which are similar in many respects to the problems affecting the utilization of the Lake Superior potential ores.

When these problems are solved for Lake Superior, the other great potential reserves likewise may become usable.

A large proportion of the potential reserves must be considered as available only after we find out how to utilize them and are willing to pay the price to make them adaptable to our needs.

World Reserves of Actual Iron Ore

It is, therefore, mainly the actual reserves of iron ore with which we are immediately concerned. These are the ores we are mining and feeding into the furnaces of the world today; the ores from which steel is now being made in plants operating in successful competition with each other.

The Mikami table shows that, based on our present information, the estimated actual ores of the world contain about 16.2 billion tons of metal. Only in a broad world sense can it be said that nature has distributed this total with a fairly even hand. Brazil is credited with 2.4 billion tons; India with 2.2 billion tons; Russia in Europe and in Asia with 2 billion; the United States with 1.7 billion; France with 1.6 billion; Cuba with 1.2 billion; Great Britain with 0.9 billion; Sweden with 0.8 billion; and South Africa with 0.6 billion tons of metal in their *actual ore reserves.*

Of the 16.2 billion tons of total iron reserves, the United States has within her borders 10.5 per cent. In prewar years, this was called upon for enough ore to make nearly 40 per cent of the world's steel production. In contrast, other nations, which may be said (with considerable inaccuracy) to have behind their steel industry 90 per cent of the metal in actual world reserves, normally made somewhat over 60 per cent of the world's steel.

This makes it crystal clear that the actual known ore supply is being exhausted much more rapidly in the United States than it is in the rest of the world. However, if we assume that we may reasonably add the actual ore reserves of South America, excepting half of those of Brazil, to the actual ore reserves of all of North America, we find that the steel industry of the United States could supply its prewar rate of demand for about two thirds as long a time as other actual reserves would supply the balance of the world. Whenever ore consumption of the rest of the world more nearly approaches the per capita rate of the United States, the relative positions of the United States and the rest of world respecting reserve supplies may be more nearly equivalent or even reversed.

One trouble with these arithmetical assumptions is that seaborne imported ores cannot be used by the present steel plants of the United States on a basis competitive with domestic ores, except to a small degree. The economic use of these imported ores is limited to those steel plants which are on or near the sea coast. Imports of iron ore and manganiferous iron ore are equivalent to only 3 to 5 per cent of our domestic production. As long as present conditions affecting imports are not changed, it is reasonably accurate to use these percentages to measure the part of our steel industry—as now established—that can be supplied by imported ores.

Granted that the steel industry of the United States must be regarded as the principal source of supply for excess world requirements for years to come, the great problem immediately to be faced is: What is the future as to the supply of actual ore for the steel industry of the United States?

Accuracy of Estimates

Before proceeding with the discussion of this, it may be interesting to consider the accuracy of the estimates of the actual world supply.

More truly than in the case of potential reserves, it can be said that the actual reserves in the Lake Superior district, England, France and Sweden are far better known than are those of the rest of the world. Therefore, we are faced with estimates that may be subject to substantial changes, as exploration is carried forward in Russia, India, South America and Africa. Lake Superior actual reserves are probably the best known of all, and the greatest of these reserves—on the Mesabi Range—are better known than are the reserves of most other ranges of the district.

It is natural that most should be known about the Lake Superior district, which has been studied intensively for many years not only by geologists and engineers concerned with mining but also by tax officials who have had access to all the great mass of factual data assembled by the mining companies. These data have been used to estimate tonnages of reserves and their current value for tax assessment purposes. Estimates for such purposes are not to be considered as necessarily accurate indications at any given time of all the ore that ultimatelv may be recovered. They do furnish a highly useful record, which, if used intelligently, should provide the best means available for projecting from that record into the future.

Taxation Can Impede Exploration

While on the subject of taxes, I should like to digress to suggest that states that are blessed with resources of lower grade ores might well profit by the mistakes made by some of the iron-ore states in their taxing policies. Abuse of the taxing power has discouraged mining companies from actively furthering their search for ores, because of the penalty placed upon the discovery of ore deposits.

This unfortunate practice, especially in the state of Minnesota, could easily lead to a national disaster in time of war. Just consider the situation on the Mesabi Range if World War II had lasted 10 years. For the security of this country, tax laws should be written to encourage the finding and developing of ore bodies. On the contrary, in some states the lawmakers have seen fit to tax ore in the ground, on discovery, and the results of every drill hole must be filed with the state. This in-the-ground ore tax is a vicious, dangerous, unpatriotic practice, and for the safety of our country should be stopped.

The national government, through the depletion provisions of the tax laws, encourages the discovery and development of oil reserves to a far greater extent than it does iron-ore reserves, but, as I have noted, oil could not be discovered or developed without steel.

From our knowledge, the best we may hope for in the Lake Superior district is an unknown but limited increase in the actual reserves. Opinions vary that from 10 to 50 per cent more than the current estimates ultimately may be recovered from these deposits. Relatively smaller increases are likely in the Mesabi—which now supplies most of the ore—than in some of the other ranges, particularly the Cuyuna, Marquette and Menominee.

The actual reserves of rich ores in Sweden, and of low-grade ores in France and Great Britain, are probably known with somewhat less accuracy than are the reserves of Lake Superior. Those of important magnitude in other parts of the world are surrounded with far more uncertainty.

Large Possible Increases in Reserves

An example of the increase which may, perhaps, be expected in these less well known reserves is to be found in Russia. In 1912, the International Geological Congress estimated actual ore reserves of Russia in Europe at 865 million metric tons. At the same time, the Russian reserves of potential iron ore were estimated at 156.3 million tons in Europe, with an additional 27 million tons in Siberia; and to this last estimate is added the comment "as yet unknown." The indicated Russian total thus was somewhat over a billion tons.

Though in the decade of 1920 the Russian steel industry was still small, and ore reserves were still given low totals, Kuhn, in 1926, credited Russia with 2.2 billion tons of actual ore of a world total of 57.8 billion tons.

By the time Mikami assembled his table of estimates in 1944, the estimated actual ore reserves of Russia had risen to 4.5 billion tons—approximately one eighth of the world's total. Russia produced about 20 million net tons of steel in 1946 and hopes to be able to produce 60 million tons in 1960. To make this steel she has greater actual reserves than the United States, which produced about 66.6 million net tons in 1946.

Similar, but perhaps less spectacular, increases are being made in South America, Labrador and Mexico, as discovery and development progress there. Europe may draw on these reserves in part when they become accessible.

Current information indicates that the supplies of actual ore for the steel industries outside the United States are ample for a long time to come. While some present ore supplies, as in Spain, are approaching exhaustion, equally good ores from Africa and Brazil can take their places without too serious increase in cost. England can find increased ore supplies in the sources from which Germany formerly drew more heavily than she is likely to do for several years to come.

The conclusion is inescapable that there will be available, when needed, more actual ore than anyone today has the data to estimate or the courage to guess.

Technology Will Add to Actual Reserves

Some of the greatest additions to the actual ore reserves will come about through important advances in the technology and economics of mining, concentration and furnace practice, which will transfer vast tonnages from the potential to the actual column. Such a transfer is expected to materialize in the very near future, whenever the profitable concentration of the magnetic taconite of the Mesabi Range is achieved. If present contemplated plans are successful, they will change some 10 billion tons of ore, containing 3 billion tons of iron metal, from subpotential reserves to actual reserves.

Another such transfer may occur—and at a time not too remote—in the magnetic districts of New York, New Jersey and Pennsylvania. Well-developed concentration methods are now being successfully used there on actual reserves of approximately a billion tons. Potential ores—of low-grade magnetite—estimated at billions of tons may be revealed when adequate explorations of all the potential territory have been made.

Ore Reserves of the United States

There are three great actual ore reserves in the United States; i.e., in the Lake Superior district, the Southeastern district, and the Northeastern district. The actual reserves in each of these three districts approximated a billion tons. From one—Lake Superior—we have been securing 85 per cent of our total annual ore production.

In 1945, the Lake Superior district supplied 85.3 per cent, the Southeastern district 7.5 per cent, the Northeastern district 4.1 per cent, and the Western district 3.1 per cent of the iron ore shipped from mines in this country. Although the individual proportions supplied by districts other than Lake Superior have changed slightly in recent years, their aggregate, as well as the total proportion from the Lake Superior district, have remained approximately constant for many years.

There is a good reason for this. About 80 per cent of our steel industry is in the Great Lakes area—the United States industrial basin served by Lake ores, on the one hand, and by Pennsylvania, West Virginia and Kentucky coals, on the other.

The other districts are under the handicap of geographic location in relation to the major part of the steel industry. In the Southeastern district, there is the further handicap of quality of ore.

The Northeastern ores, high in quality after concentration, can reach some parts but not all of the Lake-based steel industry, in competition with Lake ores. The Southeastern ores do not have this possibility. As long, therefore, as the steel industry continues to cluster about the lower Great Lakes, its ore supply should come by lake from the Lake Superior district (or by lake from Labrador, Newfoundland, or elsewhere, if that be possible), and, to a lesser degree, from the Northeastern district. This is the future of about 80 per cent of our present steel industry.

Potential Lake Superior Ores

The potential ores in the Lake Superior district were estimated in 1911 by Van Hise and Leith, in *Monograph* 52 of the United States Geological Survey. This estimate was based on 25 years of continuous geological work, intensive exploration and vast mining development. The definitely known surface area of the iron-bearing formation was assumed by Van Hise and Leith to extend to average depths of 1250 feet in the steeply inclined old ranges, and 400 feet in the gently inclined Mesabi Range. This gave a total of 467 billion tons of iron-bearing rock, averaging 25 per cent iron or better. The potential ore, consisting of material averaging 35 per cent or better, was estimated at 67 billion tons. Of this, 12 billion tons lay north of Lake Superior in Ontario, and 30 billion tons in the Mesabi Range. Since this estimate was made, mining in one of the old ranges has gone to depths exceeding 3500 feet. The question arises, therefore, as to whether we would be justified in doubling the depths assumed in 1911, in arriving at a present-day potential ore estimate.

On the other hand, might not marked reduction of the 1911 estimate result from consideration of other significant facts, such as the particular mineral composition of parts of this iron-bearing rock, its physical properties and the technology and economics of producing furnace feed from it? I mention these matters merely to raise the question of the meaning of these potential estimates, and not to indicate in any way that they should be doubled or increased by any definite amount or that they should be diminished.

The important features of the potential Lake Superior ore reserves are two. First, they exist in very large tonnages, although not all the iron-bearing rock containing 35 per cent or more iron is now considered potential ore; second, and of much greater significance in our present industry, we know how to produce a usable product from only a fraction of the total volume of the iron-oxide-bearing rock.

Production versus Depletion

As to our actual Lake Superior reserves, in 1915 tax estimates showed the total at 1689 million long tons. Thereafter, by the end of 1946, 1671 million tons were produced and the remaining reserves were still estimated as approximately 1136 million tons. Mathematically, if the 1915 reserves were to agree with the 1946 reserves, the 1915 reserves should have totaled more than 2800 million tons.

From these facts many have argued that the reserves of actual ore are not as well known as has been assumed; that the estimates for Lake Superior are extremely conservative; and that increases in the reserves in the future, as in the past, will largely offset production, so that the decline in actual tonnages, year by year, will be very gradual.

However, the record of the past is hardly an acceptable guide to the future in this respect, even though its implications are not to be ignored. The nearer an ore-producing district approaches exhaustion, the more accurately can its remaining tonnage be estimated.

The failure of past estimates to agree with ultimate mine recoveries is not due to laxity on the part of tax officials. Some of the discrepancy is due to proper conservatism on their part. Much is due to the fact that mining has shown more ore than could be accurately estimated from drill records; some to changing technology and changing economic conditions. Much less has been due to the discovery of entirely new ore bodies not known in 1915. As a matter of fact, not a single great new ore body has been discovered in the United States ranges since that date.

Lake Superior Situation Today

In view of the overwhelming predominance of the Lake Superior district as a supplier of basic raw materials to the steel industry of the United States, let us examine its present status in more detail.

In 1937, the year of prewar peak demand, the Lake Superior district produced 63,219,000 long tons of ore—85.8 per cent of the total output of this country. Of this tonnage nearly 44 million tons came from Minnesota open-pit mines, which was 89 per cent of Minnesota's output. It was 70 per cent of the Lake Superior output and 60 per cent of the total iron ore shipped from mines in the United States. These figures clearly emphasize the importance of the Minnesota open pits to our steel industry.

In the same year, the other mines of Lake Superior, almost all underground, shipped 19¼ million tons of ore, or 30 per cent of the total. This was a peacetime year.

In 1942, under the stress of war demands, Minnesota open-pit output reached a peak of more than 70¼ million tons. All the other mines in the Lake Superior district, most of which were underground operations, reached a new high point of 22¾ million tons. Hence, the open pits increased their production over 1937 by 60 per cent and the other mines by 18 per cent.

Now what of the future? During the years to come, as I have indicated, we face an unprecedented demand for steel. At the same time we face a future fraught with profound economic problems and difficulties. Our national debt has reached the unbelievable and incomprehensible total of 259 billion dollars. In order to finance and reduce this debt our industrial production must be at a rate never before experienced during peace years.

Because our industrial production is so largely based on iron and steel, it is obvious that our steel production must be at a high rate.

Ore for 90 Million Tons of Steel

It has been estimated, both by governmental and private business agencies, that the industries of this country will require 90 million net tons of steel per year, if we are to operate on a basis that will furnish adequate employment and support an economy commensurate with our debt burden. Ninety million net tons of steel was about the wartime maximum. To make this would require that ore be supplied at the maximum wartime rate, which was in excess of 100 million long tons for the entire United States.

Even though we assume that somewhat more of these ore requirements may be supplied, in the near future, from imports and from other domestic sources, our demands on Lake Superior ore should average at least 75 million long tons per year for the next several years. Of this, not more than 20 million tons may be produced from Lake Superior mines other than the Minnesota open pits. Thus, the demand on the open pits would be at least 55 million tons a year.

On May 1, 1946, the Minnesota Tax Commission estimated for tax assessment an open-pit ore reserve of 575 million long tons. As has been indicated, considerably more than this tonnage is expected ultimately to be produced. Nevertheless, arithmetically, this reserve would supply 55 million tons a year for a little over 10 years.

But ore cannot be produced on the basis of mathematical averages. Some pits will be exhausted long before the computed average life of the reserves; others will persist much longer. The result will be that 55 million tons a year of open-pit ore can be produced for perhaps half the period of years indicated as the present life of the known reserves. Then the production will begin to

TABLE 1—*World Iron-ore Reserves*[a]

Country	Actual Reserve			Potential Reserve		
	Ore, Millions of Tons	Approx. Percentage Iron Content	Total Iron Content, Millions of Tons	Ore, Millions of Tons	Approx. Percentage Iron Content	Total Iron Content, Millions of Tons
North America						
Canada	100	50	50	10,000	35	3,500
Labrador				Large[b]	62	
Cuba	3,000	40	1,200	12,000		
Mexico	100	60	60	100		
Newfoundland	1,250	40	500	2,000	40	800
United States	3,800	45	1,710	67,000	35	23,450
Total North America	8,250	43	3,520	92,100		
Europe						
Albania	20	50	10			
Czechoslovakia	55	40	22	100		
France	4,500	35	1,575	6,000	35	2,100
Finland				90	35	32
Germany	800	32	256	2,000	30	600
Austria	200	35	70	200		
Great Britain	3,100	30	930	7,000	30	2,100
Greece	100	50	50	50	45	23
Hungary	80	40	32			
Italy	60	50	30			
Norway	300	35	105	1,000	30	300
Poland	140	30	42	200	25	50
Portugal	50	45	23	100		
Romania	25	40	10			
Spain	800	45	360	1,000	35	350
Sweden	1,250	62	775	1,250	60	625
Switzerland	20	30	6			
U.S.S.R. (in Europe)	3,100	45	1,395	15,000	35	525
Yugoslavia	70	50	35			
Total Europe	14,670	39	5,725	34,000		
Asia						
China	500	40	200	700	35	245
India	3,600	60	2,160	10,000		
French Indo-China	50	50	25			
Japan	70	40	28			
Korea	70	35	25	300	30	90
Malaya	75	55	41			
Neth. East Indies	100		[b]	1,500		
Philippines	500	47	235	500		
Turkey	15	65	10	35		
U.S.S.R. (in Asia)	1,400	45	630	2,400		
Total Asia	6,380	53	3,404	15,435		
Australia	400	60	240	Moderate		
New Caledonia	20	52	10			
South America						
Brazil	4,000	60	2,400	11,000	40	4,400
Chile	120	60	72			
Colombia				35	55	19
Peru	100	60	60			
Venezuela	100	60	60	1,000	45	450
Total South America	4,320		2,592	12,035		4,869
Africa						
Algeria	160	50	80			
Tunisia	30	50	15			
French Morocco				60		
Spanish Morocco	30	55	17			
French Guinea				2,500	45	1,125
Rhodesia				Very large[b]	25	
Sierra Leone	20	55	11	Large[b]	55	
Union of South Africa	1,000	55	550	7,000	45	3,150
Togo				20	50	10
Total Africa	1,240	54	673	12,000		
World Total	35,280	46	16,164	165,570		

[a] Based on table by Harry Mikami, *Economic Geology* (Jan.–Feb. 1944). As compiled by the Lake Superior Iron Ore Association.

[b] Estimate included in total.

TABLE 2—*Annual World Iron-ore Production*

MILLIONS OF METRIC TONS

	North America					Europe														
	United States	Canada	Newfoundland	Cuba	Mexico	Soviet Union[c]	United Kingdom	Sweden	Norway	Spain	France	Luxemburg	Belgium	Germany	Austria	Czechoslovakia	Poland	Switzerland	Italy	Yugoslavia
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1909–13[a]	54.8	Neg.[b]	1.1	1.3	?	8.0	15.3	6.0	0.3	9.0	16.9	6.4	0.2	24.4	2.7	2.5	0.2	?	0.5	?
1914–18[a]	65.3	Neg.	0.8	0.7	?	?	14.6	6.7	0.4	5.7	3.5	5.1	Neg.	20.1	1.9	?	?	?	0.8	?
1919–22[a]	52.2	Neg.	0.7	0.4	?	0.2	8.9	5.6	0.1	3.7	14.6	3.6	Neg.	6.1	0.6	0.8	0.2	?	0.4	?
1923–29[a]	66.5	Neg.	1.1	0.5	?	3.6	10.5	7.8	0.5	4.7	39.0	6.5	0.2	5.7	1.3	1.4	0.5	?	0.5	?
1930	59.3	Neg.	1.2	0.2	0.1	10.4	11.8	11.2	0.8	5.5	48.6	6.6	0.1	5.7	1.2	1.7	0.5	0.1	0.7	0.4
1931	31.6	Neg.	0.7	0.1	0.1	10.6	7.7	7.1	0.6	3.2	38.6	4.8	0.1	2.6	0.5	1.3	0.3	Neg.	0.6	0.1
1932	10.0	Neg.	0.2	0.1	...	12.2	7.5	3.3	0.4	1.8	27.6	3.2	0.1	1.3	0.3	0.6	0.1	Neg.	0.4	Neg.
1933	17.8	Neg.	0.2	0.2	0.1	14.5	7.6	2.7	0.5	1.8	30.4	3.4	0.1	2.5	0.3	0.4	0.2	Neg.	0.5	0.1
1934	25.0	Neg.	0.5	0.2	0.1	21.7	10.8	5.3	0.6	2.1	32.0	3.8	0.1	4.2	0.5	0.5	0.2	Neg.	0.5	0.2
1935	31.0	Neg.	0.7	0.2	0.1	27.1	11.1	7.9	0.8	2.6	32.0	4.1	0.2	5.9	0.8	0.7	0.3	Neg.	0.6	0.2
1936	49.6	Neg.	0.9	0.4	0.1	29.8	12.9	11.3	0.8	2.0	33.3	4.9	0.2	7.4	1.0	1.1	0.5	Neg.	0.8	0.5
1937	73.3	0.1	1.6	0.5	0.1	28.0	14.4	15.0	1.0	1.3	37.8	7.8	0.3	9.6	1.9	1.8	0.8	0.1	1.0	0.6
1938	28.9	Neg.	1.7	0.2	0.1	26.5	12.0	13.9	1.4	2.5	33.1	5.1	0.2	10.9	2.6	2.0	0.8	0.1	1.0	0.6
1939	52.5	0.1	1.7	0.3	0.1	28.0	14.7	13.8	1.3	2.6	32.8	?	0.2	12.0	2.9	1.4	1.0	0.2	0.9	0.7
1940	74.9	0.4	1.5	0.2	0.1	27.5	18.2	11.3	0.6	2.0	12.7	?	0.1	16.2	3.1	1.5	?	0.2	1.2	0.5
1941	93.9	0.5	1.0	0.2	0.1	22.7	19.1	10.5	0.6	1.7	10.6	7.0	0.1	15.5	2.5	1.7	?	0.3	1.3	0.5
1942	107.2	0.5	1.2	0.1	0.1	?	19.6	9.7	0.3	1.6	12.8	5.1	0.1	13.2	2.6	1.6	?	0.3	1.1	?
1943	102.9	0.6	0.6	Neg.	0.2	?	18.7	10.8	0.2	1.6	16.9	?	0.1	?	3.2	?	?	0.3	?	?
1944	95.6	0.5	0.5	Neg.	0.2	?	15.1	7.3	0.3	1.6	9.3	?	?	?	3.0	?	?	0.2	?	?
1945	89.8	1.0	1.0	Neg.	0.2	?	14.4	3.9	?	1.2	7.8	?	?	?	0.3	?	?	Neg.	?	?

TABLE 2.—(*Continued*)

	Europe			Asia and Oceania							South America		Africa						
	Hungary	Romania	Greece	British India	Unfederated Malay States	China and Manchuria	Korea (Chosen)	Japan	Philippine Islands	South Australia	Chile	Brazil	Spanish Morocco	Algeria	Tunisia	Sierra Leone	Union of So. Africa	All Other	World Totals
	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)
1909–13[a]	?	?	?	0.3	?	0.2	0.1	0.1	Neg.	0.1	0.1	Neg.	?	1.1	0.4	?	Neg.	2.4	154.5
1914–18[a]	?	?	?	0.4	?	0.5	0.2	0.2	Neg.	0.4	0.1	Neg.	0.2	1.0	0.5	?	Neg.	1.4	129.7
1919–22[a]	?	?	?	0.7	0.1	1.1	0.3	0.2	Neg.	0.5	0.1	Neg.	0.2	0.9	0.4	?	Neg.	0.4	103.1
1923–29[a]	?	?	?	1.7	0.4	1.9	0.4	0.1	Neg.	0.7	0.3	Neg.	0.8	1.8	1.8	?	Neg.	1.2	161.6
1930	0.2	0.1	0.3	1.9	0.8	2.3	0.5	0.2	Neg.	0.9	1.7	Neg.	0.8	2.2	0.8	?	Neg.	0.1	179.0
1931	0.1	0.1	0.2	1.7	0.7	2.2	0.2	0.2	Neg.	0.3	0.7	Neg.	0.5	0.5	0.4	?	Neg.	0.1	118.9
1932	0.1	Neg.	Neg.	1.8	0.7	1.6	0.4	0.2	Neg.	0.5	0.2	Neg.	0.2	0.5	0.2	?	Neg.	Neg.	76.2
1933	0.1	Neg.	0.1	1.2	0.8	2.1	0.3	0.3	Neg.	0.7	0.6	Neg.	0.5	0.8	0.3	Neg.	0.1	Neg.	91.2
1934	0.1	0.1	0.1	1.9	1.2	2.5	0.2	0.4	Neg.	1.3	1.0	Neg.	0.8	1.3	0.5	0.2	0.2	Neg.	120.1
1935	0.2	0.1	0.2	2.4	1.4	?	0.2	0.5	0.3	1.9	0.8	Neg.	1.2	1.7	0.5	0.4	0.3	0.1	141.0[d]
1936	0.3	0.1	0.3	2.6	1.7	?	0.2	0.8	0.7	1.9	1.3	0.1	1.1	1.9	0.8	0.6	0.4	0.1	175.5[d]
1937	0.3	0.1	0.3	2.9	1.7	?	0.2	?	0.6	1.9	1.5	0.2	1.4	2.4	0.9	0.6	0.5	0.2	217.0[d]
1938	0.4	0.1	0.3	2.9	1.6	?	?	?	0.9	2.3	1.6	0.4	1.3	3.1	0.8	0.9	0.5	0.5	167.0[d]
1939	0.6	0.1	0.3	3.2	2.0	4.6	1.0	?	1.2	2.6	1.6	0.4	1.0	2.9	0.8	?	0.5	0.9	198.5[d]
1940	0.6	0.2	?	3.2	1.9	7.2	1.1	1.0	1.2	2.4	1.7	0.3	0.6	1.7	0.3	?	0.6	0.5	205.0[d]
1941	0.8	0.2	?	3.2	?	11.0	1.7	1.3	0.9	2.3	1.7	0.4	0.6	0.3	Neg.	1.0	0.8	0.3	219.5[d]
1942	0.8	0.2	?	3.3	?	17.6	2.3	2.1	?	2.2	0.4	0.3	0.5	0.3	Neg.	0.6	0.7	0.2	229 0[d]
1943	0.8	0.2	?	2.7	?	?	2.4	2.5	?	2.2	0.3	0.3	0.5	0.2	Neg.	0.5	0.7	0.3	227.0[a]
1944	0.4	?	?	2.4	?	?	3.4	2.7	?	2.1	0.7	0.2	0.7	0.8	0.1	0.6	0.8	0.3	206.5[d]
1945	?	?	?	?	?	?	?	?	?	?	0.9	0.3	0.8	?	?	?	0.9	0.1	185.0[d]

Compiled by The Lake Superior Iron Ore Association.

Data from Minerals Yearbook (U. S. Bureau of Mines), Mineral Trade Notes, U. S. Tariff Commission and Other Sources.

[a] Average annual tonnage.

[b] Neg. indicates production is negligible. ? indicates that data are not available.

[c] Includes Asiatic Soviet Republics.

[d] Includes estimates of production where data are not available.

decline. A year will come all too soon when the open pits will produce only 40 million tons, then 35 million tons, and progressively less.

I have used definite figures to illustrate my point. You may not agree with those definite figures. Whether you do or not is not important. It makes small difference whether the shortage comes in five years, ten years or even longer. The point is that, in a distressingly short period of years, Minnesota open-pit ores will be available in insufficient quantity, with all that other mines of Lake Superior can produce, to supply the needs of the steel industry dependent upon Lake ore.

Three Sources of Supply

How, then, will the shortage be supplied? Only three domestic sources of ore to meet the needs of the present Lake supplied steel industry offer large possibilities.

One source is an ore supply from the Northeastern magnetite district where, as I have noted previously, are potential reserves which can be treated with known, and now used, concentrating methods to make them available for our use. These are only moderately lower in order of magnitude than the actual reserves of the Lake Superior district. If energetically developed, they could supply the demand of a considerable part of the eastern plants of the present Lake-ore steel industry.

A second source of supply is the underground ore reserves of the Mesabi Range. As of May 1, 1945, these are estimated by the Minnesota Tax Commission at 370 million long tons, about two thirds as great as the open-pit reserves. These ores are not extensively developed at present because they cannot compete with the lower cost open-pit ores. In the war years when every producer was trying to get out the maximum tonnage, Mesabi underground mines shipped a maximum, in 1943, of 2,692,000 tons, about 4 per cent of the Mesabi open-pit production in that year.

These individual underground ore bodies, on the average, are both smaller and more deeply buried than the open-pit ore bodies. They can add perhaps 12 to 15 million tons to the total yearly shipments, when ore prices are high enough to justify their operation at maximum rates. This supply will be an invaluable aid in postponing the evil day of an insufficient ore supply for the present Lake-based steel industry, but it is inadequate to take the place of the open-pit production.

The Mesabi Taconites

The greatest source of a possible future ore supply lies in the potential ores of the Lake Superior district. The magnetic taconite of the Mesabi Range

TABLE 3—*Annual Estimates of Taxable Reserves of Merchantable Ore in Lake Superior District, U. S. Ranges*[a]

INCLUDING MINE STOCK PILES ON DATE INDICATED.

THOUSANDS OF GROSS TONS

Year	Minnesota Ranges (as of May 1)				Michigan Ranges (as of January 1)				Wisconsin (as of Jan 1) Gogebic	Combined Ranges
	Mesabi	Vermilion	Cuyuna	Total Minnesota	Gogebic	Marquette	Menominee	Total Michigan		
1915	1,389,004	11,012	72,403	1,472,419				212,000[c]	5,000[d]	1,689,419
1916	1,384,636	13,058	77,926	1,475,620	59,211	82,547	69,645	211,402	5,000[d]	1,692,022
1917	1,381,754	11,962	70,160	1,463,876	46,711	95,809	69,709	212,229	5,000[d]	1,681,105
1918	1,362,277	12,251	63,209	1,437,737	55,814	78,175	66,155	200,144	5,000[d]	1,642,881
1919	1,328,821	11,621	59,393	1,399,836	63,497	64,255	75,820	203,572	5,000[d]	1,608,408
1920	1,305,927	10,928	24,820	1,341,675	64,563	70,633	63,896	199,093	5,000[d]	1,545,768
1921	1,273,129	13,202	25,081	1,311,411	64,965	73,854	65,312	204,130	5,000[d]	1,520,541
1922	1,252,820	14,354	29,485	1,296,660	62,405	72,954	64,386	199,745	5,000[d]	1,501,405
1923	1,254,861	13,688	43,041	1,311,591	58,315	72,103	66,410	196,827	5,000[d]	1,513,418
1924	1,275,347	13,170	46,121	1,334,638	54,950	70,384	66,555	191,889	5,000[d]	1,531,527
1925	1,250,086	13,539	52,125	1,315,750	52,026	68,988	67,184	188,198	5,000	1,508,948
1926	1,233,979	12,383	51,091	1,297,453	52,131	67,161	69,188	188,480	5,000[d]	1,490,933
1927	1,201,054	12,126	49,653	1,262,833	53,343	63,613	67,103	184,059	5,000[d]	1,451,892
1928	1,190,481	14,483	53,268	1,258,233	48,681	60,220	64,753	173,654	5,500[d]	1,437,387
1929	1,178,856	14,940	48,265	1,242,060	48,587	57,921	62,922	169,430	6,000[d]	1,417,490
1930	1,154,434	14,251	66,543	1,235,228	51,347	55,655	61,347	168,350	6,800	1,410,378
1931	1,162,777	14,789	66,757	1,244,323	51,144	57,666	62,178	170,987	6,500[d]	1,421,810
1932	1,190,295	14,238	69,700	1,274,233	50,793	56,336	59,940	167,069	6,500[d]	1,447,802
1933	1,205,213	14,007	70,025	1,289,246	50,474	55,894	58,265	164,632	6,000[d]	1,459,878
1934	1,195,272	13,243	47,554	1,256,068	48,613	54,564	60,845	164,022	6,000[d]	1,426,090
1935	1,777,302	13,657	[c]46,874	1,237,833	47,721	53,514	60,979	162,213	5,400	1,405,446
1936	1,180,392	13,490	63,227	1,257,108	45,615	52,461	60,348	158,424	4,700	1,420,232
1937	1,190,838	14,393	62,275	1,267,506	42,757	51,339	59,937	154,033	5,600	1,427,139
1938	1,161,173	14,111	60,775	1,236,058	40,676	49,869	58,032	148,577	4,700	1,389,335
1939	1,149,873	14,235	62,076	1,226,185	40,456	52,130	57,169	149,755	5,000	1,380,940
1940	1,139,314	13,841	65,431	1,218,587	37,161	49,574	56,923	143,657	5,000	1,367,244
1941	1,113,368	14,505	65,505	1,193,378[a]	31,604	48,370	55,852	135,826	5,500	1,334,704
1942	1,085,669	15,455	64,760	1,166,134[a,b]	28,312	48,283	55,661	132,256	5,000	1,303,390
1943	1,056,180	14,164	63,880	1,134,484[a,b]	32,902	50,992	55,564	139,457	6,500	1,280,441
1944	1,032,001	13,221	62,324	1,107,778	32,792	49,652	53,903	136,347	6,000	1,250,125
1945	973,130	12,715	59,788	1,045,633	32,687	51,358	50,376	134,421	6,000	1,186,053
1946	935,312	11,851	59,229	1,006,392	31,828	51,648	48,261	131,737	6,000	1,144,129

Compiled by the Lake Superior Iron Ore Association.

Authority: Annual Mining Directory of Minnesota (Tax Commission figures); Mine Appraiser of Michigan; Tax Department of Wisconsin.

[a] Minnesota range figures for 1941, 1942 and 1943 only, differ slightly from figures in Tables 2 and 3, which include ore in state lands not under lease.

[b] Includes Fillmore Co. limonite ore: 250(000) tons in 1942, 260(000) tons in 1943.

[c] Estimated from figures published beginning 1916.

[d] Interpolated on basis of published figures for 1925, 1930 and 1935.

TABLE 4—*U. S. Lake Superior Reserves Classified as to Direct Ore and Concentrate, and as Open-pit and Underground, in 1939 and 1946*[a]

THOUSANDS OF GROSS TONS

Ore Classification	Year	Minnesota Ranges—on May 1				Michigan Ranges—on January 1				Wisconsin on Jan. 1	Total Michigan and Wisconsin	Total All Ranges
		Mesabi	Vermilion	Cuyuna	Total Minnesota	Gogebic	Marquette	Menominee	Total Michigan	Gogebic		
Direct shipping	1939	988,546	13,632	54,578	1,056,756	40,456	52,130	57,169	149,755	5,000	154,755	1,211,511
	1946	779,640	11,523	49,337	840,500	31,828	51,648	48,261	131,737	6,000	137,737	978,237
Concentrate[b]	1939	143,967		7,325	151,292							151,292
	1946	145,263		9,725	154,988			[b]	[b]		[b]	154,988
Mine stock piles	1939	17,360	603	174	18,137	[b]	[b]	[b]	[b]		[b]	18,137
	1946	10,409	328	167	10,904	[b]	[b]	[b]	[b]		[b]	10,904
Total reserves	1939	1,149,873	14,235	62,077	1,226,185	40,456	52,130	57,169	149,755	5,000	154,755	1,380,940
	1946	935,312	11,851	59,229	1,006,392	31,828	51,648	48,261	131,737	6,000	137,737	1,144,129
Open pit	1939	719,245		23,944	743,189	[c]	[c]	[c]	[c]	[c]	[c]	743,189
	1946	555,167		19,746	574,913	[c]	[c]	[c]	[c]	[c]	[c]	574,913
Underground	1939	413,268	13,632	37,959	464,859	40,456	52,130	57,169	149,755	5,000	154,755	619,614
	1946	369,736	11,523	39,316	420,575	31,828	51,648	48,261	131,737	6,000	137,737	558,312
Mine stock piles	1939	17,360	603	174	18,137	[b]	[b]	[b]	[b]	[b]	[b]	18,137
	1946	10,409	328	167	10,904	[b]	[b]	[b]	[b]	[b]	[b]	10,904
Total reserves	1939	1,149,873	14,235	62,077	1,226,185	40,456	52,130	57,169	149,755	5,000	154,755	1,380,940
	1946	935,312	11,851	59,229	1,006,392	31,828	51,648	48,261	131,737	6,000	137,737	1,144,129
Decrease in reserves in 7 years		214,561			219,793						17,018	236,811
Total shipments—7 years (1939–1945, incl.)		391,820			420,721						106,202	526,923

Compiled by The Lake Superior Iron Ore Association.

Authority: State Tax Commission of Minnesota; Mine Appraiser of Michigan; Tax Department of Wisconsin.

[a] Figures do not include ore in state lands in Minnesota not under lease.

[b] Included in totals.

[c] Included with underground.

TABLE 5—*Mine Shipments of Iron Ore,*[a] *1942–1946, Inclusive*

District	1942		1943		1944		1945		1946	
	Gross Tons (Millions)	Percentage of Total	Gross Tons (Millions)	Percentage of Total	Gross Tons (Millions)	Percentage of Total	Gross Tons (Millions)	Percentage of Total	Gross Tons (Millions)	Percentage of Total
Lake Superior: Minnesota, Michigan and Wisconsin	93.01	87.10	85.98	85.85	81.86	85.52	75.96	85.35	59.59	84.58
Southern: Alabama, Georgia, Virginia, Texas, and Missouri	9.21	8.63	8.53	8.52	7.40	7.73	6.66	7.48	6.45	9.16
Eastern: New York, Pennsylvania, and New Jersey	3.08	2.88	3.19	3.18	3.50	3.66	3.62	4.07	2.24	3.18
Western: Wyoming, Utah, California, New Mexico, Arizona, Nevada, and Washington	1.48	1.39	2.45	2.45	2.96	3.09	2.76	3.10	2.17	3.08
Total	106.78	100.00	100.15	100.00	95.72	100.00	89.00	100.00	70.45	100.00

Compiled by The Lake Superior Iron Ore Association.

Sources: U. S. Bureau of Mines, Lake Superior Iron Ore Association, and others.

[a] Exclusive of by-product pyrite cinder and sinter from various sources.

seems to offer the chief available source of a large supply to meet the deficiency when the inevitable decline of open-pit ore production gets to the hunger line.

In addition, there are the large tonnages of low-grade hematite ores. Methods for their concentration are being studied intensively but have not yet reached the stage where a finished product that is commercially attractive can be produced. Probably it will be necessary to grind these ores very fine, then roast them in a reducing atmosphere so that the iron material can be magnetically separated. Another problem, however, is to agglomerate these finely ground concentrates—from whatever source produced—into a product suitable for furnace use. Intensive research is being done on these problems. Several steel companies and ore-producing companies have been engaged in a cooperative program for over three years, and most of them, and other companies also, are working in their own laboratories to the same end. When this research will have arrived at the proper answer is still to be demonstrated.

TABLE 6—*Mine Shipments of Lake Superior Iron Ore, 1850 to 1946, Inclusive*

THOUSANDS OF GROSS TONS

	Minnesota Ranges				Michigan-Wisconsin Ranges							
	Mesabi	Vermilion	Cuyuna	Total Minn.	Gogebic	Marquette	Menominee	Baraboo and Mayville Wis. Dists.	Total Mich-Wis.	Total U. S. Ranges	Canadian Ranges	Total Lake Superior District
1850 to 1900 Incl.	31,390	15,191		46,581	31,201	59,833	34,033	327	125,394	171,975	65	172,040
1901	9,005	1,786		10,791	2,938	3,247	3,619	22	9,826	20,617	233	20,850
1902	13,331	2,084		15,415	3,659	3,865	4,613	30	12,167	27,582	303	27,885
1903	12,894	1,677		14,571	2,939	3,040	3,750	28	9,756	24,327	203	24,530
1904	12,157	1,283		13,439	2,399	2,852	3,075	94	8,420	21,859	118	21,977
1905	20,159	1,677		21,836	3,706	4,236	4,495	132	12,569	34,405	170	34,575
1906	23,821	1,793		25,614	3,642	4,057	5,110	144	12,953	38,567	122	38,689
1907	27,492	1,685		29,177	3,633	4,388	4,965	96	13,082	42,259	143	42,402
1908	17,258	842		18,100	2,700	2,414	2,679	122	7,915	26,015	151	26,166
1909	28,178	1,109		29,287	4,088	4,253	4,875	83	13,299	42,586	196	42,782
1910	29,200	1,203		30,403	4,316	4,393	4,238	92	13,039	43,442	188	43,630
1911	22,099	1,089	48	23,336	2,603	2,836	3,911	116	9,466	32,802	155	32,957
1912	32,045	1,845	305	34,195	5,006	4,203	4,711	104	14,025	48,220	88	48,308
1913	34,040	1,567	733	36,340	4,532	3,968	4,967	145	13,612	49,952	165	50,117
1914	21,468	1,017	868	23,352	3,569	2,492	3,222	106	9,388	32,741	208	32,949
1915	29,757	1,734	1,128	32,619	5,478	4,106	4,983	81	14,648	47,266	369	47,635
1916	42,526	1,947	1,716	46,189	8,490	5,410	6,365	219	20,484	66,673	230	66,903
1917	41,441	1,531	2,422	45,394	7,980	4,874	6,046	137	19,036	64,430	265	64,695
1918	40,399	1,193	2,479	44,071	7,937	4,354	6,379	98	18,768	62,839	188	63,027
1919	32,004	929	1,859	34,792	6,230	2,992	4,447	93	13,761	48,553	168	48,721
1920	37,150	1,007	2,192	40,349	8,763	4,608	6,569	130	20,070	60,419	114	60,533
1921	16,350	869	490	17,709	2,337	1,117	1,584	52	5,090	22,799	53	22,852

1922	28,064	1,212	1,496	30,772	6,221	2,818	4,079	110	13,229	44,001	14	44,015
1923	41,806	1,279	2,221	45,306	6,580	3,892	4,855	138	15,465	60,771	27	60,798
1924	29,142	978	1,469	31,589	5,160	3,175	3,837	135	12,307	43,896	[b]	43,896
1925	35,890	1,438	1,514	38,842	7,068	4,198	5,270	157	16,693	55,535		55,535
1926	38,251	1,586	2,083	41,920	7,537	4,435	5,946	132	18,050	59,970		59,970
1927	32,976	1,548	1,981	36,505	6,385	4,148	5,213	93	15,839	52,344		52,344
1928	35,399	1,671	2,098	39,168	6,540	4,299	4,842	7	15,688	54,856		54,856
1929	43,008	1,874	2,596	47,478	7,624	5,410	5,645		18,679	66,157		66,157
1930	31,067	1,885	1,929	34,881	5,064	3,634	3,609		12,307	47,188		47,188
1931	15,270	1,141	898	17,309	2,908	1,809	1,469		6,187	23,496		23,496
1932	1,935	217	99	2,250	673	357	308		1,338	3,589		3,589
1933	13,472	740	741	14,953	2,401	2,807	1,511		6,719	21,672		21,672
1934	14,650	785	533	15,968	2,287	2,474	1,335		6,096	22,064		22,064
1935	18,877	857	798	20,532	3,071	3,266	1,634		7,971	28,503		28,503
1936	31,459	1,064	1,305	33,829	4,630	4,628	2,164		11,422	45,251		45,251
1937	45,933	1,453	1,775	49,161	5,661	5,748	2,649		14,058	63,219		63,219
1938	13,304	930	582	14,816	2,278	1,476	980		4,734	19,550		19,550
1939	30,315	1,417	1,291	33,023	5,346	4,908	2,161		12,414	45,437	111	45,548
1940	45,668	1,547	1,734	48,949	5,976	5,920	3,103		15,000	63,949	361	64,310
1941	59,773	1,847	2,441	64,061[a]	6,301	6,254	4,131		16,687	80,748	463	81,211
1942	70,280	1,925	3,036	75,300[a]	6,238	6,541	4,930		17,709	93,009	487	93,496
1943	64,906	1,779	3,066	69,971[a]	5,487	5,601	4,903		15,991	85,962	451	86,413
1944	62,509	1,539	2,538	66,586	5,604	4,790	4,876		15,271	81,857	499	82,356
1945	58,369	1,446	3,016	62,831	4,304	4,585	4,241		13,130	75,961	1,019	76,980
1946	46,326	1,330	2,354	50,010	3,717	3,270	2,591		9,578	59,588	1,440	61,038
Total......	1,482,812	78,547	57,933	1,619,572	253,207	237,982	214,918	3,223	709,331	2,328,903	8,767	2,337,670

Compiled by The Lake Superior Iron Ore Association.

[a] Includes Fillmore Co. limonite: Shipments,

1941 .... 47 tons
1942 .... 59,171 tons
1943 .... 220,427 tons

Total .... 279,645 tons

[b] Less than 500 tons.

TABLE 7—*Mine Shipments of Lake Superior Iron Ore during Last Five Years to Lake Ports and All Rail, 1942–1946, Inclusive*

THOUSANDS OF GROSS TONS

	1942	1943	1944	1945	1946	Total 5 Years, 1942–1946	Percentage of Total (5 Years)
U. S. Ranges:							
Mesabi	70,280	64,906	62,509	58,369	46,326	302,390	75.55
Vermilion	1,925	1,779	1,539	1,446	1,330	8,019	2.00
Cuyuna	3,035	3,066	2,538	3,016	2,354	14,009	3.50
Total Minnesota	75,300[a]	69,971[a]	66,586	62,831	50,010	324,698[a]	81.12[a]
Gogebic	6,238	5,487	5,604	4,304	3,717	25,350	6.33
Marquette	6 541	5,601	4,790	4,585	3,270	24,787	6.19
Menominee	4,930	4,903	4,876	4,241	2,591	21,541	5.38
Total Michigan-Wisconsin	17,709	15,991	15,270	13,130	9,578	71,678	17.90
Total U. S. Ranges	93,009	85,962	81,856	75,961	59,588	396,376	99.03
Canadian Ranges:							
Michipicoten	487	451	482	514	610	2,544	0.63
Steep Rock	.....	.....	17	505	830	1,352	0.34
Total Canadian	487	451	499	1,019	1,440	3,896	0.97
Total Lake Superior	93,496	86,413	82,355	76,980	61,028	400,272	100.00

Compiled by The Lake Superior Iron Ore Association.

[a] Includes some ore taken from S. E. Minnesota in 1942 and 1943.

Future of Our Steel Plants

The prosperity of the United States is based upon a plentiful supply of high-grade, cheap furnace feed, convenient to ample reserves of coking coal and both near markets for the finished product—steel.

When any one of these three factors gets out of balance, our economy will suffer. It is because of this fact that the iron-ore situation in the Lake Superior region is of paramount importance, not only to the great industrial centers in the lower Lakes region but to the nation and to the world as a whoel.

Should the ore production of the Lake Superior region be seriously

TABLE 8—*Mine Shipments from U. S. Lake Superior Iron-ore Ranges, 1942–1945, Inclusive*

THOUSANDS OF GROSS TONS

	Mesabi Range			Five Other Ranges			All U. S. Ranges		
	Open-pit	Underground	Total	Open-pit	Underground	Total	Open-pit	Underground	Total
1942, tons	67,642	2,638	70,280	4,129	18,600	22,729	71,771	21,238	93,009
Percentage of total	72.72	2.84	75.56	4.44	20.00	24.44	77.16	22.84	100.00
1943, tons	62,214	2,692	64,906	4,212	16,844	21,056	66,426	19,536	85,962
Percentage of total	72.37	3.13	75.50	4.90	19.59	24.49	77.27	22.73	100.00
1944, tons	60,186	2,323	62,509	3,467	15,881	19,348	63,653	18,204	81,857
Percentage of total	73.53	2.84	76.37	4.23	19.40	23.63	77.76	22.24	100.00
1945, tons	56,580	1,789	58,369	3,316	14,276	17,592	59,896	16,065	75,961
Percentage of total	74.49	2.35	76.84	4.37	18.79	23.16	78.85	21.15	100.00
Total 4 years	246,622	9,442	256,064	15,124	65,601	80,725	261,746	75,043	336,789
Percentage of total	73.23	2.80	76.03	4.49	19.48	23.97	77.72	22.28	100.00

Compiled by The Lake Superior Iron Ore Association.

TABLE 9—*Iron Ore, Steel, Pig Iron and Scrap Statistics of the United States, 1942–1946, Inclusive*[a]

THOUSANDS OF NET TONS

	1942	1943	1944	1945	1946
1. Iron ore shipped from mines	119,593	112,163	107,210	99,679	78,906
2. Total iron ore consumed	110,931	113,291	111,426	95,635	80,836
3. Lake Superior ore consumed	93,760	96,975	94,902	80,864	67,526
4. Pig iron produced (includes ferro-alloys)	60,903	62,770	62,866	54,919	45,379
5. Steel produced (ingots and steel for castings)	86,032	88,837	89,642	79,702	66,591
6. Pig iron consumed	59,042	60,315	60,952	53,187	39,949
7. Ferrous scrap consumed:					
Total[a]	60,265	61,651	61,359	56,191	43,442
Purchased scrap	27,136	26,614	25,923	25,230	20,435
Home scrap	33,129	35,037	35,426	30,961	23,007

Compiled by The Lake Superior Iron Ore Association. Authority: 1 and 2, Lake Superior Iron Ore Association and U. S. Bureau of Mines; 3, Lake Superior Iron Ore Association; 4 and 5, American Iron and Steel Institute; 6 and 7, U. S. Bureau of Mines.

[a] In all types of furnaces.

TABLE 10—*Annual World Production of Steel (Ingots and Steel for Castings)*

	1909–13 Avg.	1914–18 Avg.	1919–22 Avg.	1923–29 Avg.	1930–34 Avg.	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
North America:																	
United States	27.3	37.6	33.0	47.1	25.9	34.1	47.8	50.6	28.4	47.1	59.8	74.0	76.8	79.3	80.0	71.2	59.5
Canada	0.8	1.2	0.8	0.9	0.6	0.9	1.1	1.4	1.1	1.3	1.9	2.3	2.7	2.6	2.6	2.5	2.1
Total	28.1	38.8	33.8	48.0	26.5	35.0	48.9	52.0	29.5	48.4	61.7	76.3	79.5	81.9	82.6	73.7	61.6
Europe (except Soviet Union):																	
United Kingdom	6.6	8.9	6.6	7.8	6.7	9.9	11.8	13.0	10.4	13.2	13.0	12.3	12.9	13.0	12.1	11.8	12.9
Sweden	0.5	0.6	0.4	0.5	0.7	0.9	1.0	1.1	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2
Spain	0.3	[e]	0.3	0.6	0.6	0.6	0.6	0.1	0.6	0.6	0.7	0.6	0.6	0.7	0.6	0.6	0.6
France	3.8	1.9	3.2	7.8	7.0	6.2	6.6	7.8	6.1	7.8	4.3[f]	4.2[f]	4.4[f]	5.0[f]	3.1[f]	1.7[f]	4.3[f]
Belgium	2.1	0.3	1.0	3.2	2.9	3.0	3.1	3.8	2.2	3.1	1.9	1.6	1.4	1.6	0.6	0.7	2.2
Luxemburg	0.8	1.1	0.8	2.1	2.0	1.8	2.0	2.5	1.4	1.8	1.0	1.2	1.6	2.1	1.3	0.3	1.3
Germany	14.3	13.9	9.0	12.3	8.9	16.2	18.9	19.5	22.3	22.0	20.5	27.7	28.0	30.0	25.0	2.0	2.7
Saar	[d]	[d]	0.9	1.7	1.7	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[e]	[e]
Czechoslovakia	2.3	2.7	0.8	1.5	1.1	1.2	1.5	2.3	1.8	2.3	2.4	2.4	2.4	2.6	2.5	0.9	1.7
Austria			0.3	0.5	0.3	0.3	0.4	0.6	[d]	[d]	[d]	[d]	[d]	[d]	[d]	0.2	0.2
Hungary			0.1	0.4	0.3	0.4	0.5	0.7	0.6	0.8	0.8	0.8	0.8	0.8	0.7	0.1	0.4
Poland	[a]	[a]	0.9	1.1	0.9	0.9	1.1	1.5	1.4	2.0	[e]	[e]	[e]	1.5	1.4	0.5	1.2
Italy	1.0	1.1	0.8	1.7	1.6	2.2	2.0	2.1	2.3	2.4	2.3	[e]	1.9	[e]	[e]	0.4	0.6
Total	31.7	30.5	25.1	41.2	34.7	43.6	49.5	55.0	50.1	57.1							
Soviet Union:																	
(Europe and Asia)	3.9	4.7	0.2	2.6	6.5	12.3	16.1	17.5	18.1	18.5	19.5	[e]	[e]	[e]	[e]	15.0	18.0
Asia:																	
Japan (incl. Korea and Manchuria)	0.2	0.6	0.9	1.6	2.7	4.9	5.6	5.7	6.4	6.6	6.8	6.7	6.9	7.7	5.8	1.1	0.6
India	0.1	0.1	0.2	0.4	0.7	0.9	0.9	0.9	1.0	1.0	1.3	1.4	1.3	1.4	1.3	1.3	1.2
Total	0.3	0.7	1.1	2.0	3.4	5.8	6.5	6.8	7.2	7.7	8.3	8.8	9.0	14.2	14.7		
Australia	[b]	0.1	0.2	0.4	0.3	0.7	0.7	1.1	1.2	1.2	1.3	1.7	1.7	1.7	1.5	1.4	1.3
Other Countries	[c]	[c]	0.1	0.2	0.3	0.3	0.6	[c]	[c]	[c]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
World Total	64.0	75.0	60.5	94.4	71.7	97.7	122.3	132.5	106.3	133.0							

Prepared by The Lake Superior Iron Ore Association. Data from U. S. Tariff Commission Report 128; *Steel* magazine; Reports of the U. S. Bureau of Mines; American Iron and Steel Institute; Reports of Statistical Office of United Nations; and other sources.

[a] Included with Soviet Union.
[b] Less than 50,000 tons.
[c] Estimate included in total.
[d] Included with Germany.
[e] Data unavailable.
[f] Excluding Alsace-Lorraine.

decreased, and if abundant ores from elsewhere were not made available in the lower Lakes area, it would mean that much of our steel industry eventually would be forced to migrate to the eastern seaboard—and perhaps to the Gulf to utilize seaborne imported ores. There would be nothing to attract any appreciable percentage of the steel industry westward from the Lakes. Such a migration to the seaboard would effect vast changes, of far-reaching consequences, not only in what we now regard as the "industrial heart of America" but in the entire nation and its economy. There is, of course, the possibility that the recent discoveries in the Labrador Peninsula ultimately may reveal very large reserves which might provide ore for the Lakes furnaces as well as to the eastern seaboard. But regardless of that possibility, within relatively few years, the Lake-based steel industry must begin to equip itself with plants capable of concentrating low-grade ores—either in the Lake Superior or the Eastern district, or in both districts—into material usable in its furnaces. Otherwise it must resign itself to a declining steel production when the Lake ore supply begins to be insufficient, and elect to watch its present plants gradually become of secondary importance as they yield to expansion of plants elsewhere in this country.

Whether the decline in production from commercial reserves becomes material in five or ten years, or not until later, the period is too short to permit a passive course.

Conclusions

Your assumption is correct that I have not written this paper as a prophet of doom for the steel industry dependent on Lake ores. Our own company is an important part of this industry and I can assure you that we are not contemplating any slow disappearance of our business. Our company has taken steps to assure itself an adequate ore supply. Others have followed a similar policy. Nevertheless, the industry as a whole faces dire shortages in a period too short to be comfortable.

I believe the situation will be met with that energy and determination that has always characterized our steel industry. But the problem is before us, not yet behind us.

With regard to the larger picture—that of the future of the iron-ore supply of the world—I want to express my personal conviction that any serious shortage of the supply is farther into the future than I can foresee. Our civilization, which is so firmly based on steel, is not going to find its foundation disappearing. Rather will that civilization grow and spread more widely among the human population of the globe.

Furthermore, I am frankly skeptical of the idea that future wars or atom bombs may wipe out the race or our civilization. I am confident that civilization will not plunge into the abyss of oblivion. The human race is tough. It is not moribund. It is not going to permit all the good things we have built on a foundation of steel to be taken away from it. It is going to demand and get more and more of the goods that make our civilization possible.

Three quarters of the human race, to modify an overworked remark of the recent past, are ill provided with machines, transportation and communications. In other words, they have too little steel. Consequently they are ill clothed, ill housed, and ill fed. They lack the mechanical equipment to multiply the effectiveness of their labor sufficiently to provide for themselves the comforts and necessities of civilized living.

They will demand these things and they will get them. They will make vastly greater use of the world's iron resources.

It has been estimated that we in the United States are today using a billion and a quarter tons of iron and steel. It is the equipment with which we operate our present economy. When most other peoples of the earth acquire similar proportions of machines—which they must have if they are to enjoy a similar economic level of life—many billion tons of iron and steel must be provided for the manufactures they must make or acquire by trade.

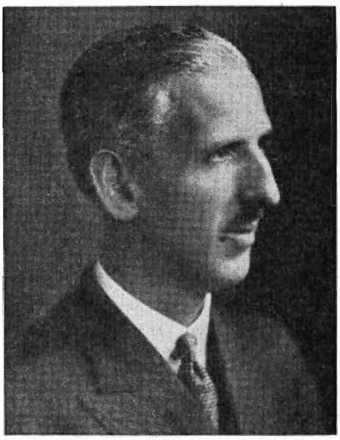
This iron and steel will not all be produced from what we now consider actual ore. More and more must come from that vast supply of what we in our present ignorance know only as potential ore. Initially it will cost the world considerably more to make a ton of iron from this raw material.

But engineers and industrialists have a way of making great progress under the spur of necessity. Hence there is every reason to believe that when the abundant low-grade iron ores have become the principal sources on which the world must depend for its iron and steel supplies, engineering achievements will rapidly overcome present handicaps to the utilization of these deposits.

All mankind—if willing to work together intelligently—can look forward to long enjoying, in greater abundance than heretofore, the many good things that iron and steel make possible for better living.

International Aspects of the Petroleum Industry of the Future

By Sir William Fraser



SIR WILLIAM FRASER

As Chairman of the Anglo-Iranian Oil Company, Sir William is a key figure in the petroleum industry of Great Britain and of the world. He was educated as a chemical engineer and has been identified with the oil industry since 1909. In 1939, he was knighted for his long and valued service to his country. He was elected an Honorary Member of the A.I.M.E. in 1946.

Since the operative word in the subject on which I have been asked to speak is "international," I need hardly emphasize before such an audience as this that it is one which calls for some discretion on my part at the present juncture of world affairs, since, in some respects, it may not be devoid of a controversial aspect. For though the war is over, it has left behind it a sorry state of health in the political and economic complex of the world we live in; and however different may be the impact of these factors on each of us, yet none of us can any longer hope to devise a system or policy to escape from much of its controversial heat, or evade the obligation of doing what we can to diminish it.

I would like, therefore, to consider with you how one great form of world enterprise whose range is coextensive with material civilization itself—that is, the Petroleum Industry—can make and is competent to make, a contribution to international health; for it is now an agreed commonplace that oil is arterial in the world's system and we need no telling that a healthy body needs healthy blood.

Before embarking on my subject, let me assure you that I have no need to be told that this country before all others—and for obvious reasons—is the major sounding board of opinion in matters affecting most aspects of the petroleum industry—technical, economic, national and international (but, may I please add parenthetically, not to the exclusion of quite a volume of sound from other quarters). I am, indeed, conscious of the fact that much of what can be usefully said to you may be somewhat devoid of novelty, since it will probably have already been better expressed by responsible men or by responsible papers in this country.

Clearly, any review of the international aspects of the petroleum industry must be prefaced by some allusion to their major determinant, which is, of course, the extreme disparity, in most parts of the world, between national oil assets and domestic oil needs.

Oil as a source of power stands apart from coal, although, in terms of energy generated, coal is of greater importance. But coal reserves are so widespread that only few nations are completely without indigenous supplies; in consequence the coal trade has developed mainly as a national rather than as an international industry. Petroleum, on the other hand, has been developed quite differently and under a system which is much more highly integrated internationally

The Oil Age

I do not intend to produce—nor do I think you will want—a mass of speculative figures concerning the much debated subject of world oil reserves. I must, however, dwell a little on this; though, in doing so, I want to confine myself to the subject of natural petroleum to the exclusion of what is often, but I think possibly wrongly, regarded as the natural second-line reserve; that is, oil derived from shale and coal. My own earliest oil experience was in the Scottish shale industry—not a large one as oil industries go, but, notwithstanding its physical handicaps, a very efficient one. The ratio of human effort and consequent costs to all other expenses in winning oil from solid mineral deposits seems to me so prejudically high that I cannot foresee these so-called second-line resources ever succeeding free petroleum without material detriment to national economy unless there be a complete revolution in current production technique. I may be wrong but, anyhow, I do not feel that this need worry us unduly, since I am far from taking a pessimistic view as to the character of the world's aggregate stock of petroleum. And when, in the fullness of time, even this begins to approach exhaustion, it may well happen that more elemental and less exhaustible sources of power will have been brought under effective control and the Oil Age, as we know it, be near its allotted end. However, I refuse to feel despondent about this indefinite future.

The increase in world consumption of petroleum gives a measure of the increase of world mechanization, and it is significant that consumption doubled every ten years from 1880 to 1930. The years of depression, civil rationing and war had their effect and the next doubling took 15 years;

from 1930 to 1945. I make no attempt to estimate the future, but there can be little doubt that we must plan for a continuing increase. There is also nowadays a growing tendency, which must not be overlooked, for oil to replace coal in many of its uses by reason of changing economic factors.

Apart from what it has done to revolutionize all our ideas of mobility, the oil age has opened up possibilities of human betterment unattainable under any earlier system of power control; but there still remains a vast scope for betterment, particularly among those teeming millions in the Far East whose very lives are dependent on primitive methods of transport and agriculture.

Oil now flows in so many ways into the main currents of human activity that it might not be unreasonably urged that the national per capita fuel consumption is in direct relation to the national standard of industrial and agricultural welfare.

The International Problem

It is, as I have already said, the extreme disequilibrium in national resources which makes the international problem. Dame Nature, always capricious, has here been exceptionally so. The future may bring some surprises, but it certainly looks as though two great continental zones, Australasia and Africa, are not possessed of large deposits in any way comparable with those of the major oil zones, judging at least from the very disappointing effort-discovery ratio. Admittedly there is a case for thinking that certain areas may make modest contributions to the world total—New Guinea is a case in point—but I know of no present reason for thinking they will be sensational. The great mass of Africa is geologically continental and therefore appears to be excluded from any hopeful speculation. With the major exception of Soviet Russia, and a minor exception for such countries as Romania and Hungary, Europe too seems to be in an almost similar plight. In respect, incidentally, to that small part of it known as Great Britain, it is unfortunate that wide and prolonged search by well equipped British and American concerns has been but poorly rewarded and, so far, discovery, though valuable, is too slight to boast about.

So here we are, faced with practically three continents which seem likely to remain the indigent oil clients of the remaining two.

Taking now a brief glance at the remaining two, we are again faced with a very varied distribution of liquid wealth. The United States is, first and foremost, the greatest industrial country in the world, the greatest consumer and the greatest producer of oil and the fortunate possessor of great home resources. How long these resources can stand up to the heavy annual demands made on them is a hotly debated question in expert circles, but it does appear that the outlook is sufficiently obscure to occasion understandable anxiety in the minds of competent judges. Active exploration, on a scale and with a drive distinguished by great technical ingenuity, has proved and will surely continue to prove new areas from year to year; but concern for the future is naturally also influenced by the rising standard of consumption. So, surely, it would be idle to question the prudence of a policy aimed at safeguarding this uncertain future by recourse to external sources of supply.

If this be true of your country, the home of oil production, it must apply very much more strongly to your many infinitely poorer relations in the world of oil, and it is this great task of making the oil resources of the world available in so far as possible to those who need them which, in the future even more than in the past, will in my view constitute both the duty and the opportunity of our great international industry. This task, involving as it does an extremely wide range of activity, will not be an easy one; but I am quite confident that as an industry we can carry it out, and I am equally certain that in doing so efficiently and fairly we shall be making a very important contribution to the peace and well-being of the world.

Sources of Oil

Looking now at the major producing or potential areas in somewhat more detail, a large element of insurance is naturally provided by the great proved and possibly even greater unproved oil deposits in the southern zones of the American Continent, in most of which the home demand represents only a small portion of the disposable production, so that a large surplus is left free for export. I think we must assume that the tendency will be for this surplus to be more and more attracted to the United States and less and less to more distant and less well placed consumers. Therefore, as a factor of insurance it seems to be less attractive as a dependable long-term source of supply elsewhere than to the U.S.A. The tempo of this selective tendency may be checked, of course, by large new discoveries—which seem most probable—but it is clear that it can no longer be ignored in future planning. And thus the international perspective brings ever more clearly into view the oil wealth of Asia, and very particularly of those areas loosely grouped under the term "Middle East."

As you are aware, it is only some three years ago, and after visiting some of these areas, that a Commission sponsored by the U.S.A. Government, under the leadership of Dr. De Golyer, reported that:

> The center of gravity of world oil production is shifting from the Gulf-Caribbean area to the Middle East—to the Persian Gulf area—and is likely to continue to shift until it is firmly established in that area. . . .

This Commission went to considerable pains to appraise the position

The conclusion was that the Middle East countries possess proved or semi-proved reserves on a scale comparable with those of the U.S.A., and that the scope for new discovery is very much greater. If I were now reviewing the Committee's statistics in the light of present knowledge, I should say that they did not err on the side of exaggeration.

The operating advantage that the Middle East has over most other oil-field areas is compounded of high yield per well, large individual fields and complete freedom for unit development. The proved reserves at present are contained in six fields in Iran, two in Iraq, one in Kuwait, three in Arabia, one in Bahrein Island, and one in Qatar Peninsula. The individual fields are also of giant size. Two of them, Masjid-i-Sulaiman and Haft Kel in Iran, have already produced about 100 million tons each; and a third, Kirkuk in Iraq, is approaching the 50-million-ton mark. In terms of current rate of output, after only the great East Texas field, Haft Kel has the distinction of being the largest producing field in the world. East Texas is producing at the rate of about 17 million tons per year from, I am told, about 24,000 wells, whereas Haft Kel is producing 9 million tons per year from 24 wells.

The natural production advantages of the oil fields of the Persian Gulf area have been to a large extent offset by certain physical drawbacks. The long tanker haul to European markets, involving a circuit of Arabia and the passage through the Suez Canal, has been a substantial handicap; yet further trouble was once occasioned by the intractable quality of the crude oil for the production of high-grade motor spirit, but this has already been eliminated, not without cost, as a result of advance in refining technique. The geographical disadvantage still remains, but may be much reduced when the projected large-diameter trunk pipe lines from the Persian Gulf area to the Mediterranean are eventually in position.

Petroleum Engineering

The technical experience gained in the Iranian limestone oil fields has had far-reaching influence on subsequent developments there and elsewhere. The early drilling program at Masjid-i-Sulaiman was based on then current practice in sandstone fields; and the well spacing in those pioneer days was arranged in an understandable ignorance of the nature and magnitude of the underground oil reservoir. Some 250 wells were drilled, whereas later experience has shown that perhaps only 50 wells would have sufficed.

Since those days, petroleum engineering practice has evolved with an ever-widening appreciation of scientific principles. Under the unit system of development, it has been possible to conserve reservoir energy in such a way as to ensure optimum well production and flowing conditions throughout the life of a field.

The more recent field of Haft Kel has been developed in the light of this gradually acquired knowledge and experience, applied to these unit conditions. Hence, although only 24 wells are currently in production, 16 others have also been drilled for observation and control of gas-oil and oil-water reservoir levels. The cumulative effect has been to make possible the exceptional production rate of this field while at the same time ensuring maximum oil recovery from the structure. The newer oil fields of White Oil Springs, Gach Saran and Agha Jari are being similarly developed.

Early experience in Iran indicated that similar possibilities and conditions might govern the oil prospects of Iraq, which rank very high indeed. The formation of the Iraq Petroleum Co. was an outstanding event in the development of international oil affairs. The great oil fields of Kirkuk was discovered in 1927 and the transdesert pipe lines carrying Iraq oil to Mediterranean terminals were completed in 1934, since when the field has been producing to the pipe-line capacity of around 4 million tons per year, except for temporary interruptions during the war. Further pipe lines are now under construction, to permit a greatly augmented production.

Foreign Concessions and Social Progress

The latest phases in the effort to establish a comprehensive view of the actual and potential wealth of this great Middle East oil zone, which has been so much extended in recent years, arise from American enterprise in Bahrein and Saudi Arabia, Anglo-American in Kuwait, and that of the Iraq petroleum group in Qatar and elsewhere.

Complementary in great measure to the international significance to the oil consumer at large of all these discoveries is their relationship to the social and economic structure of the States in which they have been made, for it would clearly be wrong to regard these States—any more than they do themselves—as merely passive recipients of the material profits that accrue to them.

As far as the concessions that primarily establish this relationship are concerned—perhaps I may be pardoned for concentrating on those in the Middle East, with which I am most familiar—they are modern in character and bring into relief a multitude of desiderata apart from that of finding oil and of paying the concessionary duties. It seems to me that a fair balance has, in fact, been established in the overall contractual relationship. To countries whose pre-oil budgets were often painfully attenuated, the new outlook must surely be highly gratifying. Not only does it promise the means for many measures to the national advantage, which once seemed financially excluded, but, and perhaps equally important, it brings opportunities for employment and vocational training on a very large scale and on many levels of technical and manual capacity.

From experience in Iran, which predates that of other oil enterprises in the Middle East, one can point with some pride to all that has been done to ease, and often to revolutionize, the general living conditions as they once existed in the operational zone. Early oil pioneers would be at a loss to identify the conditions under which they and their helpers once worked with the character of the amenities that have since been and are still being provided in the general interest of all classes of workers, by way of housing, medical, social, educational and other services.

Far be it from me, however, to claim that this is peculiar to Iran. Rather, let me say, I think it represents—though not unfavorably so—a stage in the normal evolution of large-scale oil enterprise in territories which, apart from oil, are often singularly barren of natural or industrial resources.

Apart from this, the social progress which I have mentioned as being a derivative of well-conducted oil enterprise often extends beyond the range of the enterprise itself, for it tends to give a general stimulus to social progress. Even in these cases, however, it is sometimes possible for the concessionary company itself (for instance, in matters concerning medical service and technical training) to give much appreciated advice or assistance. All these things make for good feeling and understanding and are, therefore, not unrelated to the international aspect.

The successful conduct of large operations in strange lands among nations whose general ways of life are not ours is, you will agree, largely dependent on the purely human side of the contact. In this particular connection, nothing, surely, is more likely to ensure the amicable nature of this relationship than a working knowledge, with all it implies, of the languages currently spoken in the oil-producing lands, especially among those who look forward to spending there much of their working career. I look to a time when, by steady encouragement, it will be normal rather than exceptional for such men to acquire this knowledge. The benefit of it will be felt in many ways.

The International Outlook

I am convinced that it lies within the range of those who serve the industry in other lands to render good service to the cause of international amity in many ways additional to observance of the letter and spirit of the concessionary relationship—always provided, of course, that they sedulously avoid any attempt (or any suspicion of one) to air their views or meddle in matters of internal politics. Nothing could be more calculated to create distrust and undo all the good done in other spheres of the work. We are all inclined to look askance at the foreign critic, however well meaning he may be.

And now let me make a confession. When first requested to give my views on certain international aspects of our industry, I asked myself: "What do my American friends mean by international?" I hoped they did not mean political. I know, of course, that many matters have been much discussed and many are still under review on the political level; and that, as in so many similar issues, the road to unanimity is a very toilsome one. However, it is difficult to escape the idea that the international oil industry may be regarded in certain quarters as one susceptible to some measure of ultra-commercial integration. If this idea substitutes state regimentation in some form or another for the element of healthy commercial competition, I must candidly say I think it underrates the capacity of the industry to conduct its own affairs on a proper level of competence. Equally, however, I feel that the idea of such commercial competition should not, and need not, eliminate that of cooperation within the limits of what is economically beneficial to producer and consumer.

Within such limits as these it is not only in respect to policy governing world production and world trading that concepts of cooperative action have for some considerable time played a part on the international level of thought. Indeed, the discussions that we are now engaged in here are, in effect, not unrelated to a long and helpful series of meetings in which scientific, technical, and other aspects of the industry have been reviewed by experts from various countries, free from any undue deference to limitations imposed by frontier lines or inventive precedence. In short, they are inspired by what we may fairly call an international outlook, even though the ideal and the reality are not always reconcilable.

Out of the long period of international instability through which we have passed has been born, in a very natural sequence, a vastly increased sense, throughout the nations concerned, of their extreme dependence on petroleum under war as under peace conditions. Not that, in the center of affairs, this had not been long the case. We need only recall the historic words of Clemenceau and Curzon, uttered long ago, regarding the equivalence of a drop of petrol to a drop of blood, or the voyage to victory on a sea of oil, or words of similar import from others on this side of the Atlantic.

It is of course no matter for human pride that those arts in which science and industry have marched side by side in the path of civilization have also been so decisively mobilized in times of international hostility. But, in passing, I should like to record my own impressions that the Petroleum Industry provided in a manner unexcelled by any other a most capable reinforcement of personnel to those on whom then devolved the supreme official direction of affairs; and in the public interest a most thorough integration of its resources. Those competitive energies that were healthily normal in days of peace were catalyzed, may I say, into one dynamic unity.

However, considerations relating to national and international security lie outside the scope of this paper. My aim has been to illustrate, and to confine myself to illustrating, how one great international industry has a full realization of its own position, its own problems, and its own responsibilities in contributing to the health of a world at peace—and I must leave it at that.

Copper, Lead and Zinc Mining in the Future

By Clinton H. Crane

CLINTON HOADLEY CRANE

No one enjoys the universal respect of the mining and metal industries more than Mr. Crane, who became President of the St. Joseph Lead Company in 1913 and served in that capacity until he became Chairman of the Board on June 1, 1947. He was the organizer, and for many years has been President, of the Lead Industries Association. In 1936 he was awarded the William Lawrence Saunders Gold Medal for distinguished achievement in mining.

When I agreed to accept your Committee's suggestion that I talk to you at this meeting on the future of copper, lead and zinc mining, I could not help wondering why I had been chosen to be a prophet. Knowing the pious nature of your committee, I thought I had better look up and see what the Bible says about being a prophet, and what the dictionary definition of a prophet is. The word "prophet" comes from the Greek and is defined as "one who speaks through a divine inspiration." Also, in the Gospel of Saint Matthew, Christ tells us that a prophet is "not without honor save in his own country and in his own house." That gave me pause until I remembered that after all, I had started my professional career as a Naval Architect, not as a Mining Engineer, and consequently, this might be a clue to the fact that the eminent geologists of this society, who know infinitely more about the world's crust than I do, were passed over in this assignment. In thinking back, I then remembered that the first really successful prophet was Noah and that Noah was a Naval Architect. Here then was the answer. One more quotation from the Bible I shall take as my text: In Ecclesiastes, chapter I, verse 9: "The thing that hath been is that which shall be." Now, with this preamble, and not being bound by anything save inspiration, I will proceed to prophesy:

As far as the next 15 to 25 years are concerned, from the studies made by

Messrs. Leith, Pehrson, Shea and others, there is no doubt that the ore reserves in copper, lead and zinc are ample to continue to produce at the current rate, and even at an increased rate. These ore reserves are based on existing mines and mining districts and are qualified on the basis of present costs, and reasonably conservative guesses as to the future selling prices of the metals involved. For lead, 6 cents a pound is used as the price. The reserves of lead at 20 cents would be infinitely greater than the reserves at 6 cents, undoubtedly. Just what they would be if we should make the price a dollar, who can say? It is quite apparent that we must go farther afield for our supplies as the near-by sources are exhausted. The world, in spite of the airplane, is still a fairly large place and there are a number of places in it that have not yet been explored adequately. My prophesy for the next hundred years is that there will be enough of these three metals for every essential need and I do not feel that this society can very well expect me to go beyond that point. I am likewise comforted by the fact that no matter how wrong I may be, no one here is going to be in a position to blame me.

Essential Needs

I should like to define a little of what I mean by "essential needs." Each one of these three metals, copper, lead and zinc—and in fact, all and each of our mineral resources—has certain qualities that are irreplaceable by any other; for instance, copper in the building of electric motors, lead for storage batteries and shot, cannot be replaced by any other known substance. The price of a commodity is only partly dependent on its usefulness. A substance that is in plentiful supply may be essential and yet may be entirely free. We could not exist without oxygen and yet we pay nothing for it in our daily use except the physical effort of drawing it into our lungs. Steel, without which our modern civilization could not exist, is cheaper to buy than either copper, lead or zinc. Just imagine chopping down a tree with a lead axe, or even with a copper axe. In the bronze age, only limestone could be drilled with copper tools. We are paying more than ten times as much for cadmium as for lead or zinc, but I venture to say that if no more cadmium were produced we could get along very happily without it.

All three metals of which we are talking are used principally in the capital goods industries, which are much more subject to ups and downs than the consumer goods industries—consequently, in boom times there is nearly always an apparent shortage, which is followed in periods of slumps by a real glut. I remember very well a meeting on lead 22 years ago, of the Mining and Metallurgical Society of America, when everybody was talking about the lead shortage. Lead was then selling at 8½ cents London, 9½ cents New York, but only seven years later more lead was being produced than could be consumed and prices had dropped to 2 cents London, 2¾ cents New York. We can all recollect a time when the copper industry in this country had accumulated such stocks that a large loan was placed in order to carry this great surplus.

Basis of Price

We should remember that the price must be high enough to pay all the expenses not only of mining, milling, smelting, refining and transporting, but in the long run sufficient overage to pay the cost of exploration and capital equipment. The human animal being what he is, the mines that are nearest to market will usually be first exploited and exhausted. They will also contain marketable by-products, that could not be transported a long distance. The sulphur content of the ore in a New York, New Jersey or Pennsylvania mine is valuable; the sulphur content of the ore in an Arizona or Utah mine is wasted from the top of a tall smokestack and not only is of no value but may cause damage, which adds to the cost.

The human animal is also extremely wasteful. We have only to consider the slaughter of our herds of bison for the sake of their hides, the destruction of our wonderful forests of white pine in Maine and Michigan, to realize that man left to his own devices has nowhere near the self-control of a pig, which, I am told by my farmer friends, rarely eats more than is good for him. We can expect, then, that at the present prevailing high prices, all our equipped mines will be driven to their full capacity, with no thought of the future. The search for ores all over the world will be intensified. In the past, in this country particularly, the finding of ore was the most poorly paid occupation in the world except possibly fishing. The prospector was paid largely in "hope." The fact that a handful made fortunes induced the large majority to work for bare sustenance. In the more settled parts of the world, this era is coming to an end. The mines that show on the surface in the civilized parts of the world have probably mostly been found. Let us hope that the metal-mining geologists may learn from our oil friends some cheaper method than drilling to search the earth's crust for the concentration of minerals that are necessary to form a mine.

Sources of Minerals

Do not forget, however, that in going farther afield we sometimes overlook the near-by deposits. I have faith that the eastern part of the United States and Canada may still contain substantial deposits of minerals. Our own mine at Balmat, N. Y., is after all not more than 20 years old, and there are evidences of mineralization from Maine to Alabama.

I am going to say nothing about the recovery of metals from scrap except that, judging from the past, in the future all possible recovery will be made of metals that have already been used, and a proportionately greater amount will be put on the market in hard times than in good times—which always greatly annoys the primary producer. So far, most of the world's lead and zinc have come from Europe, Australia and North America. Their combined area is roughly 14,000,000 square miles, but to date they have produced almost 95 per cent of the lead. The three great continents, Asia, Africa and South America, have a combined area of 35,000,000 square miles and they have produced little lead to date. There seems to be no particularly good reason why these great continents should be barren, although probably it would be unwise for anybody to apply the simple equation $^{35}/_{14}$ multiplied by the content of Europe and North America and Australia, as representing what there is elsewhere. In my early days with the St. Joseph Lead Co., one of our banker directors who was used to figuring said, "Why, you are mining about 20 acres a year and you have 65,000 acres, so we have probably got lead enough to last 3,000 years!"

Although copper usually has sold for from three to four times as much as lead, it was not until in the '30s that the world's production of copper exceeded the world's production of lead. Back in the '80s actually twice as much lead was being produced as copper, although at that time copper was selling for four and a half times as much as lead. However, most of this lead was being produced as a by-product of silver. The value of the silver in the ore was roughly twice the value of the lead—in other words, silver, the money metal, was acting as a premium price plan on the lead production of the world. I venture to say that without the silver buying of the United States of America, it would have ceased to be quoted by the ounce.

Relation of Price to Use of Metal

In Table 1, showing the prices for copper, lead and zinc by decades since 1880, there is a column for lead plus silver, in the making of which it was assumed that each pound of lead contained 0.05 ounces of silver. During this period of large cheap lead supply, there was virtually no other outside paint than white lead and red lead. The farms of New England, as anyone who has been there will remember, were almost completely covered with lead paint. With rare exceptions, it was the only paint that could be bought in the country stores. Almost all the plumbing of the world was lead; in fact, plumbing takes its name from the Latin word for lead. With the passing years, however, lead has almost ceased to be used for plumbing, except for special purposes, and in the paint trade much less lead is being used today than there was 20 years ago, and infinitely less actually than there was 60 years ago. So does price affect the uses of a metal.

Although the generalization that the price must be high enough to pay all expenses of mining, milling, smelting, refining, transportation, and the cost of exploration and capital equipment must be true in the long run, it is quite fallacious as applied to a particular time. Here another element comes in, which for the sake of brevity let us call *Y*, which may act either as a plus or minus. If there is a scarcity in a raw material, *Y* becomes a plus factor; if there is an oversupply—that is, more on hand to be sold than customers are prepared to buy—*Y* becomes a minus quantity, and this minus quantity may very well bring the price to a point where all allowance for capital charges or exploration charges are wiped out for even the lowest cost producer, and the high-cost producers may be put out of business altogether. On the other hand, in times of scarcity, the price may run far in excess of the normal charges. One has only to look at the fluctuation in the price of lead between 2 and 11 cents, and copper between 6 and 30 cents, and zinc between 3 and 16 cents, to realize how important this factor *Y* may very well be. In going over the prices for the past 60 years (Table 3), it is surprising to notice that in the '30s our three metals were selling for lower prices in actual dollars than they were in the '80s, in spite of the fact that wages had risen nearly tenfold. A dollar a day for ten hours of work was quite common then; in fact, just as common as a dollar and a half for one hour of work is today. Our engineers, metallurgists and chemists can rightly be credited with this amazing performance—mechanization that has enabled one man to do the work of ten to twenty, or improved metallurgy that has made immensely valuable ore bodies that formerly were worthless. Differential flotation made a great mine in Canada earn more in a month than the amount it was sold for in the early part of the century. Zinc is now recovered from the ore and not penalized by the smelters. The slag piles of our western smelters, containing from 10 to 18 per cent zinc, are relics of this wasteful period. A pound of coal produces nearly five times as much power today as it did in the '80s.

We do know that we are approaching perfection when we recover 98 per cent of a product and produce a kilowatt for less than a pound of coal. Whatever may be said of atomic energy, I am certain that we cannot continue to advance wages in a like proportion over the next 60 years without raising the prices of our various metals. In fact, it is certain that no improvement in metallurgy or machinery can bring costs in the '40s to where they were in the '30s. There is still the unknown quantity *Y*. In the longer future, will demand for metals continue to be greater than the supply, or will it be enough less so as to confine production to the old properties that already have been developed? A consideration of this unknown quantity must come on the desk of the major executives who are deciding the policies of their companies. Engineers left to themselves are bound to be very conservative, they are bound to assume that the metal prices of the future will bear some relation to the metal prices of the past. I think very few engineers would care to recommend the development of a copper property with costs over 10 cents, of a lead property with costs over 6 cents, or of a zinc property with costs over 7 cents, and I am sure their estimated prospective value of the precious metals contained in the ore will be equally conservative. There is still the unknown quantity *Y*. Will the demand continue to be so great that the factor *Y* is a plus quantity? That is dependent, of course, very largely on the ability of society to work together and to continue to consume the world's wealth, to produce commodities useful to man. We are now so dependent on each other, our jobs are so specialized, that unless we all work together, we cannot count on a plus *Y*.

TABLE 1—*Prices of Metals at London*

CENTS PER POUND

Period[a]	Lead	Silver	Lead plus Silver[b]	Copper	Zinc
1880–1889	2.84	97.871	7.73	12.34	3.53
1890–1899	2.43	69.241	5.89	10.85	4.21
1900–1909	3.06	54.448	5.78	14.61	4.73
1910–1919	4.84	67.377	8.21	18.11	8.79
1920–1929	5.67	63.423	8.84	13.58	6.40
1930–1939	3.13	38.325	5.05	8.21	3.13

[a] 1880–1919, rate of exchange used 4.86; 1920–1929, rate of exchange used, 4.52; 1930–1939, rate of exchange used, 4.63.

[b] Assuming average of 1 per cent lead and 1 ounce silver in ore; thus 20 pounds of lead to 1 ounce of silver.

The United States has been using between five and ten times as much copper, lead and zinc per capita as the rest of the world. It has been doing this because it has been able to produce in its own borders enough more of the things that the world wanted, to draw to itself the things which it could use. This particular 6 per cent of the world's population, although they are of the same stock as the population of Europe, has been more productive per capita than any population in the world. This must have something to do with the so-called "American system," in which the members of this Institute are among the leaders. As we go farther afield to acquire the metals we are going to need, the exploration, mining and smelting of the world needs American capital, but most of all, American geologists, engineers and metallurgists to direct it. We are more wanted by the other nations of the world than ever before, and are less suspected of having ulterior objects of conquest.

It would be very easy at this time to be discouraged and to predict a dark future. The unrest of the past year, the importation of foreign leaders by our labor unions who, in spite of the failure which has been made by the countries they have left, feel they have a right to tell us how to run ours, might well cause us to fear for the future. However, one thing that I have noticed in my life, not only in my own life, but in the study of history, is that Cassandras have never been popular and almost never have been believed. I am no Cassandra. I believe in the future and I believe in the leadership of the members of this society.

TABLE 2—*Metal Price Ratios—London Prices*

Period	Lead[a]	Copper[a]	Ratio Cu to Pb	Zinc[a]	Ratio Zn to Pb	Silver[b]	Ratio Ag to Pb
1880–1889	13.07	56.87	4.35	16.27	1.24	48.094	3.68
1890–1899	11.22	50.00	4.46	19.41	1.73	34.025	3.03
1900–1909	14.08	67.34	4.78	21.80	1.55	26.756	1.90
1910–1919	22.32	83.45	3.74	40.51	1.81	33.109	1.48
1920–1929	28.12	67.32	2.39	31.70	1.13	33.676	1.20
1930–1939	15.12	39.71	2.63	15.14	1.00	19.866	1.31

[a] Pounds per long ton.
[b] Pence per Troy ounce.

TABLE 3—*Metal Production*

THOUSANDS OF SHORT TONS

Period	Copper	Lead	Zinc
1880–1889	2,356	5,006	3,217
1890–1899	3,909	7,510	4,516
1900–1909	7,227	10,491	6,990
1910–1919	12,077	12,230	9,721
1920–1929	14,268	15,398	11,443
1930–1939	17,761	16,225	14,272
Total 60 years	57,598	66,860	50 159

The Future of Gold in World Economy

By P. M. Anderson

In recent years many prophets have arisen who hold that gold has outlived its days and that its monetary use is now an anachronism. These prophets include well-known politicians, economists and businessmen. Some of them have called it a joke that metal should be dug up at heavy cost in Africa and elsewhere and shipped to the United States of America only to go underground again at Fort Knox. Others have claimed that all the gold in the world could be sunk in the ocean without anyone being the poorer. The fact that you have invited me to address you on the future of gold may perhaps reflect the fears caused by these various predictions.

PETER M. ANDERSON

Born and educated in South Africa, Mr. Anderson started as a mine sampler and surveyor and advanced steadily in responsibility to become Managing Director of the Union Corporation and chairman of its seven important gold-mining subsidiaries. He has served five terms as President of the Transvaal Chamber of Mines; has an honorary doctor's degree from the University of Witwatersrand and honorary membership in the Institution of Mining and Metallurgy (London).

At present the prophets' taunts show no sign of coming true. The demand for gold is greater than ever before, although stocks held are the largest in history. Nearly all governments have gone to great lengths to suppress any demand that might be made by the public; they have reserved to themselves the right to hold gold and have lost no opportunity of satisfying their own demands. Where the public has been allowed to buy gold, the demand has proved impressively strong. In India the price of gold equals about $82 per fine ounce, having been $90 earlier in the year; in Egypt $65 to $70, after having been $87, and elsewhere it is even higher. In Palestine, for instance, the golden sovereign is traded at about £5, equivalent to $86 per fine ounce, having been nearly £6, equivalent to some $100 per fine ounce, earlier in the year. Mexico and Brazil are at present selling gold to the public for the equivalent of $40 per fine ounce. In Switzerland, the National Bank, which holds enough gold to exchange its whole note issue, started a few years ago to issue gold coins, but gave up when it found that immediately they disappeared from circulation. In other European countries, where dealings in gold coins are illegal and therefore take place in what is called the "Black Market," premiums of gold coins not only on local currencies but also on dollars are very much higher.

Sales of Gold to the Public

In the United States, the use of gold in the arts has soared in recent years. The last reliable figure known to me is for 1943, when the U.S. Mint reported a release of 2,466,952 ounce fine of new gold to industry and arts. This was slightly less than the record of 1919, of 2 and ⅔ million ounce fine (2,665,545). Since 1943, consumption in the United States has increased further and new records probably have been established. In that year, the output of gold in the United States was only 1.4 million ounce fine (1,394,552 ounce fine) and in following years about one million. During the past 3 years, therefore, America's gold output was less than half its nonmonetary consumption. This increased demand for arts is in part no doubt a response to the prosperity of the United States, but it also arises from the essentially monetary desire to put aside against hard times something that is not subject to Government whims and caprices.

No official statistics have been provided for the sales of gold to the public in India or in most of the Middle East, nor for arts and hoarding in the western world, but estimates show that during the past 3 years nearly one third of the world gold production outside the U.S.S.R. has been bought by the general public. Such a proportion is not exceptionally high.

What is exceptional is the suppression by the monetary authorities of the public's demand for gold. Until the economic crisis of 1929, the public used to buy nearly one half (47.4 per cent in the 20 years 1909 to 1928) of the gold produced. The trust of the people of Asia in gold as a treasure has not diminished. India has recovered from her economic depression and is a creditor on international account instead of, as for a long time past, a debtor. Her people are certain to be buyers of gold in substantial amounts for a long time to come. As soon as they gain free access again to gold, their effective demand will rise over that of the 1920s. China too is on the point of becoming a buyer of gold. She has ahead of her, one hopes, the prospect of a long period of peace and of capital assistance from the United States. If so, she will acquire a measure of prosperity unknown to her for decades. Nothing would be more natural then than that her 450 million people should develop a strong demand for both silver and gold.

The Middle East too has attained new levels of prosperity and has changed from the position of debtor to creditor in international account. For many years to come the peoples of the Middle East will not only be able to acquire more gold than ever before, but are likely to be most anxious to do so. Gold will not for a long time lose its appeal as a treasure in these countries, and the demand will fluctuate with their level of prosperity. Therefore, provided governments will permit so much, it is not too optimistic to assume that Asia and the arts will once more absorb close on one half of the world production of gold, even though the rate of production has doubled since the 1920s.

APPEAL OF GOLD IN THE WESTERN WORLD

But what of the western world, which is the market for the other half of the world's potential output of gold? At present the appeal of gold, or—to put it differently—the mistrust of fiat money, is so strong that the remainder of the gold produced would find its way readily into the coffers of the public, as would also a part of the gold held by the monetary authorities if the public were given access to it. The western world, and in particular Europe, has twice faced the physical destruction of war and the attendant depreciations in the value of all kinds of paper money. Not unnaturally, the western world is safety minded in monetary matters, but at the same time it is highly enterprising. Generally speaking a policy of "safety first" has only a limited appeal, except when people feel that the monetary authorities are incapable of maintaining the value of paper money. The public want safety and at the same time such economy of gold as their exchange position requires. Hence, monetary authorities must try to bring into harmony these two trends. In the western world, therefore, the underlying tendency is to economize in gold. Irrespective of what they may do as individuals, people as nations are bent on increasing their earning capacity, and they prefer to apply their savings in the first place to this end. To build factories at home or to invest abroad is their chief aim—an aim made even more desirable by a costly and destructive war.

In my view, the time will come when the public in the western world will be content once again voluntarily, and not as at present compulsorily, to let their governments administer the gold stocks on their behalf and to have this done as economically as possible. True, they have shown their governments that they retain the right to mistrust any fiat money, but we need not assume that the present monetary hazards will become permanent. On the contrary, in examining the future of gold in world economy I shall assume that a well-ordered administration will be reestablished in all relevant countries and that monetary authorities will be advised by the best contemporary experts in their respective nations.

The question I have put to myself is this: What part will be accorded to gold by the monetary authorities of the western world? How will they view the need for gold for monetary purposes? When will ordered administration be re-established? It is presumed that they will think and act in a rational way even though they and their legislatures are as much subject to prejudices and political emotions as anyone else. I assume, therefore, that they will look upon the monetary system as they would upon a tool, something necessary to assist the nations in their economic pursuits. Gold then will be regarded as one of a number of instruments designed to help the production of goods and services as efficiently and smoothly as possible.

CONTRIBUTION OF GOLD IN ECONOMIC MACHINERY

I want to emphasize that my faith in gold and my belief that the governments of the western world will continue to make use of gold in their monetary systems rest on the real and practical contribution that gold can make to the efficient and smooth working of our economic machinery. Even economists have been puzzled when confronted with the problem of gold postulated in this way. Apparently they fail to realize that monetary systems that do not use gold, or do not do so in sufficient measure, are exposed to holdups and restrictions, which cost them more by loss of output than would the use of gold. The task of gold in the monetary system may be compared with the task of reserve equipment in, say, an electric power system, which pays well enough, though put to use only occasionally, by preventing breakdowns in the power-consuming industries at the peak periods. This comparison illustrates only one of the tasks performed by gold in the economic system of the western world. In the past, gold has promoted efficiency mainly in three ways: (1) by acting as a reserve of "universal" purchasing power—a reserve of international legal tender, as it were; (2) by guaranteeing and, indeed, enforcing a measure of moderation in monetary experiments, either because of gold circulated as coin or because it was used as backing to paper money; and by introducing into the monetary system an element of steady expansion.

To what extent can gold contribute in future in these ways? I will begin my review with the third and least appreciated quality; namely, as a means of steady expansion to be infused into a monetary system. In this respect gold is unique. Apart from a few early bursts of exceptional growth due to the accident of discoveries, the output of gold during the past 100 years has permitted the stocks available to the world to grow at an average rate of

2.5 per cent per annum at compound interest. Since 1860 the rate has never been more than 3.8 per cent and never less than 1.4 per cent; any changes were slow and regular, the extremes being separated by periods of not less than 25 years. In the period between the two wars, the rates of growth were never more than 3.1 per cent and never less than 1.7 per cent.

These rates compare with a rate of expansion of total world economic activity of 4 per cent per annum calculated by one of your most renowned statisticians, the late Dr. Carl Snyder, of the Federal Reserve Bank of New York. If one takes into account that during this time economies were developed in the use of gold, and that therefore the required rate of growth of available gold was somewhat below the rate of growth of trade, it is plain that trade and gold production moved very much in step. There is a rhythm in the production of gold in its relation to total gold available, and to the total economic activity, which neither the ingenuity of man nor the intervention of governments has appreciably affected. This fact continues to commend gold as a monetary medium that cannot be tampered with, and is indeed a much stronger reason for its use than tradition or mythical faith in the metal, strong as these are.

Future Output

Now let us consider the future output of gold. In South Africa, the world's largest gold producer, the output in 1945 was approximately 12,200,000 fine ounces, having fallen to this figure from the record high production of approximately 14,400,000 fine ounces in 1941. This decrease was due to restrictions imposed by the war, which caused severe curtailment of development and prevented the opening of new properties and the expansion of some existing places, which otherwise might have compensated for the diminishing output of some of the older mines during that period. Development and the opening of new properties is now proceeding as rapidly as postwar conditions permit, but it may well be that the downward trend of production that has taken place over the past four years will continue a little longer before the rate of new development overtakes the closing down of older mines.

Estimates made in 1941 by the most competent authorities on the Rand predicted that the industry would continue until about 1952 to produce between 14,000,000 and 15,000,000 ounces fine of gold per annum, after which there would be a gradual falling off to say 7,500,000 ounces in 1970. Since these predictions were made in 1941, there has been the setback caused by war conditions mentioned above, and more recently there has been conclusive evidence that the new gold fields to the southwest of the Rand in the Odendaalsrust area of the Orange Free State will, in due course, be substantially larger producers of gold than was anticipated in 1941. I incline to the view that the effect of these new Orange Free State gold fields will not be to increase the annual output of gold in South Africa above the figure previously predicted—i.e., 14,000,000 to 15,000,000 ounces fine per annum—but rather to delay the onset of the decline in production to a date much beyond the year 1952.

Sixty years ago, when the Rand reefs were discovered, the production of gold in South Africa was negligible, but by the end of the last century it had grown to about one fourth of the world output. Since the South African war at the beginning of this century, South Africa has contributed more than 40 per cent of the world's output of gold, while for the 10 years 1920 to 1930 the ratio reached a peak of over 50 per cent. This great activity in gold production has been the backbone of South Africa's whole mining, industrial and financial expansion. A measure of this expansion is the average rate of growth of economic activity, which, calculated in physical terms, has been more than 5 per cent per annum at compound interest for over 30 years.

In the light of our present knowledge, it is not unreasonable to expect that South Africa will still be producing gold on a substantial scale at the end of the present century. The gold-bearing area is vast but in some of it the ore lies at great depth, so that much will depend on the solution of problems associated with deep mining.

Many previous long-term forecasts of the future gold production in South Africa have proved in time to be very wide of the mark. Like these previous forecasts, the rough picture of the future I have given may well be upset by changes in the price of gold, changes in working costs or in taxation, or by the discovery of some new fields. Viewed, however, in the wider light of the future of gold in world economy, there seems no chance that any such changes would be so radical as to affect the views expressed in this paper.

With regard to the production of gold in the rest of the world, there may be material changes over a period in the contributions of individual countries, but it seems reasonable to expect that in the aggregate the previous trend of production will be maintained. Practically nothing is known of the actual or the probable output in Russia. Some estimates speak of 3 million ounces, others of 5 million per annum; but as every million ounce fine is equivalent to less than one tenth of one per cent of the gold stocks in the rest of the world, the uncertainty is not material for the purpose of our present estimate.

In any event, it seems certain that for a considerable time to come gold will be added to the existing world stocks at a steady rate of between 2 and

3 per cent per annum; therefore I conclude that, if made the basis of money management, gold would induce a steady expansion of money very much in line with the probable expansion of world economic activity.

Distribution of Gold

With regard to the distribution of gold it is true, of course, that since the first World War gold has not flowed in a steady stream to the various countries, but has accumulated in a few particular ones. These accumulations were mainly due to money movements in consequence of two world wars and their attendant disorders. The fact that in those years money was managed by governments and banks with hardly any regard to the influx of gold has tended to accentuate such movements. It is now accepted that, where such movements do not originate in the economic necessities of a country, they should be controlled so as not to affect the monetary system. Bretton Woods in particular recommends this kind of control and the governments are resolved to stop needless money movements. Before such movements have abated, however, we cannot expect gold to be made the basis of money management.

When they have ceased, will the nations of the western world return to using gold as money at home? I am confident they will, but probably they will do so gradually and by stages. This restoration of gold in the national sphere will follow upon recognition of freedom as the main organizing and constructive principle in the western world. Experience teaches the lesson that freedom of enterprise and the use of gold are closely related. Where there is little room left for freedom of enterprise, there is no room left for gold; where there is no gold, there will be hardly any freedom of enterprise. Where societies are organized on the basis of free enterprise and free movement, the citizen has a right to mistrust economic or political conditions and to dislike monetary experiments. By buying gold he can express his opinion by a kind of poll without waiting for a general election. Will this right be restored or has the citizen now an infinite trust in his national money? We know well, and so do governments, that he has not yet acquired such a trust. Otherwise there would be no reason for preventing the citizen from owning gold. Nor will he ever trust fully any money whose output is limited by nothing more than the wisdom of officials of whom he knows little, or by the vote of a parliament. In an emergency the modern citizen is prepared to abide by the decisions of the majority and to follow the lead of his elected Government. When the emergency has passed, however, he will assert his right to go his own way, to trust and mistrust as he thinks fit, wherever he lives in a free country.

The Right to Own Gold

At present the western world is divided between countries that have been badly damaged or exhausted during the war, and need further time to recover, and countries that have come through unscathed. In the latter, the two emergencies of economic depression and of war have passed. These countries can afford to let their citizens have gold, and no doubt their citizens will in the end claim and get their right. I believe they will do so in the near future in the United States and in most of the British Dominions, in many Latin American countries and in Sweden and Switzerland. In some of these countries, for instance in Switzerland and Sweden, the citizen has never lost the right to own gold, although at present he cannot draw it from the Central Bank. Once the right to own gold like any other commodity has been restored, the monetary authorities will naturally try to economize in the accumulation of gold. They will keep an appropriate stock of gold so as to give the citizen an assurance that legal tender can always be exchanged for gold. In this way, gold can be reintegrated into the domestic monetary system, without legally binding the monetary authorities to contract or expand money in close correspondence to the influx or efflux of gold. But I want to emphasize that in the devastated countries of Europe this process will be delayed, perhaps for a long time. In all of them gold can be bought only against foreign exchange. Their governments will continue to give priority to the import of food, raw materials and equipment, and to the payment of war debts until they feel certain that their international account is balanced. It is unlikely that they will use gold other than as a reserve for international payments.

I cannot predict how much gold will be gradually absorbed by individuals and governments for domestic purposes. That depends upon how much can be spared from the larger and more urgent outlet provided by the need for gold to be accumulated in the hands of the monetary authorities as a reserve of "international legal tender." For a long time the domestic market will get only the leavings. When a greater measure of confidence has returned, international intercourse and world economic activity will have expanded, and with them the stocks of gold kept as reserve of international money.

Gold as Universal International Money

Its usefulness as a "universal" international money in the near future will afford the main outlet for gold in the western world. International trade obviously will continue throughout the western world, mainly conducted by individuals, though partly also by government agencies. Balances will remain to be settled and foreign investments will be made for the good of both sides. Governments will want to reconcile the two claims, freedom of enterprise and security of employment, and for this purpose will experiment with their "national" money, or at least reserve to themselves the right to do so. The public abroad, including foreign governments, will not easily trust another government's "fiat" money, and the less they do so, the more the latter are likely to experiment with their "fiat" money for the sake of their economic stability at home. At the same time they will try by mutual agreements to limit the range of arbitrary interference. Bretton Woods and the Sterling Area Cooperation are instances. But the right to unilateral action has been reserved even in the Bretton Woods agreement. Had it not been reserved, it would still be exercised in what each nation considers to be an emergency.

Consequently, a stock of "universal" money will be indispensable, a stock of international legal tender free from the "fiat" of any particular government and acceptable to all. Its value to each nation is proportionate to the help it renders in an emergency, the recent war having clearly shown that a reserve of international cash money is as valuable in its way as are reserves of commodities and of equipment. Credits cannot always be arranged in time, or under proper conditions. A nation requires cash balances apart from reserves of raw material and equipment just as a large private enterprise does. Moreover, the more governments are expected to shield their internal economy from the effect of fluctuations of foreign balances, the greater is the need for a reserve stock of "universal" cash money. In the past, governments have been content to let the flow of foreign funds react to fluctuating interest levels, with inevitable consequences on business at home. They are no longer prepared to do so, and it stands to reason that even if political security were not at stake governments would need a greater margin of international cash for the sake of business stability.

Provided, therefore, that international trade outside the Soviet-controlled area is going to expand, and assuming that governments, for the sake of internal economic stability, will experiment with their money, the nations will need larger rather than smaller stocks of "universal" money for international trade than they needed in the past. On the other hand, Bretton Woods and the control of capital movements help them to economize with "universal" cash money. Without doubt this "universal" money will be gold, and not paper dollars nor paper sterling, nor even silver. The decisive fact is that in all countries people have shown and continue to show their preference for gold. This verdict has now been acknowledged by the monetary authorities of all countries, who continue to resort to gold as the unrivaled form of "universal" money. In international dealings gold has proved to possess universal and undisputed purchasing and debt-liquidating power. In fact, it possesses all the properties of an international legal tender. Before this audience I need not enlarge upon the physical qualities of gold that make it a perfect medium for money, as compared with all other media hitherto tried, in any conditions in which paper money is not trusted. If the world requires for its international dealings some kind of legal tender not subject to the whims of governments it, will certainly choose gold as its medium.

Amount of Gold Needed

How much will the world need for this purpose? New economic conditions tend to increase the need for stocks of "universal" money over what was required in the past. However, Bretton Woods and the control of capital movements provide an antidote.

The Monetary Fund (of the Bretton Woods agreements) affects the use of gold in two ways, one of which increases and the other reduces the demand for it. The Fund makes gold officially the general measure of money, and a number of provisions raises it to the status of legal tender in dealings with the Fund. In particular, the Fund is required to buy against deposits all the gold offered to it, and, unless a particular currency is declared scarce, to sell any of its existing deposits against gold at fixed prices. Fund deposits are convertible into gold. These provisions enhance the value of gold and facilitate its marketing. On the other hand, the Fund offers to the Central Banks opportunities of settling international balances by book entries with the Fund and by short-term credits. But the facilities of the Fund are so limited that they cannot make gold reserves unnecessary; at best, they may take the place of the services rendered by the international banks, which in the unsettled conditions of our time cannot function as efficiently as in the past. I understand that even the maximum credit that can be gradually raised from the Fund over 5 years hardly reaches 5 per cent of a member's quinquennial average trade and services payments abroad, whereas in the case of many members exchange revenues in a depression will drop by very much more than 5 per cent. Very probably, if the Fund is successful, it will save its members from some of the excess requirements otherwise caused by the political disturbances and monetary experiments of our age. It will, in fact, help to bring requirements back to normal without offsetting them entirely. Furthermore, any right to an overdraft is conditional upon the currency requested being needed for payments "consistent with the provisions of the Bretton Woods agreement." This clause may cover all normal trade payments in times of peace, but not necessarily payments in war. Lastly, the Fund will be domiciled in the U.S.A.; therefore, as far as all other countries are concerned, must be considered to be domiciled "abroad."

It comes down to this. The credit facilities of the Monetary Fund represent, as it were, a first line of defense. But will the nations be content with first-line defence? Will they not want second and third lines of defence nearer home upon which to fall back in an emergency, whether the emergency is trade depression, political unrest, or war?

The reply can be only speculative. Personally, I believe that for a considerable time to come most nations will want second and third-line defences under their own control, and therefore will accumulate gold for reserve purposes as soon as they have the means so to do. The Fund is an economizer of gold, particularly useful in a world that, because of the lowering of the international credit standing of nearly all countries, would have needed more gold than ever before, but it is no substitute for gold stocks.

Conclusions

Whether we review the position of gold against the background of present semi-inflationary conditions or from the viewpoint of orderly monetary administration and settled conditions of a better future, we may be confident that there is a ready market for all the gold that can be mined profitably at the present price. One half of the yearly output should in future again be absorbed by the people of Asia and by arts in the western world. The other half will serve the monetary system of the western world. The forms in which gold will be used in these monetary systems may differ in certain ways from what they were before 1931, but the quantities will be no less than they would have been under the previous conditions. For instance, the gold standard—i.e., the legal obligation to manage money on the basis of fluctuating gold stocks—will not be revived, but the right to own gold and to convert paper money into gold will be revived; not at once in all countries, but gradually and inevitably. Under the new flexible systems the need for gold will be no smaller than it used to be under the old rigid ones.

The prime necessity will be for reserve stocks of international legal tender. In many countries these gold stocks may be held separately, as were the exchange equalization stocks in Britain in the 1930s, and their fluctuations may not be readily disclosed. They may not even form part of the backing of the Reserve Bank Money nor be encumbered with any limit expressed as a percentage of the note issues. The second necessity is that gold may be acquired by the public or held in sufficient quantities by the monetary authorities for sale to the public if the latter should desire it. Gold will once more be available to the public, without obligation on the monetary authorities to sell it at the present price in all circumstances. However, those countries in the western world that may be described as the front-line or devastated areas of Europe will be very slow in giving their people access to gold.

The extraordinary movements of gold, which resulted in the holding by the United States of two thirds of all the monetary gold in the world, will not be repeated. These movements were due to noneconomic capital movements, which in future will be better controlled in most countries.

At the present price of the metal, gold will be produced in quantities sufficient for a steady expansion, but not in any great abundance. Gold will presumably be added to the world's stock at a rate closer to 2 per cent than to 3 per cent per annum.

The outlet for gold does not depend on particular forms of monetary policy; for instance, on a return to a gold standard. It depends, however, on the recognition of the economic freedom and independence of the individual. Orators have sometimes spoken of "nailing nations to a golden cross"—but in fact the integration of gold into monetary systems makes the individual less dependent on the vagaries of his own government, and nations less dependent on those of foreign governments and institutions. I am confident of the future of gold in world economy, because I am hopeful that a large measure of economic freedom will be restored throughout the western world in due course.

Acknowledgment

In conclusion, I wish to acknowledge the invaluable aid I have received in the compilation of this paper from the staff of the Union Corporation, and in particular from its economist, Dr. E. Stern.

Tariffs, Cartels, and the Mineral Industry

By Willard L. Thorp

WILLARD L. THORP

A noted scholar and economist, Dr. Thorp has served industry and his government for the past decade. He taught economics for nearly 10 years before becoming Director of the U. S. Bureau of Foreign and Domestic Commerce. He served as special adviser to the United States delegation at the Paris Peace Conference and has held many other important economic positions. He is now Assistant Secretary of State for Economic Affairs.

After the first session which Secretary Marshall had with the Foreign Relations Committee, the members of the press asked what he had said. His only comment in summarizing his two-hour conference was, "The world is in a very critical condition." Undoubtedly he had many different aspects of the world in mind, but I wish to underline today the truth of the statement with reference to the economic field.

V-E day was 22 months ago; V-J day was 19 months ago. The hoped-for world of peace and plenty gives signs of attaining the peace, but the plenty seems tragically remote. For great areas in the world, the present level of economic activity is very, very low. Men are not working; goods are not being produced; whole areas of activity suffer from economic paralysis. We in this country do not fully appreciate the situation because the United States is above prewar levels in economic activity. We are the exception. The same cannot be said for the world in general. There are still large areas where industrial activity is not more than half the prewar level.

A number of causes have brought about this situation and I am certain that I do not need to elaborate them. Global war, by definition, means not merely the effort to destroy the military forces of the enemy but to undercut the effectiveness of their military operation by destroying and disrupting the economic life which supports them. Modern methods of warfare proved to be so thoroughly effective in this destructive process that the heritage of the war in many countries is not merely the simple effects of conversion to war and undermaintenance during war, but the disastrous total loss of significant elements in the economy itself.

The problem is not merely one of physical equipment, of fixed capital. I could talk about the effects of the war on manpower, on the displacement of skilled management, and on the thousand and one elements that must all work together smoothly to create what we call a "going concern."

Nor is the problem merely one of the direct elements or factors of production. Financial resources are a necessary part of modern economic life. Enterprises must have working capital as well as fixed capital. Nations must have foreign exchange. Currencies must provide some assurance of stability, or goods are hoarded. Obviously, the burdens of war and the enormous requirements of reconstruction have put tremendous strains on the financial machinery and already there have been many sad instances where it has broken down entirely.

Political Instability

In addition to the physical destruction and the financial disturbances, still another deterrent is present in many countries in political uncertainty. Economic processes must be carried on within a framework of law and order or else they become threatened with piracy, theft and special privilege. The postwar period has seen the rise of political instability in many forms. Within some countries, a struggle for power is going on, with the result that whatever government may have formal authority, it is greatly limited in the extent to which it can take effective action. There are other areas of the world where native populations have achieved a new and uncertain independence and where the young, unseasoned governments have not yet established any firm pattern of new policy. Many of these areas are important to the world economy as sources of raw materials, and yet the increased uncertainties concerning their probable political behavior create a risk which stands in the way of immediate economic investment and development.

Under all these circumstances, it is not surprising that country after country has found it necessary to take all sorts of extraordinary measures. These vary from the operation of relief programs to the taking over of sections of industry for direct government control through the process of nationalization. Unusual fiscal measures are seized upon in the effort to prevent runaway inflation; and in the field of foreign economic relationships, most countries are now exercising controls through quota systems over the type of goods to be moved, and through foreign exchange control over the process of international payments.

These various steps should not be regarded as some conspiracy against the business community or even against the principles of freedom of enterprise. To a large extent, they are the inevitable consequences of the present state of the world, and more particularly of the countries where the distress is greatest. When we in the United States had a major economic job to do in producing the goods needed for the war, we found it necessary to establish many of these same types of control; and the foreign countries today have a much more difficult task.

It is inevitable that many of these controls should be essentially restrictive. They arise because of the necessity for allocation to the most essential use of some short facility or material. But this leads to a basic difficulty. If a number of countries all adopt restrictive devices, trade among them is established at a minimum. In fact, it must then be carried on by the painful procedure of bilateral barter agreements under which arrangements are made for the exchange of specific quantities of specific goods. Obviously, such a way of carrying on trade cannot help but fail to uncover most of the opportunities for working out transactions in the interest of all concerned. And it makes all trade dependent upon arrangements made by governments rather than by businessmen.

Up to now, I have pointed out that the world is in a critical economic state, and that the result of this necessarily has been a wide extension of government controls and restrictive devices. A third proposition, which I am sure I need only to suggest, is that there is no single grand action that can resolve these difficulties—no one remedy for the world's economic ills. The domestic rate of production, the volume of foreign exports, the volume of foreign imports, the convertibility of foreign exchange, the stability of domestic currency, the extent of reconstruction and rehabilitation and the standard of living are all completely intertwined with each other. Economists have sometimes tried to picture the operation of the economic system in terms of a series of complicated simultaneous equations. In mathematical terms, none of the elements I have been describing is an independent variable and it follows necessarily from this basic fact that any program to deal with the situation must contain a number of elements—and failure to act in any area provides a brake on the possibility of progress in the others.

Restrictions on Foreign Trade

I shall not endeavor today to outline the efforts made by the United States Government to deal with each of the variables in the international economic picture. We have provided goods and financial support to many countries through the very extensive relief program carried out by UNRRA. We have extended loans to foreign countries whose purpose has sometimes been to take care of foreign exchange deficits for items immediately needed, such as the (so-called) British loan and others for the purchase of goods needed for reconstruction, such as that made to France. We have sold ships and other surplus items on liberal credit terms. We have taken steps in other fields, but today I wish to speak in greater detail concerning the steps needed to deal with the restrictions that bear directly on foreign trade itself.

In the period before the war, interferences with trade were clearly on the increase. The world depression threw trade out of balance, and restrictions were used to prevent any drain on the assets backing the various currencies. Furthermore, it was a period when forces of aggression were leading countries to adopt nationalist economic programs, and many nations were endeavoring to reduce their dependence upon foreign sources of goods and materials Trade barriers rose rapidly.

However, the present picture is far worse. Much of the world's trade today is carried on within a framework of specific quota restrictions. These obviously are likely to be much more harmful than tariffs. The quotas are absolute and under no circumstances can trade expand beyond their rigid limits. Tariffs do impose a hurdle but it is always possible for goods to flow over a tariff barrier if there is a sufficient need for them. Quota systems carry with them another type of limitation not found in tariffs and that is that quotas necessarily imply allocation. A quota means that less can be imported than would move in a free market. But how will the reduction be made? By the government issuing specific licenses for specific imports. This means that the trade relationship of the quota-establishing country with each other country becomes a matter of separate controversy and negotiation. Thus a tremendous amount of specific government interference arises and the individual businessman is helpless in the face of decisions made by his and by foreign governments.

INTERNATIONAL TRADE ORGANIZATION

It is against this background that the United States put forward the proposal that an International Trade Organization should be established as one of the essential institutions of the United Nations and that a fundamental purpose of the organization should be to find ways and means of reducing barriers to trade. Here in this country, we went so far as to develop, through an interdepartmental committee, a proposed charter for such an organization. Last November, this whole problem was discussed in London by a commission consisting of representatives of 18 countries, which had been set up by the United Nations for the purpose. The American draft was taken as the basis of discussion. At the conference, a substantial part of the charter was agreed upon by the conferees although, of course, such agreement had no binding effect on the governments concerned.

Since the conference, the revised charter has been printed and distributed widely in the United States. The interdepartmental committee involved, the Executive Committee on Economic Foreign Policy, has held informal hearings in Boston, New York, Washington, Chicago, Denver, New Orleans, and San Francisco. In general, the hearings indicated widespread support for the general idea and a number of specific suggestions were presented which are now being given careful study in Washington.

However, it is not enough for the United States to urge that an international organization be established. For 14 years, as expressed in the authority given by Congress to the President, we have had as our national policy the negotiation of reciprocal trade agreements bilaterally, by means of which very carefully selected reductions in the American tariff were made in exchange for reductions in the trade barriers in the other country with which we were negotiating. Beginning in April in Geneva, we will carry on simultaneously the negotiation of 18 such reciprocal trade agreements and thus demonstrate, in no uncertain terms, our willingness to lower trade barriers, providing other countries will show their willingness to follow the same general course.

LEGISLATION WITH RESPECT TO INTERNATIONAL CARTELS

As we studied the area which should be covered by the International Trade Organization, it became clear that it was not enough merely to have as a general purpose the reduction of trade barriers imposed by governments. There are also restrictions on trade set up by private arrangements among businessmen. In general, these come under the label of international cartels. As a matter of fact, it might well be that if governmental restrictions were substantially reduced, we might find that these private restrictions would be greatly expanded, as a method of providing protection for the markets and profits of private businessmen.

This is, of course, an entirely new field for international action. Monopolistic practices are subject to varying types of regulation within various countries. We have our own Sherman Anti-Trust Law. But there has never been any international agreement providing, so to speak, legislation with respect to international cartels. I should certainly not want to indicate that the proposed charter is the last word on this general subject. Our own experience certainly indicates that efforts to deal with this problem require the most careful study of individual cases and that policy in this field probably must develop case by case. Nevertheless, the charter does establish the basic principle that world trade should not be restricted by international cartels and that private international agreements which have any such purpose should be subject to challenge and examination by the International Trade Organization. Furthermore, the governments that belong to the organization agree to take all possible steps, by legislation or otherwise, to prevent enterprises under their jurisdictions from engaging in practices such as price-fixing, market allocation and limiting production through international combinations.

ACCEPTANCE OF GENERAL PRINCIPLES

In view of the fact that there are substantial differences among the different countries with respect to their economic organization, their degree of industrialization and their legal institutions, it is obvious that there would be differences in point of view, when this subject was reached on the London agenda. There are many individuals in the United States who do not feel that our own legislation, and particularly its enforcement, have been completely successful in preventing the growth of monopolies and combinations in restraint of trade. Nevertheless, it is true that the United States and Canada are the only countries in the world that can point to any substantial effort to preserve competition. Some other countries have antimonopoly legislation or provisions in their constitutions but they have been much less active than we in an effort to make it effective. As you well know, most European industrial countries have at the least maintained a neutral policy toward industrial conditions, and in many cases have actually encouraged participation in international cartels. It is, therefore, of major significance that the London committee adopted the fundamental features of the United States draft charter as originally proposed.

In order to make the record clear, I should say that the final line adopted resembles the original American proposals rather than a more drastic suggestion advanced to the London meeting. We would have preferred to have the charter indicate that certain business practices are *per se* restrictive, and that there would be a clearcut presumption of guilt with respect to them. However, in its present form, the charter makes no *prima facie* assumption, but condemns these business practices whenever they are found to have restrictive effects. This of course means that the individual case will have to stand on its own merits. However, since one of the major contributions to be made by this whole procedure will be to bring these cases out into the open, it is perhaps more important at the present time to indicate the basis on which complaint can be made and to establish a procedure for dealing with it with appropriate publicity. The acceptance of the general principles by the member countries is the most significant development, of course. After all, our own approach to the problem has involved the "law of reason" and we are at last making a substantial approach to bringing reason into this important area in the international field.

World Trade a World Recovery Program

It is always a temptation to a speaker to take some single limited topic and to use his time in giving a carefully detailed analysis of its every angle. Today I want to be sure that you all see the whole program rather than the pieces—the entire machine rather than its carefully designed parts. For this purpose, I have pointed out that tariffs are public barriers to trade while cartels may be private devices to the same end. Thus the tariff and cartel provisions in our policy compliment each other in the world trade program, and world trade becomes in turn a part of a whole world recovery program. It is even more than that. Beyond recovery lies, we hope, a period of international economic cooperation. The principles now being advanced are those which provide the best possible environment for future trade to flourish, to realize to the full the possible expansion of world trade and employment.

I suppose that there is no general sector of international trade where the resolution of these many problems is more important for the world and for the United States than in the field of minerals. Men can decide to make cotton textiles at almost any point on the earth's surface but they cannot as easily proceed to obtain minerals within any particular set of political boundaries. Natural resources are where they are and individual countries are fortunate or unfortunate in this respect almost by chance.

One of the reasons of particular interest to the United States for trying to reopen the channels of world trade is the increased necessity for this country to be able to obtain raw materials from foreign sources. In some instances, the change in our situation caused by the war has been spectacular. For example, we have apparently shifted from being an exporter of lead to the necessity of importing substantial quantities of lead in the future. You who are concerned with mining and minerals have clearly a direct interest in the type of program which I have been describing.

And I should like to mention one other way in which your interest is involved. Many of you have spent much of your lives in other countries, and may spend more. American capital and American know-how have played a very important part in the discovery and development of the world's natural resources. In the past, such projects have involved not only personal discomfort but also varying degrees of personal danger. It is obviously much pleasanter to live in areas of law and order where the requirements for a decent living are available.

You can all visualize these problems in terms of yourselves, but today it is actually a problem involving more than mining engineers—it involves whole populations. The world is disturbed, upset, uncertain of the future. Obviously, the future depends upon international cooperation. And the United States must provide much of the leadership. This is not a matter just for the State Department. Whether you like it or not, many of you act as ambassadors of this country—you represent American thinking and the American way of life in foreign countries. It is a great responsibility, and may we all live up to it.

South American Minerals in the Future World Economy

BY PEDRO BELTRÁN

PEDRO BELTRÁN

One of Latin America's outstanding statesmen, Pedro Beltrán was for several years Peruvian Ambassador to the United States. His wide and intimate knowledge of industry, finance, and economics has made him a valuable representative of his government in many international conferences. He is particularly well qualified to present the point of view of Latin America with respect to the exploitation of its invaluable mineral resources.

DURING the war South America attained a very important position in the production of metals and minerals, brought about by her strategic location near the "Arsenal of Democracy" and the loyalty of her peoples to the cause of freedom.

This seemingly miraculous achievement in the wartime delivery of the all-essential metals—copper, tin, lead, zinc and tungsten—as well as 35 other war-important minerals and metals, was not the simple result of orders received and of routine production. It was the end result of pioneering, prospecting, developing, planning and plodding throughout the lifetime of your organization. It was the introduction of new engineering principles, mining techniques, smelting procedures and refining practices, which presaged the entrance of the vast amount of venture capital essential to carry these promising mineral potentials through the dangerous stages of early development. Many of those attending the meeting must in the past, as young engineers, have braved the untold hardships and discouragements that beset them at every turn. Only they can really appreciate the true meaning of the overwhelming wartime demand on the mineral production of every one of the South American countries.

No one country has all of everything necessary to produce armaments on a scale imperative during an emergency. Not even the United States, with its wealth of natural resources, could hope to meet the unprecedented demands of modern mechanical war. Huge imports were necessary, and South America was prepared to fill the bill, as can be seen from the record. During 1944, the last full year of the war, it supplied 100 per cent of the import needs of the United States in such materials as antimony, white arsenic, bauxite, bismuth, vanadium, quartz crystal and crude petroleum. It furnished well over half of the imports of beryllium, cadmium, copper, lead, manganese, molybdenum, tantalite, tin, tungsten, zinc, fluorspar, amorphous graphite, and natural asphalt. In addition to these major contributions, South America supplied sizable quantities of chromite, rutile titanium ore, silver and mica in that same year. This most impressive record is a true indication of South America's potentialities as a reservoir of strategic materials; strategic not only as a vast untouched mineral stock pile against future armament requirements, but strategic in its location so near the demand belt of future world industrial progress.

Distribution of Minerals in South America

In considering the future role of these minerals in the world economy, it must be realized that the South American nations are not a homogeneous group economically. The one common characteristic observable in all is the use of economic resources in the production of raw materials. From the earliest days production for export has been the mainstay of their economy. It is only recently that the trend toward a more diversified industrialization is becoming apparent.

History tells us that it was the lure of gold and silver that led to the discovery of the continent and to its earliest exploration, and the first forms of industrialization were based on the extraction of those minerals. Today the people of the region, in whose blood are mingled the strains of the hardier, more resistant natives and the more venturesome and energetic races of Europe, still look upon the natural products of inorganic processes as one of their main resources. But the trend in development has been away from the narrow field of precious metals toward materials that have proved essential to modern industrial needs. A new El Dorado has long since been recognized as the true way to lasting prosperity.

In my own country, Peru, we find the mineral industry based on the all-important nonferrous metals copper and lead, and the ferroalloying metals tungsten and vanadium. Silver, with its growing industrial applications, is another important source of potential wealth. At present we are attempting the major development of extensive anthracite deposits. One of our principal metallic exports is copper. The rich, widely scattered deposits are well known to you, I am sure, as they are to anyone. United States capital and engineering advice have been of inestimable aid in turning the ore into usable red metal. Your counsel and assistance have been welcomed throughout the development of our copper properties, from the Celendin-Trujillo area through Cerro de Pasco, Morococha and down to the mines in the south. Large reserves of lead-zinc ore have been developed at Cerro de Pasco and near-by districts. Antimony, molybdenum, quicksilver—all these minerals contribute to our natural wealth; and iron has a distinct possibility for further uses in industrialization in years to come. With an enlightened and liberal attitude toward industrial undertaking, Peru truly presents a rich prospect for future development and enlargement of present enterprise.

Our neighbor to the south, Chile, with her huge deposits of copper, has long maintained South America's position as a principal world supplier of this important metal. Here again, since early in the century, the skill and capital of private enterprise from the United States has helped to turn incipient treasures into thriving industry. The world position that Chile enjoys in natural nitrates is fully recognized. So far, present problems of their cost in relation to synthetics has not presented the insurmountable problem once anticipated. Thus, mining and its allied activities continue to be of greatest economic importance to the nation. The government is continually stressing the development of technical experts among its own nationals. The university and technical college of Santiago have educated many highly competent engineers, and there are available large numbers of men who have become skilled in the trades needed for mineral-based enterprise. The trend toward overall industrialization in Chile must constantly be considered in the light of available markets, both world and domestic, and the competitive forces of other suppliers in those markets must continually be recognized.

As in Peru and Chile, other countries of South America have also progressed along industrial lines in accord with their mineral resources. Brazil may point with pride to the rapid development of her iron, manganese and bauxite mining industries. In addition to diamonds and tungsten, Brazil contains the outstanding tantalite and beryl-producing region of the world. Over half of the world's supply of tantalum—the metal stronger than steel, as acid resistant as glass and with a melting point of 5100°F.—has come from the bulge of Brazil, where rich deposits have been found. She is also the world's only large source for piezoelectric quartz, important to the growing electronics industries of the world, and is second only to India in production of mica. The enormousness of her overall potential mineral resources is exemplified by iron-ore reserves, said to be unequaled in any other part of the world, and estimated at six billion tons of high-grade ore. Such a potential is a factor not to be lightly discounted in the economic mineral future of the world. The seemingly unsolvable problem of transportation to ports is a challenge Brazil offers for serious consideration.

In Bolivia, tin mining is the principal economic activity, but oil is fast approaching tin in national importance. The relatively high cost of tin production is a constant threat to Bolivian economy in any but a controlled world market. Deposits of lead and zinc are important. Tungsten, antimony, sulphur and some bismuth are minor in volume produced. Opportunities for agricultural development have been neglected in favor of the more profitable mineral exports.

In contrast to the Bolivian pattern, Argentina derives her favorable balance of trade through agricultural and pastoral products. Exports to the United States are small in comparison with those to the United Kingdom and the countries of Europe. Mining developments, heretofore considered of secondary importance, are a significant factor in lead-zinc production. Lead will satisfy all domestic requirements and zinc is produced in sufficient quantity to be exported. A degree of self-sufficiency in coal is being sought. Nevertheless, Argentina seems destined more and more to depend on her neighboring countries for her principal raw-material requirements.

Venezuela cannot be overlooked as a mineral producer and exporter in the years ahead. An economy based on oil exports coupled with rich soil provides a background for continuing exploration of indicated bauxite and extensive iron-ore deposits, as well as nickel, silver, magnesite and asphalt, asbestos, salt, industrial diamonds and coal.

Of singular importance to future world markets for aluminum are the Guianas. British, Dutch and French Guiana have been outstanding in their contribution to the United Nations war effort through their bauxite exports to the United States and Canada. High-grade bauxite now being shipped at capacity to alumina plants in Canada and the United States is proof of their assured prominence in the commercial markets of the future. Gold deposits and diamonds are important as well in the mineral future of these colonies.

Colombia, with its extensive mineral resources, has been disappointing in the realization of its mineral wealth. Known for the exploitation of its rich emerald and gold mines by the Spaniards in the fifteenth and sixteenth centuries, little real progress has been made in succeeding centuries. The war, however, has provided an interesting impetus to further exploration, and the attitude of the government should play a decisive role in future mineral economy.

Pan-Americanism Requisite

There is a lesson that we should learn from the last struggle. The peoples of this hemisphere cannot stand apart. We must close our lines, we must draw together if we want to maintain an unassailable position. The fact that we have at heart the independence of our different countries need not drive us apart. As long as we respect each other, as long as none of us mingles in the problems of the others, as long as we do not try to interfere with their freedom of action and as long as we sincerely practice the "Good Neighbor Policy," the very belief in our independence, the resolution to preserve our individuality, should rather bring us together. Only by remaining free from outside interference can we be sure of being able to preserve our sovereignty and our freedom to work out our own salvation according to the peculiar beliefs and inclinations of the peoples of each of our countries. Pan-Americanism as a living doctrine could never develop as long as there was reason to distrust the stronger member of our community of nations. If the United States continues to be loyal to the "Good Neighbor Policy," if it practices rather than preaches, as the late President Roosevelt always did, no fear need be entertained about the future of Pan-Americanism. It will continue to grow stronger every day.

This is to the interest of us all. Not even the United States, with her great resources, could face calmly another world struggle if she stood alone. Modern warfare has revolutionized the problem of the defense of our borders—not only because of increased vulnerability due to new weapons, which shorten distances, moving ever further from home our first lines of defense, but also because of the demands of modern mechanized warfare on the supply of strategic materials, the need of which will be practically unlimited in any future war. North America itself is not self-sufficient in this respect. From among the costly war-learned lessons the importance of accessibility to the supply of strategic materials is indelibly stamped on the minds of statesmen and industrialists alike. Stock piles may prolong the struggle for national survival but access to world mineral production may well be decisive in the future in a nation's fight for its very existence.

In any future war into which our countries may be drawn, the United States, for many years to come, will continue to be, as it was in the last struggle, the "Arsenal of Democracy." Yet it may be cut off from its outside sources of supply of strategic materials and may have to rely on hemispheric resources alone. It is true that we all hope that no new world war will come to trouble the peaceful pursuit of our happiness in this part of the world; but as none of our countries dreams of territorial conquest it can well be said that we can prepare for the worst with a clear conscience, and that no one need worry about our providing for any emergency because no one can honestly entertain any doubts as to the sincerity of our peaceful intentions—not even of those of the United States in spite of its might. In this hemisphere we stand above all for peace—but we also want to feel certain that we will be able to defend our freedom.

Wise Development of Mineral Resources

Let us examine what is needed to develop our natural resources so that we may be in a position to produce the necessary materials for the defense of the hemisphere should the need arise. We are here concerned with mineral resources, so let me limit my remarks to this part of the problem. Mineral production cannot be stepped up overnight. Mining engineers are aware, far better than I am, of the amount of money and the years of labor that may well have to be spent in the mere discovery of new deposits. Once found, development work will take a long time to prove a sufficient tonnage to justify the expenditure of further large amounts of money necessary for setting up concentrating and smelting plants and for providing the required power to operate them. It is a long way from the original prospector to the first shipments of metal or even of concentrates. Transportation in itself may prove to be an almost insurmountable problem requiring further big outlays. In fact, mineral production cannot be improvised. It can result only from many years of heavy expenditure. Advanced work—in other words, peacetime development and enterprise—are absolutely necessary to assure the supply of required strategic materials for an emergency. This can take place only if there is sufficient economic inducement, which can be reasonably expected to last for a number of years. Otherwise people will not dare venture large investments that will repay only in the course of time.

The first requisite in this respect is availability of suitable markets. Before the war, as far as we were concerned, we knew we could always sell our products at any time to European and particularly British buyers. It is no use thinking of our own domestic markets in Latin America for disposing of our raw materials. Only large-scale industry is capable of absorbing such production. In so many lines only mass production can be efficient and competitive; otherwise, costs are too high. But a large output depends on a suitable consuming public, which cannot be found in our countries, with their scant population. For very many years to come, therefore, we will have to rely primarily on foreign markets.

Unfortunately, the last war has adversely affected our position in this respect. Many of our best European customers are not now in a position to buy freely from us, or can afford to do so only if we accept payment in their own local currencies, not always freely convertible into dollars. It is said that the Bretton Woods organization will do away with this difficulty, but, practical men that we are, life has taught us to rely on facts, on things as we know them to be, rather than on beautiful schemes that are the products of the imagination of certain well-meaning men who may not be as free from the mistakes and weaknesses that human flesh is heir to as they themselves believe. It is said that at the time of the Russian Revolution, Lenin, when confronted with unexpected results of his social experiments, used to cry: "To hell with facts." The same attitude, however, would not help us in finding the solution to the problem we are now studying.

So many of the things we need can be obtained only in the United States that currencies not readily convertible in actual practice into American dollars can be accepted by us to a very limited extent only. The truth is, therefore, that, because of the drain of resources of most European countries during the war, we will be able to sell to them for quite some time much smaller quantities than in former years. Unless we can have access to the American market, our production of minerals, as well as of other raw materials, will have to be restricted. This will bring to a standstill further exploration and development work.

Barriers to World Trade

Public men in our American countries, including the United States, never seem to tire nowadays of preaching the gospel of Pan-Americanism. Yet, as so often is true of politicians, they seem to practice the opposite of what they preach. No better example of this is to be found than the history of your own tariff policy during the past 15 years. According to a pamphlet published by the United States Tariff Commission at the beginning of the last war in Europe, 33.5 per cent of imports by the United States, from all countries, paid duties in the year 1932, whereas less than 29 per cent of imports from Latin America were subject to the tariff. But in the year 1937 less than 41.5 per cent of imports from all sources was dutiable, whereas more than 48 per cent of imports from Latin America came under the tariff. Besides, duties paid by Latin American imports represented 47.5 per cent of the value of such imports whereas those coming from nonhemispheric sources paid duties that amounted only to 37 per cent of their value. What an extraordinary way to help them develop commercial intercourse with the rest of the hemisphere, and to bring about a real sense of Pan-American interdependence!

Whether trade agreements negotiated since 1937 have altered things for the better, I cannot say, but unless this is done the United States will never be for us a market that can replace that of our old European customers. There is little to be hoped for unless the American Government radically alters its policy. Nothing can be more hopeful, therefore, for the future development of South American mineral resources than the policy repeatedly stated by the Under Secretary of State for Economic Affairs, Mr. William L. Clayton, who has unequivocally asserted that the objective of the policy of the present administration in Washington "is to lay the foundations for peace by an expansion of world economy" entailing "an increase in production, distribution, and consumption of goods throughout the world." As Mr. Clayton says, within the Atlantic Charter and again in the Mutual Aid agreements were laid the foundations for "nondiscriminatory trade." The Under Secretary further recommends: "the reduction of tariffs and other barriers which restrict world trade and limit the production and consumption of goods." Only through such enlightened policy can the world hope to achieve a reasonable amount of sustained prosperity. Whether a man of the vision, the character and the earnestness of Mr. Clayton will be able to carry into practice the high aims he has set for himself, and overcome the many obstacles that stand in his path, is something to which we hope the future will bring an affirmative answer.

Paths to Inflation

It is high time that governments should follow enlightened policies like those advocated by the Under Secretary. Unfortunately, this seldom seems to happen. It is not only the United States Government that has sinned in this respect. Other American Governments are not less guilty. Of late, particularly, their fiscal and monetary policy has been disastrous. Inflation has always been an evil influence. No country that has fallen into this mistaken course has been able to avoid a serious dislocation of its national economy.

The primary cause of inflation is the same today as it was in the past: excessive government expenditure. That is true at present in most Latin American countries. Governments pay no attention to the lessons of past experience. Expediency seems to be the only consideration. They follow the line of least resistence in the present regardless of its catastrophic consequences in the future. Let him who comes after find a way out of the mire into which the country is sunk!

But inflation means rising prices, a rise in the cost of living, and a consequent rise in wages and salaries and in costs of production. In other words, the economic value of money is lowered, and as the value of money depreciates, more money is needed to produce the same thing. From the point of view of the producer, these rising costs can be compensated only by rising prices. If more has to be spent to produce because money is worthless, more should be received for the product, for the same reason. This is not so, however, in regard to exports when the rate of exchange is artificially maintained by the government at a certain level, as is today the general practice. There seems to be hardly any instance in which government measures defeat their own purpose more than in this matter of the exchange value of currencies when they try to maintain it by artificial methods.

Countries should worry more about keeping the value of their currencies stable than about anything else. They should remember, however, that there is only one way to do this—the amount of currency in circulation should not be increased, and budgetary deficits should not be met with fiduciary issues of new currency. When these tenets are not followed, when the currency is unduly watered, the value of money depreciates and prices rise. This depreciation cannot be stopped by artificial controls, which are nothing but an attempt to make water run uphill. The reason is obvious. If costs of production rise because of currency depreciation, and the producer, who has to incur larger expenditure to produce, sees only the depreciation reflected on the debit side (in his outlays) but not on the credit side (in what he receives for his product), he will be put out of business sooner or later. He is squeezed, so to say, between rising costs of production in a depreciating currency and a controlled stationary income in the same continuously depreciating money. Thus eventually he will end on the rocks. This is bound to happen. There is no way out. For the present, rising prices have allowed producers to continue to make money in spite of rising costs, but if inflation continues, as soon as prices remain stable for any length of time, and more so the day they drop to any extent, as they are almost bound to do before they reach what will prove to be the normal postwar level, many producers will be driven out of business. The result will be smaller exports, fewer sales abroad and a consequent reduction in the amount of foreign exchange available.

There is nothing more deceiving than the control of exchanges when inflation is continuously depreciating the currency. Exchange control can work well for any length of time only when the currency is maintained stable, but, in such case, exchange control is unnecessary because a shortage of foreign exchange never occurs. This shortage usually has its origin in government overspending. When this takes place, and more so when treasuries begin to meet deficits by drawing on the bank of issue, demand for consumer goods of all sorts increases. As no country is self-sufficient, this means a larger demand for foreign goods, and causes a shortage of foreign exchange to pay for such imports. This demand for larger imports is further intensified by rising prices at home, which drive people more to purchase abroad. It is at this stage usually that exchange control is resorted to, but this only helps to make things worse, for it prevents a rise in the price of foreign wares at the same time that the internal depreciation of the currency is causing internal prices to soar.

Unwise Taxation

Inflation is indeed a terrible curse and its evil results can be prevented only by balancing the budget, by spending only what the country can afford;

in other words, by the nation's living within its income just as any individual must do unless he wants to go bankrupt. But governments have also done other things harmful to the development of new enterprise—as with many of our revenue laws. It is a commonly accepted principle today that people should contribute to the general needs of the community in proportion to their income. For this reason, treasuries are coming to rely more and more on direct taxation. But it often happens that for reasons of expediency these principles are forgotten and politicians, ever in need of more money to spend, fall upon any kind of taxation that may seem easy to collect and difficult to evade.

A good example is to be found in export taxes so common in many South American countries. The United States constitution, I understand, very wisely, forbids any tax on export, but we seem to be relying on it more and more. This kind of taxation usually provides for an export duty equal to a given percentage of the difference between the world quotation of the product and the estimated cost of production arbitrarily set by law. As world prices are quoted on the exchanges in the main markets, no difficulty can arise in computing the tax at the time the product is exported, and, as shipment is not allowed unless the duty is previously paid, evasion seems impossible in practice. Yet there is nothing more unscientific than this kind of taxation because the estimated cost of production arbitrarily set by law can at best be nothing but a fair average of the varying costs of individual producers. As no two mines have the same costs, this simply means that some pay in taxes a higher percentage of their profits than others, which runs counter to the principle of equality of sacrifice and, in many cases, even to that of ability to pay, for it may happen that some mines with a cost of production above the official figure will have to pay export taxes even when they work at a loss. Others may have to close down even when the quotation for their product is high enough to allow a certain profit if that profit is more than absorbed by the export tax computed on the basis of a figure lower than their actual cost of production.

But in these days of inflation and rising costs this kind of taxation becomes more dangerous because no finance minister is willing to readjust the basis for calculating the tax if this entails a reduction in taxation. This occurs when the point at which the tax becomes effective—in other words, the cost of production arbitrarily set by law—must be raised because of an actual rise in costs of production. In many cases this lack of readjustment is entailing today great hardships, which may not yet have forced many mines to close down simply because prices have so risen since the end of the war. But if they drop or even if they remain at their present levels while inflation continues to raise costs of production, many mines will have to stop producing unless these readjustments are made.

Free Use of Natural Resources Desirable

The Lord was more than generous to us. He gave us untold wealth. He gave us much more that we ever deserved. He filled Mother Earth with unending resources, so that we could improve our lot by using them. If we were to do what He expected from us, there would be no limit to our achievements. The well-being of the people at large would be assured and the standard of living in all our countries would go on rising indefinitely. Unfortunately, men have thought otherwise. Our governments have stepped in with unreasonable measures. They seem to try to make it as difficult as possible to utilize the natural resources that the Lord placed at our disposal. We must come to the conclusion that most of our troubles are of our own making.

It is high time that the trend should be reversed and that governments should open their eyes and stop all these nonsensical regulations, which act as terrible brakes to the progress of our peoples.

World Coal Resources

By C. Augustus Carlow

C. AUGUSTUS CARLOW

One of the leading personalities in British coal mining, Mr. Carlow is a distinguished mining engineer and is Chairman and Managing Director of the Fife Coal Company of Scotland. He is an official of numerous other British industrial companies; and has been President of the Institution of Mining Engineers (Great Britain). In recognition of his great contribution to the work of mechanizing British coal mines, he was elected an Honorary Member of the A.I.M.E. in 1946.

The subject which has been allotted to me is so vast and far-reaching that it is impossible to deal adequately with it in the time available. A complete survey would occupy the spare time of any one man for many years, whereas the time available to me is measured in weeks.

In the circumstances, I have been fortunate in securing the aid of several willing collaborators, and shall endeavor to represent such information as presently exists in published form, examine the situation critically in the light of present-day conditions, and arrive at certain conclusions which I shall venture to put forward for your consideration.

No one who has lived through the past 25 or 30 years, and who has witnessed the amazing achievements of recent scientific research, would venture to deny the possibility that new sources of energy may yet become available, or to prophesy to what extent these may be harnessed to the service of mankind. So far as we can see, however, coal, as a source not only of power and heat but also of that wonderful range of derivatives that form the raw materials of so many industrial processes, must continue to play a vital role in our economic life. It is the chief mineral fuel, exceeding all other mineral resources in value, production and demand.

In value coal overshadows the industrial metals, while of the sources of energy—coal, oil, gas and water power—the first named is the most important. Thus, for example, in the United States, coal as a fuel (that is, as a source of heat and power) is still predominant, the figures of percentage of the three great energy sources contributing to American needs during the decade from 1933 to 1943 varying as follows: coal, 45.6 to 52.2 per cent; oil and natural gas, 37.5 to 43.5 per cent; hydroelectric power, 9.6 to 11.9 per cent.

Accordingly, the question of the available reserves of coal is a paramount consideration and one which should be closely examined periodically, from every point of view. It is only right that we should try from time to time to reexamine and reassess our reserves in the light of growing knowledge, and such an undertaking would indeed seem essential and urgent at the present time, when we are passing from the dangers and anxieties of a world war into the manifold perplexities and hazards of the new economic conditions that war has left in its wake. There is, further, grave need for consideration of the problem of the conservation of our available supplies of coal.

The resources are sometimes regarded as so large as to constitute a reserve sufficient, to use the words employed by one authority, "for an unthinkably long period." On the other hand, M. R. Campbell,* writing of the coal resources of the United States in 1917, after examining all the data then available, pointed out that if the acceleration of production manifest between 1834 and 1914 were to be maintained (it is noteworthy that between 1890 and 1930 the *per capita* consumption of coal in the United States more than doubled itself) until the coal is completely exhausted, the supply probably would not last 100 years. He went on to say:

> Although . . . the ultimate exhaustion of the coal reserves of the United States appears to be an event so far in the future that it need concern this generation but slightly, the fact must be remembered that the bulk of the coal being mined today is the best in the country and that before long, perhaps within 50 years, much of the high-rank coal will be exhausted.

This may well be a much more pertinent and significant estimate than one which puts complete exhaustion at the remote distance of 4000 years. Whatever figure is taken as the limiting factor, whether 100 years, 1000 or even more, the period is short when compared with the life of a nation, and cannot in any material way affect the need for, and the desirability of, husbanding our resources. One pertinent criticism of the long-life figures that have been given for the world's coal reserves is this: The quantitative assessment of known or available reserves is not in general a difficult matter and can be made within reasonably accurate limits, but the estimation of reserves, commercially usable in competition with other sources of heat and power, stands in quite a different category.

* References are on page 682.

It is proposed to deal with the subject under the headings mentioned below:

1. Presentation and discussion of the estimates of the Executive Committee of the Twelfth International Congress held in 1913, commenting on the geological position and character of the deposits.

2. Reasons for modification of the tonnage estimates: (1) quality of marketable products, (2) geological conditions limiting extraction percentage, (3) loss in mining, (4) geographical isolation and inaccessibility to world markets.

Estimates of Coal Resources

The results of the inquiry into the coal resources of the world made upon the initiative of the Executive Committee of the Twelfth International Geological Congress held in Canada in 1913 have received wide circulation. These results were published in three large volumes, accompanied by an atlas of maps, which together constitute an immensely valuable storehouse of information regarding the world's coal position at that time. According to the estimates there provided, the coal resources of the world, taken by continents, may be set out in Table 1. In preparing this table, certain minor adjustments have been made, to which reference is made later.

TABLE 1—*World Reserves, Actual and Probable*

		Tons, Millions	Percentage of Total
North America:			
Canada (excluding Yukon, Northwest Territories and Arctic Islands)		1,218,529	16.5
United States (excluding Alaska and coal deeply buried)		3,838,657	52.5
Central and South America		32,102	
Europe (excluding Spitzbergen)		775,440	10.5
Asia (nearly 82 per cent in China)		1,279,584	17.4
Oceania:			
Australia	165,572		
New Zealand	3,386		
British North Borneo	75		
Netherlands India	1,311		
Philippines	66	170,410	2.3
Africa:			
Union of South Africa	56,100		
Rhodesia	569		
Belgian Congo and Southern Nigeria	1,070	57,739	0.8
		7,372,461	100.0

The output of coal from the principal producing countries in 1913 amounted to 1478 million tons, which allows, at this rate of depletion, of a life of some 5000 years. These figures of reserves and of duration, while not exactly astronomical in size, are yet sufficiently large to merit close examination. Various practical considerations invite a careful scrutiny of the data on which they are founded. Obviously it would have been quite impossible for any individual investigator even to attempt a reassessment of coal reserves throughout the world. All that can be attempted is to mention certain limiting factors of a practical and economic character, which it is suggested ought to be taken into account in any inquiry into world reserves that may be undertaken in the future.

It may be useful to regroup these reserves, continent by continent, in certain broad categories, so as to focus attention on the essential aspects of the problem, before suggesting reasons why the 1913 estimates must be scaled down.

Some general remarks on the 1913 estimates may be made here. For example, in the table of *actual* reserves (Vol. 1, pages xxxiii and xxxviii), North America is listed as possessing 414,804 million tons falling into this category, but the whole amount, including 675 million tons of anthracite, is credited to Canada. Admittedly the United States more than makes up the leeway in *probable* reserves. It ought also to be emphasized that of the total actual and probable reserves of coal in Canada, some 95.1 per cent is in seams of Cretaceous age, while only 0.6 per cent belongs to the Carboniferous or True Coal Measures. On the other hand, of the actual and probable reserves in the United States, about one third is in the great Carboniferous coal fields of the Eastern Provinces (or what are commonly known as the Eastern and Interior Provinces). In this connection it is pertinent to note that the large figures of Canadian reserves have been challenged on more than one occasion, and the total very seriously reduced (see page 648 of this paper).

For the purposes of the 1913 compilation, information was sought: (1) as regards seams one foot and over in thickness down to a depth of 4000 feet, and (2) as regards seams 2 feet and over in thickness between 4000 and 6000 feet in depth, as well as under the headings of (*a*) actual, (*b*) probable, and (*c*) possible reserves. The minimum thickness of coal seams mined in Great Britain and in the United States is about 15 or 16 inches, but must vary according to the rank of the coal. Thus, while the minimum thickness of 15 inches *might* be taken for a high-rank coal, the limit would be considerably higher for coals of relatively low rank, such as most of the Cretaceous seams. Perhaps also 3000 feet would have been a more suitable depth for general adoption in framing estimates for available, easily accessible reserves, a depth figure that actually was used in the returns made from the United States.

Again, the categories "actual," "probable" and "possible" are, at least in certain cases, somewhat loosely used. For example, the Queensland "possible reserve" of 13,122 million tons appears under the heading of "probable reserves," while the "probable reserve" of 1685 million tons appears under the category of "actual reserves" (1913, Vol. 1, pages xxix and 37). This has the effect of multiplying the "actual reserves" four times, and the "probable reserves" seven times. For Nova Scotia, the "probable reserves" down to 4000 feet are increased by the inclusion of 2639 million tons of submarine coal estimated to lie between 4000 and 6000 feet (*ibid.*, Vol. 1, page xxxiii, and Vol. 2, page 442). It might be suggested that the terms "actual," "probable" and "possible" are somewhat vague and liable to subjective interpretation, and that a more useful and practical grouping would be under the more contrasted headings of "proved," "partly proved," and "inferred."

Finally, it would seem desirable to stress more fully than has been done in the 1913 tables the geological ages of the coal-bearing groups of rocks in different countries. An approximate estimate of the coals of the United States under geological ages is given in Table 4.

The question of the relation of the age and fuel value of a coal is not a simple one. Time (or the period that has elapsed since the coal was formed) is certainly one factor in determining the progressive series of changes from lignite to anthracite—changes, particularly the variations in oxygen content and inherent moisture, that must be assigned to the effects of post-depositional geological agencies. Coal is extremely susceptible to metamorphic agencies, particularly load metamorphism. This type—i.e., metamorphism produced by burial under a heavy load of overlying sediments—is regional in extent, while metamorphism due to folding of the strata varies in intensity and distribution. Thus, one consideration to be kept in mind in assessing the potential value of a coal-bearing group of rocks is their geological history; that is, the age of the coals and the different post-formational agencies that have affected them. Most of the coals of Tertiary age are of low fuel value; that is, they are high-oxygen fuels, with in addition a high content of inherent or natural moisture. To this, however, there are important exceptions. The occurrence of bituminous coals and even anthracite in the Tertiary rocks of the Western States of the U. S., where the Eocene lignites have been altered and raised in rank in the vicinity of the Cascade mountain range as a result of the great earth movements of what is known as the Cascadian Revolution, shows that age is not the sole controlling factor.

It is in the very much older Carboniferous rocks, however, that the great deposits of coal of high fuel value occur; that is, coals with a low moisture and ash content, a high carbon content, and a high calorific value. These Carboniferous coals produced more than 80 per cent of the prewar annual output. The Mesozoic era also saw the formation of coal beds on a large scale, in early Permian times in South Africa, for example, and in late Cretaceous times in Wyoming, Colorado, the western part of Dakota and the Alberta plains. These Cretaceous rocks contain very large reserves of coal, but as a rule the coal is of relatively low rank as compared with the coal in the Carboniferous formation, except where mountain-making movements have led to its devolatilization and its conversion into bituminous and even into anthracitic types.

TABLE 2—*World Resources*

MILLIONS OF TONS

America:		
U. S. A. (including Alaska)	4,231,000	
Canada	1,360,000	
Colombia	29,000	
Other countries	7,000	
		5,627,000
Asia:		
China	1,097,000	
India	87,000	
Indo-China	87,000	
Siberia	191,000*	
Other countries	13,000	
		1,475,000
Europe:		
Germany	466,000	
Great Britain	208,000	
European Russia	66,000*	
Austria	59,000	
France	19,000	
Other countries	46,000	
		864,000
Australasia		187,000
Africa		62,000
		8,215,000

* Figures used by Moscow are very different: Donbas Basin 90,000; Kuznetsk Basin 540,000; and 1,634,000 million tons for all coal fields of the Union, including Karaganda.

These aspects of the general problem have been kept in view in compiling the short summaries contained in the following pages. The data provided there are based primarily on the 1913 estimates, rearranged and set out to illustrate the main theme.

The 1913 estimates form the latest authoritative pronouncement on the subject, but reference may here be made to a compilation that appeared in the May issue of the *Mining Journal* (R. Lawrence, 1946, pages 388–390), which appears in Table 2. These figures agree very closely with the official computation of the 1913 Congress. In dealing with all such tables, however, it must be remembered that they are estimates only, and that estimates depend upon accepted data which may vary from time to time.

NORTH AMERICA

United States

The United States of America possess the world's greatest reserve o Carboniferous coals. The importance of the contribution made by the United States to world coal output may be gauged by the figures in Table 3. In 1913 Great Britain contributed 21.76 per cent (as against 45.11 per cent in 1880); Germany, 20.67 per cent; Austria-Hungary, 4.07 per cent; and France, 3.04 per cent. In 1927 Great Britain produced 17.37 per cent; Germany, 27.07 per cent; and France (including Saar mines), 3.58 per cent. During the years immediately preceding the recent World War the most notable advances in coal production were made by Germany, Russia and Poland.

TABLE 3—*Contribution of United States to World Output*

YEAR	PERCENTAGE	YEAR	PERCENTAGE
1880	19.59	1926	44.90
1890	27.90	1929	37.00
1900	31.86	1932	28.92
1913	38.53	1936	30.73
1920	45.30	1938	Not available

The reserves of coal of all ranks in the United States were tabulated by M. R. Campbell for the 1913 World Resources inquiry, and again in 1917 and 1929 (see 1917, Bibliography). His figures, including seams of 14 inches and over, down to a depth of 3000 feet, and differing slightly from the Congress total, are summarized under age groups in Table 4. On the basis of these figures the U. S. reserves are:

	MILLION TONS
Lignite and subbituminous coals	1,847,185
Bituminous coals and coals of higher rank	1,378,204

TABLE 4.—*United States Reserves According to Age and Types*

MILLIONS OF TONS

Age	Distribution	Types (or Rank) of Coal				
		Anthracitic and Semi-anthracitic	Semi-bituminous	Bituminous	Sub-bituminous	Lignite
Carboniferous[a]	Eastern Provinces (Pennsylvania to Alabama)	19,873	42,365	456,818		
	Interior Province (Michigan to Texas)	363	1,112	479,377		
Jurassic	Atlantic Coast Province (Virginia and North Carolina)			725		
Cretaceous[b]	Northern Great Plains Province			41,336	43,373	
	Rocky Mountains Province	463		325,371	643,696	
Tertiary	Northern Great Plains Province				124,750	965,902
	Pacific Coast Province	21		10,380	48,511	
	Gulf Coast Province[c]					20,953
Totals		20,720	43,477	1,314,007	860,330	986,855

[a] Pennsylvanian (Upper Carboniferous) except for a little Mississippian (Lower Carboniferous) in Virginia. A few coals occur in the Permian of Pennsylvania, Ohio and Maryland.

[b] Lower Cretaceous coals in the Kootenai series; reserves mainly Upper Cretaceous; i.e., in the Montana and Laramie Series. Some early Tertiary (Fort Union Series) coals included.

[c] Includes a little Upper Cretaceous.

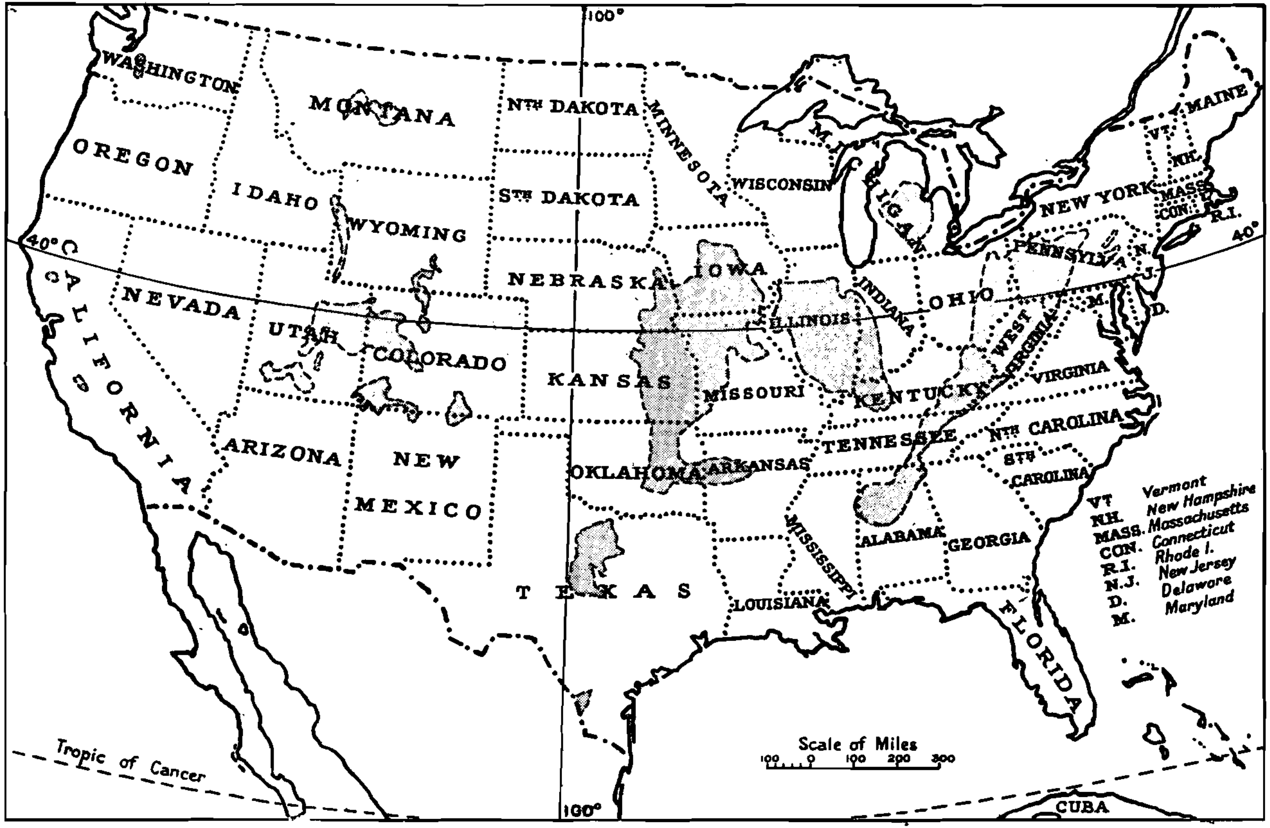


FIG. 1—*Principal coal fields of Carboniferous age (east of the 100th meridian) and of Cretaceous age (west of the 100th meridian) in the United States.*

Summarized, according to age, these figures give:

	Million Tons
Bituminous coals and coals of higher rank:	
Carboniferous	999,907
Jurassic	725
Cretaceous	367,170
Tertiary	10,401
Lignite and subbituminous coals:	
Cretaceous	687,069
Tertiary	1,160,117

These figures, of course, represent original reserves and require to be reduced by the amount of coal so far extracted. Total output up to 1927, combined with estimated loss in working, was placed at 26,481 million tons, all but a relatively trifling amount of this coming from the Carboniferous rocks of the eastern provinces. It should be remembered that:

1. The largest reserves of coal are in the western part of the continent, in Wyoming, Montana, North Dakota, South Dakota, and Colorado. The Fort Union region of the Northern Great Plains (Wyoming, Montana and the Dakotas) is estimated (Campbell, *op cit.*) to contain approximately 965,902 million tons of early Tertiary lignite, while in the Rocky Mountains fields of Wyoming (Green River Basin mainly) there is an estimated reserve of 483,771 million tons of coal, approximately 85 per cent of which is subbituminous and 15 per cent low-grade bituminous, largely of Upper Cretaceous age. These figures may be compared with the estimated reserves of the high-grade Carboniferous coals of the Eastern Province, amounting to about 518,000 million tons. The Northern Great Plains, together with the Rocky Mountains and Pacific Coast Provinces, contain more than double the reserves of the Eastern and Interior Provinces, vast although these latter are.

2. In respect of quality, however, the real wealth of the United States lies in the two Eastern and Interior Provinces and mainly in the former. The Carboniferous system is the great repository of the valuable coals but it does not extend into the western part of the continent. It is here that the vast deposits of Cretaceous and Tertiary coals occur, but as all the lignite and subbituminous coal is included in these western provinces, their actual reserves of bituminous amount only to approximately 377,000 million tons, mainly in Colorado, Utah, western Wyoming and Washington. The bituminous coals of these areas vary in age from Lower Cretaceous (Kootenai Series of the Black Hills region, etc.) to Upper Cretaceous (Montana and Laramie Series) and early Tertiary (Fort Union Series). Here, as in Canada, the older coals are the most valuable, but the only seams of really good quality are restricted in occurrence, in general, to basins or areas adjacent to the mountains where, under the influence of slow dynamic pressure, devolatilization

of the coals and consequent rise in rank have been operative. The irregular distribution of these coals, their occurrence in disturbed and faulted fields, the presence locally of bodies of intrusive igneous rock, and their relative remoteness are factors to be considered in estimating their value under present-day conditions. Sometimes, again, the same seam may show variations ranging from subbituminous to anthracitic, as in the Uinta Basin region of Colorado.

Canada and Newfoundland

Reserves of coal in Canada and Newfoundland, according to the figures supplied for the purposes of the 1913 Congress inquiry (D. B. Dowling, Vol. 2, pages 431–523) were distributed and classified as shown in Table 5.

Much the same figures of reserves are given in Mineral Industry of the British Empire and Foreign Countries: Coal, Coke and By-products, 1913–1919, published by the Imperial Mineral Resources Bureau, 1921 and 1922, by H. M. Hoar in The Coal Industry of the World, 1930, and in other publications.

In regrouping the Canadian reserves according to age (Table 6) the following have been omitted: Yukon (Cretaceous and Tertiary), the Northwest Territories (mainly Tertiary lignite) and the Arctic Islands (Lower Carboniferous), which accounts for the difference between total figures.

Thus, of the estimated reserves of Canada (1,201,030 million tons, excluding Yukon, the Northwest Territories and the Arctic Islands), 95.1 per cent, mainly in Alberta, are of Cretaceous age; 4.3 per cent of Tertiary age, and only 0.6 per cent of Carboniferous age. Since the Alberta Cretaceous coals constitute such a large part of the estimated reserves, it may be useful to arrange them in order of age and according to rank, as shown in Table 7.

The oldest of the Alberta Cretaceous coals, those in the Kootenai series, are near the surface in the foothills and fault blocks of the Rocky Mountains (Cascade, Big Horn, etc., fields), but farther east, in the undisturbed country, are deeply buried under later formations. This series of rocks contains important reserves of good quality coal in Alberta and in British Columbia, the seams ranging from bituminous types to anthracite, but often showing a fairly high ash content (10 to 16 per cent). The younger and, as a rule, thinner coals of the Belly River series are nearly all low-grade bituminous or subbituminous, high in moisture and volatile matter and in ash. The subbituminous and lignitic coals of the Edmonton series have a still higher content of moisture and a relatively low calorific value. Two general points regarding these Cretaceous coals should be noted:

1. The bulk is of inferior grade, weathers readily on exposure and does not stand transport in the raw state.

TABLE 5—*Canadian and Newfoundland Reserves (1913)*

MILLIONS OF METRIC TONS

	Reserves		Classified as
	Actual	Probable	
Canada:			
Nova Scotia	2,188	4,892	Good-quality bituminous
New Brunswick		151	Bituminous
Ontario		25	Lignite
Manitoba		160	Lignite
Saskatchewan	2,412	57,400	Lignite
Alberta[a]	386,373	673,554	Mainly subbituminous to lignitic
British Columbia:			
Southern Interior	22,586	34,873	Mainly bituminous
Central Interior[b]		487	Mainly bituminous
Northern Interior[c]		8,200	Bituminous and subbituminous
Vancouver	1,178	5,191	Bituminous
Queen Charlotte Islands	67	1,293	Bituminous
Yukon[c]		4,940	Mainly subbituminous and lignitic
Northwest Territories[c]		4,800	Lignite
Arctic Islands		6,000	Bituminous
Totals	414,804	801,966	
Newfoundland[d]		500	Medium to low-grade bituminous

[a] The figures for Alberta include an estimated actual reserve of anthracite amounting to 669 million tons and a probable additional reserve of 100 million tons. Of the other coals, approximately 82 per cent are subbituminous or lignitic, and only some 17 per cent fall within the bituminous category.

[b] Not known in detail.

[c] Largely unexplored.

[d] Coals of relatively little value; see A. M. Bryan, 1938.

In Table 5 and other similar tables of resources, the estimates quoted refer, unless otherwise stated, to coals one foot or over in thickness down to a depth of 4000 feet. In the 1913 Summary tables, on the other hand, coals between 4000 and 6000 feet in depth are included. Thus, to the Canadian total of 1,216,770 million tons shown in Table 5 must be added 17,499 million tons of coal estimated very approximately to lie *below* 4000 feet.

	MILLION TONS
Coal down to 4000 feet	1,216,770
Coal between 4000 and 6000 feet	17,499
Total	1,234,269
Deduct estimated reserves in Yukon, Northwest Territories and Arctic Islands	15,740
	1,218,529

This last figure is the one given in Table 1 of the present paper.

TABLE 6—*Canadian Coals According to Age*

MILLIONS OF TONS

Province	Upper Carboniferous		Cretaceous[a]		Tertiary[b]	
	Actual	Probable	Actual	Probable	Actual	Probable
Nova Scotia	2,188	4,892				
New Brunswick		151				
Ontario						25
Manitoba						160
Saskatchewan			108	33,800	2,304	23,600
Alberta			386,373	649,833		23,721
British Columbia:						
Southern Interior			22,586	34,291		582
Central Interior				337		150
Northern Interior				8,200		Large
Vancouver Island			1,178	5,191		
Queen Charlotte Islands			7	293	60	1,000
Totals	2,188	5,043	410,252	731,945	2,364	49,238

[a] Lower Cretaceous (later part of): coals in the Kootenai series of southern Alberta and interior British Columbia; e.g., Crow's Nest and other fields in Rocky Mountains; coals in the Skeena and Tantalus series.

Upper Cretaceous: Vancouver and Queen Charlotte Islands; coals in the Belly River series of Alberta and Saskatchewan.

Upper Cretaceous (late): coals in the Edmonton series of Alberta and southern Saskatchewan. These beds are a continuation of the Laramie series of Wyoming, Montana and the Dakotas. Some of the reserves assigned to the late Cretaceous in Alberta may perhaps fall more properly into early Tertiary.

[b] Early Tertiary: coals in the Eastern, Pascapoo and Fort Union beds of Saskatchewan, Alberta, etc.

Oligocene and Miocene: Lignites and subbituminous coals in British Columbia.

TABLE 7—*Alberta Cretaceous Coals*

MILLIONS OF TONS

Series	Bituminous		Low-grade Bituminous		Subbituminous		Lignite	
	Actual	Probable	Actual	Probable	Actual	Probable	Actual	Probable
Edmonton			1,197	10,161	382,500	407,100		
Belly River				115,000		48,000		26,450
Kootenai	2,696[a]	43,122						

[a] Includes 669 million tons classed as anthracite.

2. The good coal is limited essentially to the far west (eastern foothills of the Rocky Mountains), and to transport it by rail to Ontario means conveying it a distance of some 2000 miles.

It must be recorded that the 1913 figures of reserves for Alberta have been challenged on more than one occasion. Estimates prepared by J. A. Allan and placed before the Alberta Coal Commission of 1925–26 show:

	MILLIONS OF SHORT TONS
Bituminous coal	237,323
Subbituminous coal	52,531
Lignite	233,763

This gives a total of 523,617 million tons as against 1,072,627 million tons in the 1913 estimates. Still later (1926) the same authority greatly reduced his earlier figures of "coal workable at the present time." He included in these revised estimates only coal areas containing seams 2 feet and over in thickness and within 1000 feet of the surface:

	MILLIONS OF SHORT TONS
Bituminous coal	31,417
Subbituminous coal	14,494
Lignite	11,500

Considering the passage of time and the slightly different basis, the figures contained in the Report of the Royal Commission on the Coal Industry of Canada, published in 1945, agree fairly closely with those listed above. In this report the available reserves of Alberta were estimated at 46,562 million short tons, composed as follows:

	MILLIONS OF SHORT TONS
In the Kootenai formation (Lower Cretaceous)	29,700
In the Belly River and Edmonton formations (Upper Cretaceous)	16,862
	46,562

This figure includes only coal seams known to exist, and 3 feet and upwards in thickness, down to a depth of 1000 feet. It is noteworthy that of these reserves some 40,000 million tons is classified as anthracite and bituminous, and the remainder is classified as groups IV and V, subbituminous, lignite and brown coal.

In another section, this report refers to the great loss of coal left in pillars or abandoned on account of quality or inaccessibility. The total coal lost in Alberta through the mining practice in vogue and through abandonment of minds is estimated for the years 1886 to 1944 to be equal to the total amount

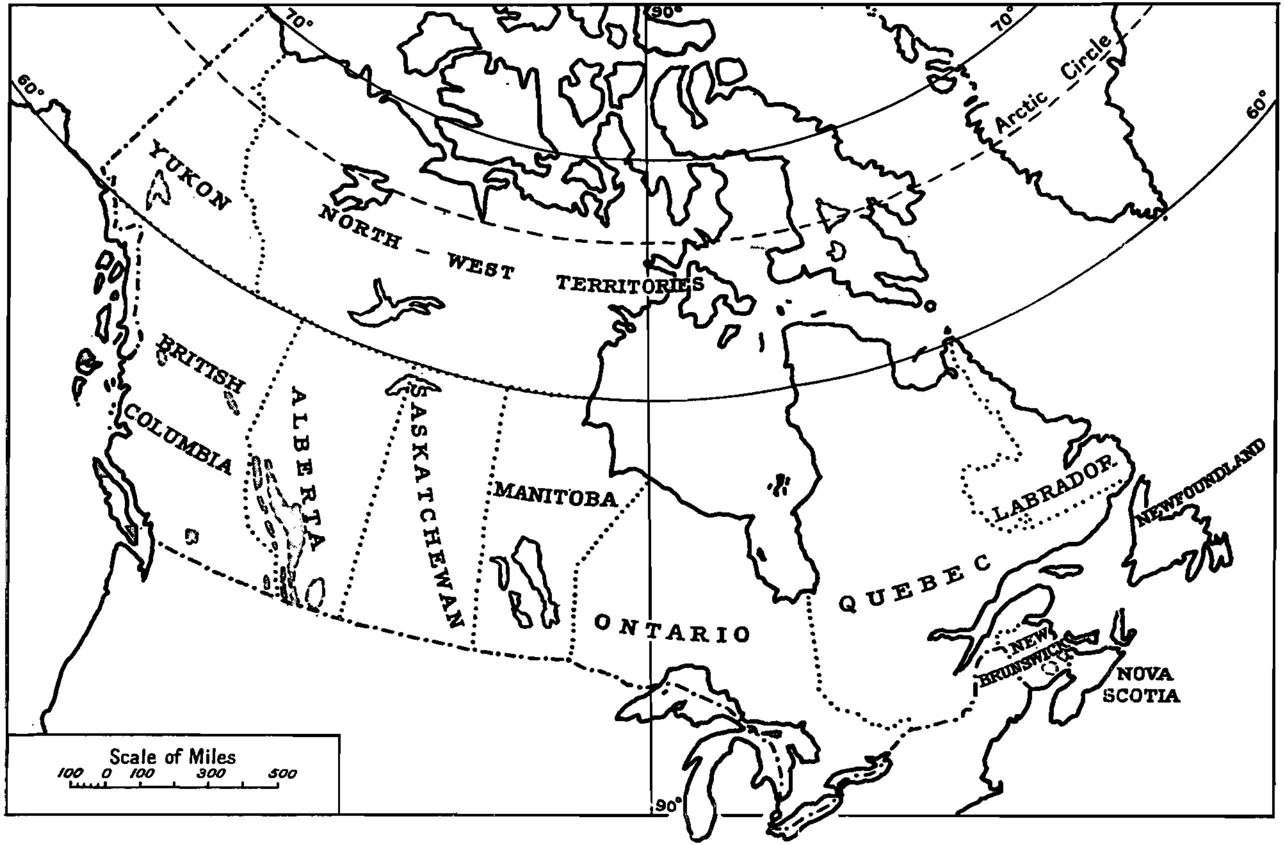


FIG. 2—*Principal coal fields of Canada; Carboniferous age, Nova Scotia and New Brunswick; Cretaceous, Alberta and British Columbia.*

produced during the same period, signifying a loss, through the consideration of circumstances mentioned later in this paper (under Reasons for Modification of Tonnage Estimates), amounting to 50 per cent of the tonnage originally available.

Later, among its recommendations, the Committee suggests that a revision of the estimated coal reserves in each of the coal-producing provinces in Canada be made by the Dominion Government and based on the present knowledge of the coal deposits, which knowledge is much more detailed than that available at the time of the Toronto Conference (1913).

In St. George's coal field, Newfoundland, there seems little doubt that there exists a considerable tonnage of coal. This area, however, was intensively surveyed by Prof. A. M. Bryan in 1938, and was found to have suffered so severely from the pressure of earth movements that, apart from any questions of quality or accessibility to markets, the folding and faulting are such that the coal field is not an economic or practical proposition.

SOUTH AMERICA

Before leaving the western continents, reference may be made to the relatively small deposits in South America. Coal is found in Brazil, Colombia and Peru, but the largest of these little detached coal fields are to be found in Chile, where an output of some two million tons was produced in 1938. The most important zone lies at the coast, from the Bay of Talcahuano and south for something approaching 100 miles. The seams are of Tertiary age, but because of the depth and pressure, and the changes brought about by earth movements, the quality has been altered and approaches that of Carboniferous age coal.

The coal generally has a conchoidal fracture, is strong physically, producing an unusually high proportion of large pieces, and has valuable coking properties. Various estimates have been made of the total reserves, but the workable reserves in sight are in the neighborhood of 200 to 300 million tons, equivalent to fully 100 years of prewar production. Small reserves exist elsewhere, but are of poorer grade, and while of considerable scientific interest, are of little importance economically.

EUROPE

The data shown in Table 8 have been taken from the individual reports supplied for the purposes of the 1913 Congress on World Supplies. No estimates of coal below 4000 feet have been included, except for the Donetz Basin in Southwest Russia. The notes that follow the table amplify the information given therein. Unless otherwise stated in the notes, all the anthracite

TABLE 8—*European Resources (1913)*

MILLIONS OF METRIC TONS

Country *	Anthracite and Semianthracite			Bituminous			Brown Coal and Lignite			Total
	Actual	Probable	Possible	Actual	Probable	Possible	Actual	Probable	Possible	
Great Britain	11,172	13		123,940	29,971	16,254				181,350
Ireland	172			8	111					291
Portugal	20									20
Spain	756	132		3,024	526	Considerable	720	379	Considerable	5,537
France	581	927	1,223	3,622	2,966	3,662	301	410	921	14,613
Italy	1	143					51	48		243
Greece							10	30		40
Bulgaria					30			358		388
Denmark (Faroes)								50		50
Netherlands	50	270		159	1,232	1,241				2,952
Belgium					11,000					11,000
Germany (including Silesia)				71,213[a]	123,334		9,314	4,068	Large	207,929
Hungary				4	109		354	1,250		1,717
Austria				2,970	25,417		12,231	663		41,281
Bosnia and Herzegovina							1,700	1,976		3,676
Serbia				2	10	33	58	182	244	529
Romania							3	36	Large	39
Sweden				106	8					114
Russia:										
Dombrova				535	855	1,134		63		2,587
Moscow								78	1,500	1,578
Donetz		37,599			18,014					55,613
S. W. Russia								43	Small	43
W. Urals				57		Large				57
Caucasus					253			12	25	290
Totals	12,752	39,084	1,223	205,640	213,836	22,324	24,742	9,646	2,690	531,937

[a] Incudes 247 million tons of Cretaceous age.

* NOTES ON TABLE 8

Great Britain—The reserves in Table 8 are taken down to a depth of 4000 feet. Additional reserves in seams of 2 feet and over between 4000 and 6000 feet are given as: actual, 6208 million tons; probable (in Scotland), 1685 million tons; possible, large.

Portugal—Reserves taken down to 4000 feet. Additional reserves of coal of Jurassic age given as 150,000 tons.

Spain—Reserves taken down to 4000 feet. Anthracite and bituminous coals mainly of Carboniferous age. The brown coal is chiefly infra-Cretaceous, the lignite Tertiary. Additional reserves of anthracite and bituminous coal in seams of 2 feet and over between 4000 and 6000 feet are given as: actual, 1720 million tons; probable, 1511 million tons; possible, considerable.

France—Reserves of anthracite and bituminous coal are taken down to 1200 meters. Additional possible reserves between 1200 and 1800 meters are given as 2970 million tons.

Bulgaria—The bituminous coal listed is low-grade coal of Cretaceous age. There is also a little Carboniferous coal in Bulgaria.

Netherlands—The reserves given are those down to a depth of 1200 meters. In addition, the following figures are given for reserves between 1200 and 1800 meters: probable, 343 million tons; possible, 1107 million tons.

Belgium—Reserves given are taken down to 1500 meters.

Germany—The figures for reserves of bituminous coal are those down to a depth of 1200 meters. Additional reserves between 1200 and 2000 meters are given as: actual, 23,653 million tons; probable, 103,276 million tons; possible, 88,500 million tons.

Hungary—The brown coals and lignites of Hungary are mainly of Tertiary age.

Austria—The reserves of bituminous coal are those down to 1200 meters. Additional reserves between 1200 and 1800 meters are given as 12,569 million tons.

Serbia—The reserves of bituminous coals given are of coals assigned to the Lias and Upper Cretaceous.

Sweden—The reserves in Sweden occur in strata referred to the Rhaetic-Lias (Jurassic).

Russia:

Dombrova (*Dabrowa*) *Basin* forms the northeast extensions of the Upper Silesian field. The reserves are calculated to a depth of about 1000 meters.

Moscow Basin coals are assigned to the Lower Carboniferous but fall within the category of brown coals; they are high in ash, often high in moisture, friable and readily disintegrating on exposure. M. Prigorovski, who contributed the account of this basin to the 1913 Congress Report, comments as follows on the decreasing output of the Moscow field (1913, vol. 111, page 1164): "The use of Donetz coal, on account of its better quality, was found to be more economical, notwithstanding the comparatively great distance of the Donetz from the Moscow industrial district. The comparative quality of the two coals can be judged by the fact that 343 cubic feet of birch wood has a heating value equal to 1.8 tons of Donetz coal and to 3.1 tons of Moscow coal."

Donetz Basin coal seams range in age from the higher part of the Lower Carboniferous to the Permian. It should be noted that the reserves of coal assigned to this basin are calculated to a depth of 1806 meters (6020 feet) and are thus not strictly comparable with other figures in the table.

Southwest Russia includes the Southwest Provinces, New Russia, Little Russia, White Russia and Lithuania. For the Donetz Basin, see above. Tertiary coals are widely distributed and only a few of the areas where they occur are included in the table.

Western Urals rank next in importance to the great Donetz field. The coal is Carboniferous in age.

Caucasus—The bituminous coal of the Caucasus is assigned to the Jurassic (Middle). Both these and the Tertiary lignites have been calculated to comparatively shallow depths.

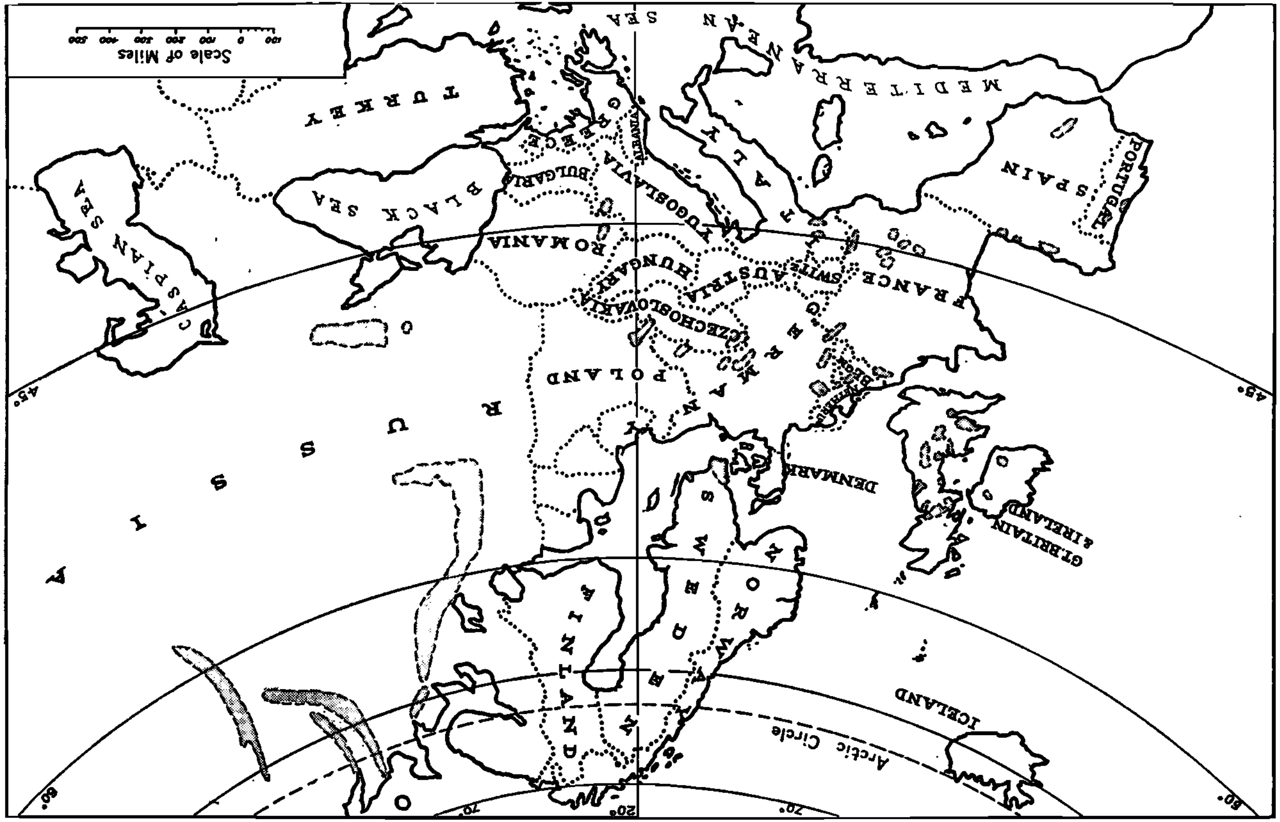


FIG. 3—*Principal coal fields of Carboniferous age in Europe. These include some Permian coals*

and bituminous coal may be assigned to the Carboniferous age, although locally workable coal occurs in Permian strata; e.g., Saxony, Donetz, and parts of France.

TABLE 9—*Summary of European Reserves by Countries*

MILLIONS OF TONS

Country	Anthracite and Bituminous	Brown Coal and Lignite	Total
Great Britain	181,350		181,350
Ireland	291		291
Portugal	20		20
Spain	4,438	1,099	5,537
France	12,981	1,632	14,613
Italy	144	99	243
Greece		40	40
Bulgaria	30	358	388
Denmark		50	50
Netherlands	2,952		2,952
Belgium	11,000		11,000
Germany	194,547	13,382	207,929
Hungary	113	1,604	1,717
Austria	28,387	12,894	41,281
Bosnia		3,676	3,676
Serbia	45	484	529
Romania		39	39
Sweden	114		114
Russia	58,447	1,721	60,168
	494,859	37,078	531,937

It has often been stated in comments on the 1913 estimates that Germany (that is, the old German Empire) controlled by far the largest coal resources of the countries of Europe. This is certainly not true if bituminous and anthracite coals down to a depth of 4000 feet are alone taken into consideration.

The figures of reserves so far given apply, of course, to the territorial divisions as they existed prior to the 1914–1918 war. By the treaties that followed the war, new political boundaries were established, with a consequent redistribution of coal resources. The main coal fields of the old Austrian Empire passed to the newly formed states of Czechoslovakia, Poland and Yugoslavia. The mines of Alsace-Lorraine were ceded to France, and, in addition, that country was vested temporarily with the ownership of the Saar region; Germany also lost to Poland the greater part of the Upper Silesian field, while the former Russian Dabrowa Basin was included in Polish terri-

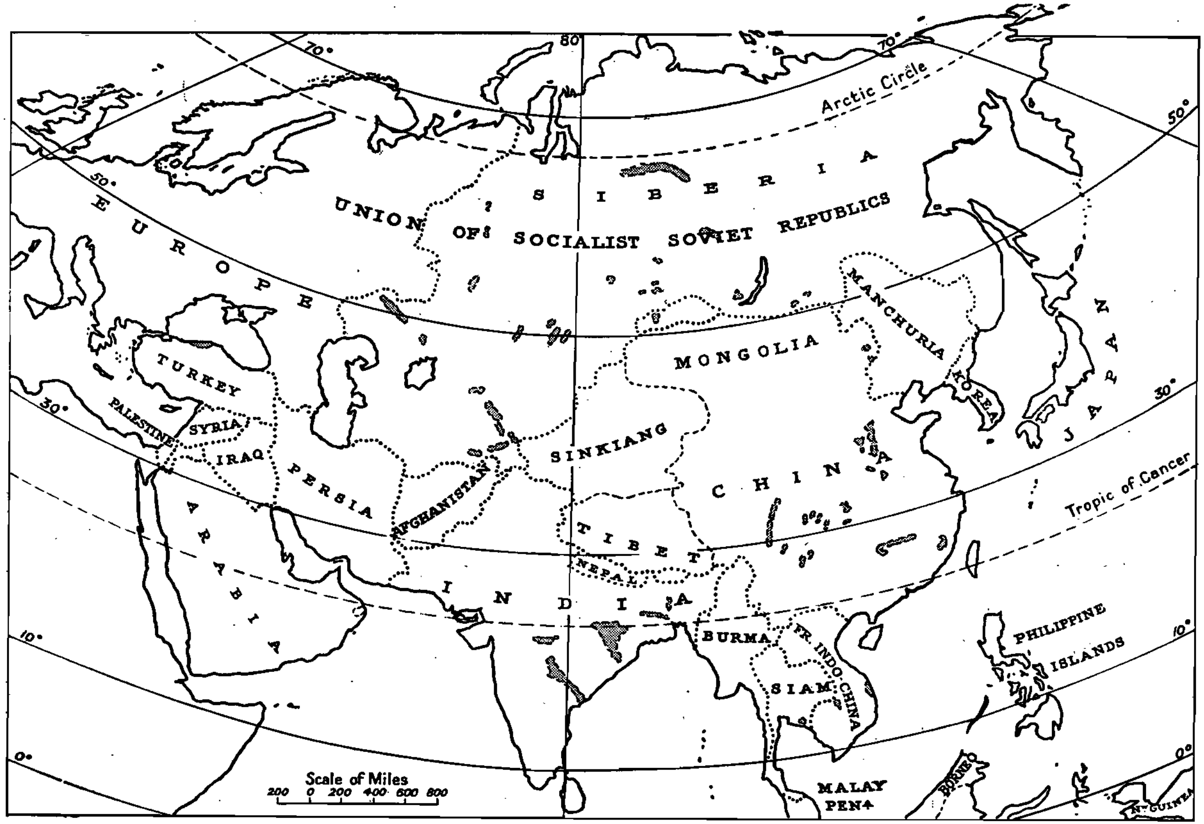


FIG. 4—*Principal coal fields of Carboniferous or Permo-Carboniferous age in Asia.*

tory. Accordingly the following figures refer to resources included in the rearranged territories.

Poland (included under Germany in Table 8)—The reserves of bituminous coal were estimated by the State Geological Institute to be: actual reserves, 5,788 million tons; probable reserves, 48,693; possible reserves, 7,400; total 61,881. These figures comprise the reserves in the Polish Silesian, Dabrowa, Cracow and Teschen districts. The total Polish reserves down to a depth of 1000 meters were estimated at 63,900 million tons.

Austria—The reserves of the new Austria have been estimated at: black coal, 7½ million tons; lignite, 330.

Romania, which was credited in the 1913 Congress returns with 39 million tons of lignitic coal of comparatively low grade, acquired at the conclusion of the 1914–1918 war important fields in Transylvania (good quality lignite) and the Banat. Its reserves were estimated in 1921 as: available from existing mines, 35 million tons; unprospected resources, 460 million tons; the great bulk of these reserves are Tertiary lignites.

Germany—More recent figures for Germany (quoted by Rice in Coal Mining in Europe, 1939) give as estimates of Germany's reserves:

		MILLION TONS
Bituminous coal and anthracite:		
"Known," to a depth of 1000 meters	87,330	288,721
"Probable," to a depth of 2,000 meters	201,391	
Workable brown coal		52,126

Russia—The total reserves of coal of all kinds in European Russia were estimated in 1928 as 70,000 million tons, equal to approximately 16.4 per cent of the reserves of the whole Soviet Union. The great Donetz Basin was assigned in workable seams down to 700 feet a reserve of 2500 million tons of anthracite and 1000 million tons of bituminous coal. The coal fields of the Western Urals were credited with at least 1000 million tons, while to the Moscow Basin were assigned resources in poor-quality coals of lignitic character, totaling 9000 million tons.

ASIA

Little is known in detail of the coal resources of Asia. According to the data provided in the summary tables prefixed to the 1913 Congress Report (Vol. 1, pages xxx–xxxi), the actual reserves were given as 20,502 million tons, and the probable reserves as 1,259,084 million tons (but see note in section dealing with China in present paper). Large unestimated reserves were also reported in Siberia, and small reserves in the Federated Malay States, Siam and Asia Minor. The details by countries are set out, somewhat rearranged, in Table 10.

AFRICA

Apart from patches of semianthracite in Morocco not far from Casablanca, the northern part of this continent, so far as is known, contains no

TABLE 10—*Coal Reserves of Asia*

MILLIONS OF METRIC TONS

Country*	Anthracite and Semianthracite		Bituminous		Semibituminous and Lignite		Total
	Actual	Probable	Actual	Probable	Actual	Probable	
Corea	7	33[b]	1	13[b]	5	22	81
China	8,881[a]	378,581	9,783[a]	597,740		600	995,585
Japan	5	57	896[b]	6,234[b]	67	711	7,970
Manchuria		68	409[b]	731[b]			1,208
Siberia		1		66,034		107,844	173,879
India:							
Bengal, Bihar and Orissa			48	53,247			53,295
Central India				22,657			22,657
Central Provinces			54	246	222	2,327	2,849
Assam, etc			119[b]	28[b]	3	50	200
Indo-China		20,002					20,002
Persia				1,858			1,858
Totals	8,893	398,742	11,310	748,788	297	111,554	1,279,584

[a] According to the detailed figures of N. F. Drake (1913, Vol. 1, pages 160–164), the estimated figures for actual reserves are very much more than set down in the summary table quoted.

[b] Low-grade coals.

* NOTES ON TABLE 10

Corea—About 63 per cent of the actual reserves and 70 per cent of the probable reserves are Jurassic in age; the remainder is Tertiary lignite. A little Carboniferous coal (anthracite) is also present.

China—K. Inouye (1913, Vol. 1, page 173) assigned a figure of 38,765 million tons for the probable reserves of coal in the better known districts. It should be noted, however, that he gave "enormous possible reserves" in addition. In 1926 the Chinese Geological Survey (see 1928, page 21) gave as the probable reserves of China:

	MILLION TONS
Anthracite	43,593
Bituminous coal	173,465
Lignite	568
Total	217,626

A still later Geological Survey estimate (1934) provided the following figures:

	MILLION TONS	
	CHINA	MANCHURIA
Anthracite	45,753	386
Bituminous coal	182,337	3,827
Lignite	2,916	197
Totals	231,006	4,410

The sweeping differences between these figures, even when allowance is made for the greater knowledge available at the more recent dates, suggests general unreliability. The computations were based on somewhat sketchy geological evidence without undertaking the somewhat impossible task of an actual survey. Comments arising on questions of quality of the actual coal and inaccessibility to markets will be touched on in a later paragraph.

The anthracite fields lie in North China in the Provinces of Shansi, Chihli and Honan, the first named containing, according to the 1934 estimates, approximately 80 per cent of the anthracite in the country. Intense folding and other geological disturbance have occurred in the anthracite and low-volatile coal fields, and considerable areas have been so crushed as to be unworkable.

The bituminous coal seams vary in quality, not only from seam to seam, but also laterally within the same seam. The seams are friable, with an ash content varying from 12 to as high as 28 per cent. The washability factor is generally low, but one exceptional case is known of a coking coal that can be washed down to 11 per cent ash content. Some Chinese coking coal is exported to Japan for mixing with noncoking Japanese produce. The extent of the coking coal deposits is unknown.

The vast proportion of China's resources lies in districts remote from the sea coast and also from any navigable river, the largest deposits being 250 to 300 miles inland over difficult country. The Manchurian Railway Co. is working the Fu-shun coal field, 150 to 200 miles from the port of Dairen, and one privately owned colliery is working at a distance of 85 miles from the seaport.

In general, because of the quality and inaccessibility, China is more likely to import than to export coal to the outer world in present times and in the predictable future.

The age of many of the Chinese fields cannot yet be definitely stated. The great bulk of the coals is Upper Carboniferous to Permian, but important deposits referred to the Jurassic are also present in the Provinces of Chihli, Shansi, Szechuan, etc. Triassic coals occur in addition.

Japan—The Tertiary (Miocene) rocks provide by far the most important source of Japan's coals. These fall as a rule into the low-grade (high-volatile) bituminous category, but include subbituminous and lignitic types. Older coals are represented locally and are referred to the Trias and Jurassic, but the fields are small and scattered and much affected by tectonic disturbances and igneous intrusions.

Manchuria—While the reserves in Manchuria are known to be large, any estimates are largely hypothetical. K. Inouye (1913, Vol. 1, pages 239–279) gave an approximate estimate for southern Manchuria. Rearranged according to age of coals his figures are:

	MILLION TONS	
	ACTUAL	PROBABLE
Upper Carboniferous	431	1,091
Jurassic		9
Tertiary	378	498

Estimates made by the Chinese Geological Survey in 1934 give a total reserve of 4410 million tons.

The Carboniferous coals are widespread but the Tertiary (referred to the Miocene) coal-bearing beds are confined to the Fu-shun Valley, where the lignite mines are situated. These Tertiary coals, which fall into the low-grade bituminous and subbituminous categories, vary much in thickness; an extreme figure of 200 feet has been recorded in one part of the main seam in the Fu-shun field, but the high number of thin partings present reduced the thickness of coal by at least 20 feet.

Siberia—The tentative figures of reserves of coal in Siberia, Turkestan and Saghalien, compiled by Th. Tschernyschew for the purpose of the 1913 Congress (Vol. 111, page 1151) were: anthracite or semianthracite, 1 million tons; bituminous and brown coals, 173,878 million tons. Comparing the classification with that of the coals of European Russia, Tschernyschew said: "For Siberia (including Saghalien) and Turkestan, the figures of the reserve are still more conjectural, and for the division of the coals into the three classes (anthracite, bituminous and brown coal) we have not sufficient information." He also added "these figures are, without doubt, too small for Siberia . . . and the reserves stated may be increased many times."

Later estimates issued authoritatively from Moscow in 1928 gave reserves of 358,000 million tons, most of this contained in the following districts:

	Million Tons
Kuznetsk Basin in south central Siberia	250,000
Irkutsk region of eastern Siberia: Jurassic: generally high-ash coals of relatively low grade	52,000
Karaganda field in the district of Akmolinsk, steppe region of western Siberia: a shaly coal with clay partings	6,000
Tungus Basin in the Lower Yenesei valley; Permian	5,600
Far Eastern Siberia (Amour River, etc.): Jurassic and Tertiary	2,600
Saghalien: Cretaceous and Tertiary, mainly the latter	2,000

Other coal deposits occur on the eastern slopes of the Urals, usually in folded and much disturbed basins; both Carboniferous and Mesozoic coals are present and are worked. The coals of Turkestan and the Caucasus are either too poor in quality or too remote and difficult to work to be of anything but local value.

The Siberian coals up to recent years have been little developed, contributing only about 13 per cent of the total Russian output. Thus in the fiscal year 1926–1927, they supplied a little over 4 million tons, half of which came from the Kuznetsk Basin. While they must play an essential part in the development of the country, their geographical isolation precludes their entry on any considerable scale into world markets.

India—The great bulk of the coals of economic value in India is contained in the Permo-Carboniferous rocks (Godwana formation), which have been preserved in portions of peninsular India. It is only in the central subdivision (or Damuda series) of the Lower Godwana that coal seams of importance occur. The Indian coals are of the same general age as those of South Africa, South America, and the main producing fields of Australia, and may be assigned to the Permian formation. Much of the tonnage of Indian reserves classified as bituminous are really of low-grade quality for that classification. Fermor (1934) estimated the reserves of good-quality, easily accessible coal present in the known fields as 4521 million tons, while Fox in the same year estimated the reserves of good-quality coal at 5000 million tons. The coals in the different fields are few in number and vary a good deal in quality. The ash content ranges from 10 up to 25 per cent and cannot be reduced much by washing. About one third of the reserves consists of caking coal, and about a third of the output in prewar years was utilized in the manufacture of coke for the iron and steel industries. The Bengal, Bihar and Orissa fields between them provide more than 90 per cent of the total production.

The figures of reserves given are very conservative and apply only to coal at comparatively shallow depths. The possible or undetermined reserves must be very large.

The Mesozoic and Tertiary coals of Assam, Baluchistan, etc., are of little importance.

Indo-China—In addition to the 20,002 million tons of anthracite credited to Indo-China in 1913, as shown in Table 10, this country possesses also reserves of bituminous coal and lignite. No estimates of resources in these materials are available, however. Indo-China made marked advances in its production of coal in the period between the two great wars; thus, its output of some 430 thousand tons in 1913 rose by 1936 to 2116 thousand tons. Almost the entire output was anthracite, although a little bituminous coal and lignite is included in the 1936 figures.

coal of economic value. Among the rich mineral resources of the Union of South Africa, in Rhodesia, and in the Belgian Congo, coal is well represented.

The reserves of coal, according to the 1913 Congress, were as stated in Table 11.

TABLE 11—*African Reserves (1913)*

MILLIONS OF METRIC TONS

	Actual	Probable	Total	Classified as
Union of South Africa:				
South Africa Cape Colony Orange Free State Basutoland Swaziland		4,800	4,800	Mainly bituminous; 20 per cent anthracitic and 20 per cent approaching subbituminous
Natal		9,300	9,300	Bituminous and anthracitic
Transvaal		36,000	36,000	80 per cent bituminous; rest approaching subbituminous
Zululand		6,000	6,000	Anthracitic mainly
Rhodesia	419	150	569	74 per cent bituminous; rest mainly bituminous to subbituminous
Belgian Congo		990	990	Mainly subbituminous
Totals	419	57,240	57,659	

In addition, southern Nigeria was credited with a proved reserve of 80 million tons of subbituminous coal tentatively assigned to late Cretaceous times, and a very large, unproved, additional reserve. Large possible reserves were also assigned to Rhodesia.

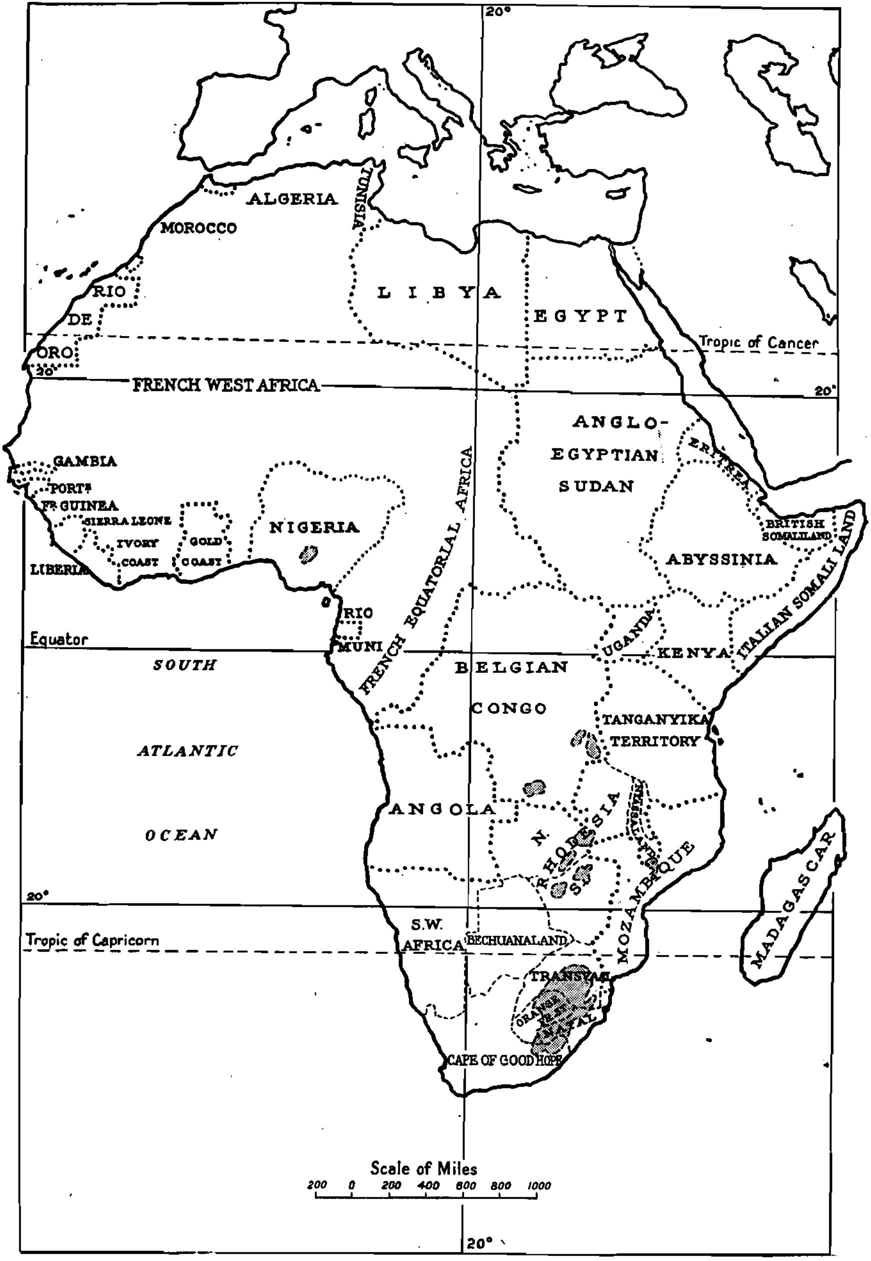


Fig. 5—*Principal coal fields of Permo-Carboniferous age, Africa.*

Union of South Africa

A more recent investigation into South African reserves was carried out by W. J. Wybergh (1, 19; see also 2, 1940, page 398), whose estimates are summarized in Table 12. Large quantities of low-grade coal occurring in Zululand and in other areas are omitted. This estimate makes the ***proved and estimated*** reserves of the Union 23,730 million tons, of which about 36 per cent falls into the former category.

TABLE 12—*Union of South Africa Reserves* (*Wybergh*)
MILLIONS OF SHORT TONS

Area	Proved		Estimated	Undetermined
	[a]	[b]		[d]
Cape Province			[c]	
Orange Free State		1,500	472	
Natal	735	89	2,204	
Transvaal	2,962	3,438	12,330	
Totals	3,697	5,027	15,006	

[a] Coals in the first column have a calorific value described as 12 lb. per lb., equivalent to 12,415 B.t.u.

[b] Coals in the second column are below 12,415 B.t.u.

[c] Not estimated because of poor quality.

[d] The figures (totaling 203,040 million tons) given by Wybergh under this heading refer to coal "about which little is known in detail, but of the probable existence and extent of which there is good geological evidence sufficient to warrant prospecting."

The geological age of the South African coals is shown in Table 13. All the chief deposits of coal are in the Ecca series, in the Middle group in the Transvaal, Orange Free State, Natal and Zululand, and in the Upper group in the northern Transvaal and Southern Rhodesia.

TABLE 13—*Age of the South African Coals*

Karroo System	Stormberg series (Trias to Lower Jurassic)		
	Molteno beds at the base (Trias)		Cape Province coals
	Beaufort series (Permian to Trias)		
	Ecca series (Permian)	Upper group	Rhodesia coals
		Middle group	Transvaal, Natal, etc., coals
		Lower group	
	Dwyka series		

Coals are found in the Lower Beaufort beds (Permian) locally in Natal and Zululand, but are of low grade and of little value. The Molteno coals of the Cape Province are high-ash seams consisting of alternating beds of shale and coal, the coal beds seldom exceeding 2 feet. The Transvaal and Natal between them produced in 1945 the greater part of the total Union output of 23 million tons, a negligible quantity coming from the Cape and the Orange Free State. The following points should be noted:

1. All the coal fields are interior. The Natal collieries, on the whole, are 200 to 275 miles distant from Durban, and in the Transvaal the collieries are situated more than 300 miles from the port of Lourenco Marquez. The railways are single track, and the gauge 3 feet 6 inches.
2. The seams are few in number and, from the point of view of the mining engineer, suffer from violent want of continuity, both in thickness and quality. The main seam may be 18 feet thick, but frequently only one third of the thickness is of marketable quality. Comments on quality occur in a later paragraph.
3. The coals are not high-grade when compared with the Carboniferous coals of America or Britain. In geological age and in their general character, they are akin to the coals of Peninsular India. Many of them are relatively high in ash and sometimes fairly high in moisture; for example, representative analyses of Transvaal seams (see Ronaldson, 1920, p. 74) indicate an ash content of from 12.34 to 21.50. The best quality seams occur in Natal, where sheets of igneous rock are widespread and where the effect of these has been to alter the coal locally to semianthracitic and anthracitic types, and also steam-raising and coking fuels of good quality. At the same time, much of the coal in Natal has been rendered useless by proximity to the igneous rocks, and the reserves of really first-class coal are not large.
4. According to Wybergh, the Transvaal carries the largest proved reserves, but the largest unproved reserves lie in the Orange Free State.

Southern Rhodesia

The principal coal-bearing groups of rocks occur in the Lower Matobola series, corresponding to the Ecca series of the Union. Mining operations are mainly confined to the Wankie field, which has an estimated area of at least 400 square miles. This field is important because of its geographical situation in relation to neighboring nonproducing countries, and the great bulk of its coal is used locally. The seams are few, the principal one varying generally between 5 and 12½ feet up to over 30 feet in thickness. This seam, where mined, is shallow, and is won by short slopes from the surface. The system of working is pillar and stall, and extraction of pillars is not generally carried out. The entries are wide, and the roof is cut in the form of an arch, requiring little or no support. To mining engineers this colliery is of fascinating interest; it is stated to be possible to drive a motor car from the surface into the underground workings.

The ash content is lower than in coals of the Union, and the calorific value is about 12,570 B.t.u. It may be noted here that the high ash content of the average South African coal reduces the calorific value below what might be expected from a consideration of other properties. An exception to this, however, is to be found in the Natal coals shipped at Durban, in which the moisture at 1.67 per cent assists in equalizing the effect of the 12.07 per cent of ash.

It should be noted that the estimated reserves in Rhodesia, given in Table 11, are extremely conservative.

OCEANIA

The returns made for the purposes of the 1913 Congress (see 1913, Vol. 1) are shown in Table 14.

TABLE 14—*Reserves in Oceania (1913)*

MILLIONS OF TONS

	Actual	Probable	Total	Classified as
Australia:				
Queensland[a]	412	1,685	2,097	Mainly bituminous (high-grade to medium)
New South Wales[b]	20,000	97,239	117,239	Mainly bituminous (high-grade to medium)
Victoria[c]	15		15	Bituminous (medium grade)
Tasmania		66	66	Mostly medium grade bituminous
South Australia				
Western Australia	153	500	653	Subbituminous
New Zealand	389	522	911	
British North Borneo				Bituminous to lignitic
Netherlands India				Subbituminous to lignitic
Totals	20,969	100,012	120,981	

[a] "Probable" figures included in "actual" in 1913 summary tables, and estimated "possible" reserves of 13,122 million tons included in "probable."

[b] No separate figure for "actual" reserves given in the 1913 tables.

[c] 37 million tons between 4000 and 6000 feet in depth included in 1913 summary table (1913, Vol. 1, p. XXIX).

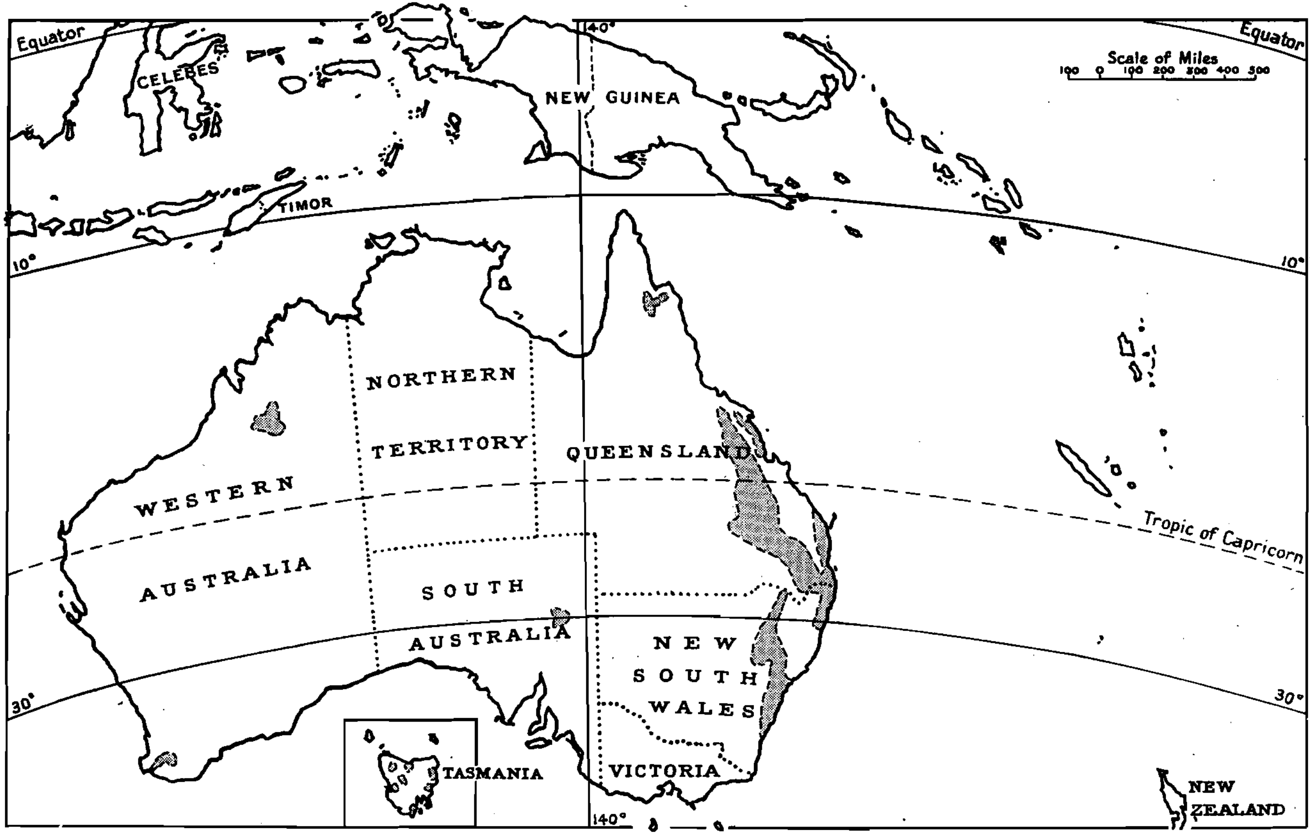


FIG. 6—*Principal coal fields of Permo-Carboniferous and Trias-Jurassic ages, Oceania.*

The 1913 figures of reserves include also the following estimates of Tertiary lignite:

	Million Tons
Victoria	31,114 (Latrobe Valley only)
New Zealand	2,475 (612 actual)
British N. Borneo	75
Netherlands India	1,311 (240 bituminous)
Philippines	66 (4 actual)
Total	35,041

Small reserves of lignite in Southern Australia, Queensland, New South Wales, and Netherlands India not estimated.

These estimates give: Tertiary lignites, 35,041 million tons; other coals, 120,981.

Australia

The Australian coals range in age from Permian to Tertiary and may be classified on an age basis (excluding "possible" reserves) as shown in Table 15.

TABLE 15—*Australian Coals According to Age*
MILLIONS OF TONS

Area	Permian[a]	Trias-Jurassic	Cretaceous
Queensland	1,362	731	4
New South Wales	117,239		
Victoria		15	
Tasmania	11	55	
Western Australia	653		
Totals	119,265	801	4

[a] Or Permo-Carboniferous.

Much of the largest reserves occur in New South Wales in an extensive basin near the important center of Sydney. The Permo-Carboniferous rocks here (up to 17,000 feet thick) include three coal-bearing series: Upper (Newcastle, where the coal measures give 35 to 40 feet of workable coal; Middle (Tobago), about 18 feet; Lower (Greta), about 20 feet.

The Greta measures are assigned by some authorities to late Carboniferous. They do not everywhere contain workable coals and indeed are completely absent on the west side of the basin. Approximately 1893 million tons has been assigned to the Greta coals out of the New South Wales total of 117,239 million tons. They are hard, low-ash (average 6.25 to 7 per cent) coals of excellent quality. The seams of the Tobago and Newcastle Permian measures have a higher ash content in general (up to 14 per cent) and a slightly higher moisture content.

A later estimate of the coal reserves of New South Wales gives: actual reserves, 5257 million tons; probable reserves, 8672 million tons; and large possible reserves. New South Wales is much the largest contributor to Australia's coal output.

In Queensland the Permo-Carboniferous occupies a very large area in the central districts, but the coastal fields, north and south of Brisbane, are of Trias-Jurassic age. It is from these coastal fields that most of the coal produced is derived. The seams vary in thickness and quality from place to place, with an ash content generally round about 10 to 12 per cent. These beds extend southward into the Clarence, Richmond and Tweed fields of New South Wales, regarded as Triassic in age.

In Tasmania the coal fields are small and scattered, and output is not sufficient to supply the demand.

TABLE 16—*Australian Reserves (1927)*

MILLIONS OF LONG TONS

State	Actual	Probable
New South Wales	20,000	100,000
Victoria:		
Coal	25	Not large
Lignite	10,400	Not large
Queensland	412	13,000
South Australia	50	Fairly large
Western Australia[a]		
Tasmania	125	123
Totals	31,012	113,123

[a] The combined actual and probable reserves for Western Australia are given as 3500 million tons.

The only field of any known importance in Western Australia is the small Collie field (Permo-Carboniferous) lying 100 miles or so south of Perth. This detached coal field is thought to owe its preservation to being faulted down into the pre-Cambrian rocks. The boundary fault is a downthrow of at least 2000 feet. The main seam is 7 to 9 feet thick and has fair continuity over a considerable area. The coals are hydrous and noncaking, with moisture up to 26 per cent, and in some parts approach to lignite. In other parts, the banded appearance suggests drift origin. Further reference to the nature of this coal is made on page 672.

South Australia contains some Jurassic coal of poor quality in the Leigh's Creek field, but little or nothing is known of any coal of economic value elsewhere.

A more recent estimate of Australia's reserves was given in 1927, as shown in Table 16.

New Zealand

The New Zealand coals of economic value are: (1) bituminous and subbituminous coals of late Cretaceous to early Tertiary age; (2) brown coals and lignites of Eocene and later Tertiary periods. The latter represent 50 per cent of the total resources, but the seams are very irregular in thickness and are lenticular.

A revised estimate of New Zealand's reserves, prepared in 1927 by the Geological Survey, appears in Table 17. The early Tertiary coals of New Zealand reach bituminous rank at a number of localities and are of excellent steam-raising quality.

TABLE 17—*New Zealand Reserves (1927)*
MILLIONS OF LONG TONS

Class	Proved	Probable
Anthracite	Very little	Very little
Bituminous	206	444
Subbituminous	60	72
Brown coal (the better lignite)	247	738
Lignite	150	377
Totals	663	1,631

In British North Borneo, the Netherland East Indies and the Philippine Islands, there are very considerable quantities of Tertiary coal, varying in quality from lignite to subbituminous and bituminous. The latter grades occur where the coal has been subjected to pressure during orogenic movements.

Reasons for Modification of the Tonnage Estimates

In the summary of, and comments upon, the 1913 estimates of world resources, given in the preceding pages, certain qualifying and limiting factors have been directly or indirectly referred to. Mere statements of reserves, expressed in millions of tons of coal, provide a quite inadequate picture of the problem before us, and indeed, if widely circulated and unchallenged, may well have harmful repercussions by disseminating a feeling of unreal security. Many factors of a practical nature must be taken into account in assessing, or attempting to assess, the coal content of a country or coal field, and some of the more important of these factors, which must necessarily modify and limit the estimates of world reserves, are briefly reviewed here under the following headings:

1. Quality of marketable products.
2. Geological conditions limiting extraction percentage.
3. Loss in mining.
4. Geographical isolation and inaccessibility to world markets.

It is not implied that these headings represent more than a reasonably convenient method of drawing attention to some essential considerations that are apt to be overlooked in the rosy generalizations that forecast, for our coal reserves, a life of thousands of years. Clearly also these subject headings are not exclusive categories, but deal with more or less closely related aspects of the wide question of actual and available reserves.

QUALITY OF MARKETABLE PRODUCTS

The classification of the world's coals adopted for the purposes of the 1913 Congress contemplated the return of data from individual countries under various quality headings based essentially on what has come to be known as the split volatile ratio. This was done "in order to have the various reports uniform and easily comparable." The classes and the subdivisions of classes were each assigned descriptive characteristics and, for convenience in tabulating results, were given letters—A, B, C, etc. It cannot be said that the result was satisfactory, and in fact the Committee that drew up the scheme recommended a discussion by the Congress, "looking to the adoption of a universal standard classification." The tabulated summaries of reserves in the Congress Report (1913, Vol. 1) show that these are brought together into categories A (anthracite), B and C (bituminous), and D (subbituminous coals, brown coals and lignites). The qualities assigned to class C are essentially applicable to coals falling within the designation of cannel coal, while classes B and C, taken together as they are in the summary tables, include a wide range of types. Within recent years a great deal of research work has been carried out on the classification of coals, and important advances have been made in this problem. For the purposes of this paper, the classification of coals recognized by the United States Bureau of Mines and the American Society for Testing Materials has been used. This is sometimes known as the A.S.T.M. classification, and in it coals are grouped according to rank, depending on the degree of alteration of the coal materials in changing from peat to anthracite, the fixed carbon and the calorific value being calculated to a mineral-free basis. Table 18 shows in a broad way how the Congress classes correspond with the nomenclature used in America.

TABLE 18—*Correlation of Types*

1913 CLASSIFICATION		CORRESPONDING AMERICAN DESCRIPTION
CLASS	SUBDIVISION	
A	A_1	Anthracite
	A_2	Semianthracite
B	B_1	Low-volatile, high-carbon bituminous (semibituminous or superbituminous)
	B_2	Bituminous
	B_3	High-volatile, low-carbon bituminous
C		
D	D_1	Subbituminous
	D_2	Lignite

The high-volatile and subbituminous coals are further subdivided in the American classification, each into three categories.

In both classifications it is recognized that there is a continuous gradation from the low-ranking lignites and brown coals to the high-ranking anthracites, and that the divisions used are necessarily arbitrary. But the mere placing of coals in a lignite to anthracite series or, in other words, in an immature to mature series, connotes the question of age and something must be said on this aspect of the whole problem. It may be illustrated by quoting three analyses of coals of widely different ages (Table 19).

TABLE 19—*Analyses of Three Coals*[a]

Constituent	Coal 1	Coal 2	Coal 3
Moisture, per cent	2.82	21.63	31.26
Volatile matter, per cent	29.97	27.84	42.42
Fixed carbon, per cent	59.84	46.98	19.52
Ash, per cent	7.37	3.55	6.80
Sulphur (included in volatile matter), per cent	1.22	0.37	0.80
British thermal units	13,991	9,508	7,337

[a] Coal 1, an Upper Carboniferous bituminous coal from Pennsylvania; coal 2, an Upper Cretaceous subbituminous coal from the Laramie series of Colorado; and coal 3, an early Tertiary lignitic coal from the Fort Union series of Montana.

Coal 1 is many millions of years older than coal 2, and the latter in turn is very much older than coal 3. Table 20 represents an attempt to relate the main periods of coal formation to the types or ranks of coal included in each.

TABLE 20—*Relation of Age to Types of Coal*

Age	Anthracite	Semianthracite	Low-volatile Bituminous	Bituminous	Subbituminous	Lignite
Tertiary					←	TERTIARY →
Cretaceous (late)				←	CRETACEOUS	→
Trias-Jurassic			←	JURASSIC	→	
Permian or Permo-Carboniferous		←	PERMIAN		→	
Upper Carboniferous	←	UPPER CARBONIFEROUS		→		

As regards the types of coal mentioned in Table 20, it may be useful to quote the relative percentage composition of coals of different ranks as given by E. S. Moore (1940, page 106) which are shown in Table 21.

TABLE 21—*Percentage Composition of Coals*[a]

Coal	Proximate Analyses, Per Cent				Ultimate Analyses (Ash and Sulphur omitted), Per Cent				Calorific Value, B.t.u.
	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Total Oxygen	
Lignite	34.55	35.34	22.91	7.20	6.60	42.40	0.57	42.13	7,090
Subbituminous	24.28	27.63	44.84	3.25	6.14	55.28	1.07	33.90	9,376
Bituminous	3.24	27.13	62.52	7.11	5.24	78.00	1.23	7.47	13,919
Semibituminous	2.03	14.47	75.31	8.19	4.14	79.97	1.26	4.18	14,081
Semianthracite	3.38	8.47	76.65	11.50	3.58	78.43	1.00	4.86	13,156
Anthracite	2.80	1.16	88.21	7.83	1.89	84.36	0.63	4.40	13,298

[a] Samples as received.

It must be remembered that the main periods of coal formation were not everywhere contemporaneous. The Upper Carboniferous was the main period in the Northern Hemisphere, and it is in the Upper Carboniferous rocks of the eastern United States and of northern Europe that the great reserves of high-quality coals are contained. This fact has been of supreme importance in the industrial development of Europe and America and must for a long time ahead remain the controlling factor in world supplies. In the Southern Hemisphere—in South Africa, Australia, India, South America, and so forth—the principal period of coal formation was the Permian, or Permo-Carboniferous as it is often termed. The coals of this period are less numerous and much more variable than the older ones in the Upper Carboniferous. The Permo-Carboniferous coals are relatively high in ash, higher in noncombustible volatile matter, and possess a lower calorific value than the true Carboniferous coals in general. They could not compete freely in the open markets of the world with the latter. Little is known regarding the quality of the vast reserves of bituminous coal credited to China (Table 10) but the coals that have been worked there are definitely not high grade; they also have a high content of inherent ash.

Late Cretaceous times saw another period marked by the deposition of coal-bearing rocks on an extensive scale. These are widely developed, for example, in the western parts of the North American continent, but while they contain there a very large reserve of coal, much the greater part of this falls into the categories of subbituminous or low-grade bituminous. The prewar output of Alberta was lignite or subbituminous to the extent of about 60 per cent of the total production. Lignite-bearing deposits of Tertiary age are widely distributed over the earth's surface, and America, Europe, Japan, and other countries possess large reserves of them.

The best quality of marketable products is provided by the Upper Carboniferous coals of the Northern Hemisphere and, though to a lesser degree, by the Permo-Carboniferous coals of the Southern Hemisphere. The coals of later geological periods, broadly speaking, are definitely inferior and are not likely to enter into the world's markets for a long time ahead. To this statement there is one qualification. In certain regions these younger coals have been brought within the influence of the mountain-building movements that have shaken the crust of the earth at different times and been raised in rank as a result of the long-continued pressures. The quality of a coal depends upon a number of factors, including: (1) the conditions under which the original plant remains were deposited; (2) the nature of these plant remains and their distribution as components of particular seams; and (3) the post-depositional agencies that have in course of time brought about their slow alteration into coal. Something has already been said on this subject earlier in this paper.

It is not possible to evaluate the varying physical conditions that have been operative. The effects of pressure due to burial under increasing load of sediments and of pressure due to crustal disturbances are both factors in coal formation. In the case of the former, the longer the time over which regional pressure continues to act, so much the greater is the opportunity for extending its effects. We can thus make the broad generalization that the older coals are higher in the lignite-anthracite series than the younger ones. Nature, however, always provides exceptions to generalizations of this kind, and there are examples of old coals that have escaped, or largely escaped, metamorphism in the course of their long history. The Lower Carboniferous coals of the Moscow Basin and the Permo-Carboniferous coals of the Collie field in Western Australia may be cited as instances.

The Collie coals are interesting in that, while the ash content is moderate, the moisture reaches up to 26 per cent and the calorific value does not on the average exceed 10,000 B.t.u. Much of the coal is regarded as "soft," and deteriorates badly when exposed to summer heat. For this reason, the Railway Department uses this soft coal "within a fortnight of its being mined" (see Report of the Herman Commission, 1931).

"Quality," for the purpose of this section, requires some definition. There are different qualities of peats, lignites, bunker coals, anthracite, etc., the word "quality" having different shades of meaning in each case. In relation to world coal resources, however, a good quality coal, whatever be its geological origin, should be considered as one that is capable of finding economically a permanent place in the world's market, in competition with all other sources of heat and power for the time being available. Judged by this standard, the world's coal reserves are seriously limited.

The immense deposits in Asia—chiefly in China—may be regarded as of little, if any, economic value, except to supply local requirements. Australia can contribute relatively little to the outside world, in ordinary economic competition, although some of the Permo-Carboniferous coals of New South Wales may yield a useful contribution. South Africa exports good quality coal of 12,415 B.t.u. or better, under Government supervision, but the greater part of the Triassic coals in the Union are of poor grade.

The inevitable conclusion is that, apart from some notable exceptions, the coals that can be relied upon as being of the quality necessary to withstand economic competition in the world's markets are to be found in the Carboniferous formation, and, what is very important, at the present rate of extraction, the best of these will become scarce in less than 100 years.

GEOLOGICAL CONDITIONS LIMITING PERCENTAGE OF EXTRACTION

The geological conditions limiting percentage of extraction may be included under the following categories: (1) structural features; (2) variations in number of seams, or in total coal content; and (3) workable thickness of individual seams.

Structural Features

These are well known in general and need be only briefly mentioned. They include the various structural features developed in coal seams, which operate to limit the extraction percentage. Among them may be noted: (1) the presence of partings that interfere with mining where the beds they separate are too thin to be worked separately; (2) folding and faulting of the coal-bearing rocks; (3) the occurrence of local unconformities, which may cut out particular seams; (4) the occurrence of contemporaneous streams, channels or "washouts;" (5) the occurrence of "rolls" and "horsebacks" in the floor and roofs of coals; (6) the presence of masses of contemporaneous igneous rocks (lavas, ashes and agglomerates) replacing the coal-bearing sediments locally; (7) the presence of intrusive igneous rocks cutting across the coals (dikes, volcanic pipes), or spreading laterally as sheets along or in close proximity to the coal (sills); locally these intrusive bodies are beneficial in raising the rank of the coal but have often rendered much of it valueless; (8) the occurrence of drift-filled, pre-Glacial river channels interrupting the continuity of shallow seams.

These factors, which of course differ widely in their importance, have been brought together here in one list because, while the incidence of one or all varies enormously, yet in their totality they must cause a very considerable reduction in available reserves. They are not all universally present in coal fields generally, but there are few fields that do not show pronounced structural irregularities of some kind or another due to original conditions of deposition (e.g., partings or splits), to igneous action, or to compressional or tensional stresses. Some coal fields, such as the great anthracite region of Pennsylvania, have undergone intense folding and faulting; others are relatively free from disturbances; but in the Luscar area of Alberta a case of folding exists which must be regarded as unique. The seam, which has an average thickness of 30 feet, lies in a series of folds doubtless originating in the earth movements from which the Rocky Mountains result. There are five folds separated by only a few hundred feet, resulting in gradients from practically vertical to about 1 in 2.

To a mining engineer, it is only the final results of these various structural disturbances and their effect upon the question of available reserves that are of interest. In the case of seams divided or split by partings of shale or sandstone of varying thickness, the practical consideration is the amount of clean, marketable coal that can be obtained. Partings seriously reduce potential output where they divide a seam into leaves that cannot be separately worked, where they are too numerous, or where they are subject to rapid variation. Faults also are a serious hindrance to mining in many fields and with increase in number and size the winning of the coal between the barren areas becomes more and more difficult and costly. Large displacements or strong folding may also carry a group of coals to a depth beyond present-day reach.

Variations in Coal Content

It often happens that a group of coal-bearing strata shows marked variation in the number and thickness of workable seams as it is followed from one part of a coal field to another. There may be a general attenuation of the strata concerned, an attenuation affecting also the included coals, in a particular direction or over a particular area. Thus a coal field may be divided into "thick" and "thin" areas. In the Lower Carboniferous (limestone coal group) coal fields of Scotland, for example, the number of workable seams of 2 feet and upward in thickness may reach 19 but falls to only two or three in some of the fields, and indeed locally there is not a single workable coal. This group of coals has been estimated to contain (1944, page 100), on a conservative estimate, 4654 million tons of coal, but assuming that nothing had been known of its striking variation in coal content, and that the figures of reserve had been based on data derived from the productive areas the estimates would have been much more than doubled.

Workable Thickness of Individual Seams

The economic thickness at which seams can be wrought depends on a number of factors, including depth to and quality of the coal; absence of disturbances and continuity persistence of the seam; nature of the floor and roof; and, perhaps above all, an experienced mining personnel. Thin seams can be worked profitably only in an old established mining field where thicker coals are also being mined or where some special inherent quality finds a ready demand for them in a neighboring market. An extreme case of this is provided by the once well known torbanite of Scotland, which has given its name to a variety of boghead cannel coal. This seam was mined for a number of years towards the middle of the last century, both for local use and for export to America and Germany. It seldom exceeded a thickness of 14 to 15 inches (occasionally it reached 18 or even 21 inches), and actually was wrought when only 3 or 4 inches. It has to be remembered, however, that the material was of quite exceptional value owing to its high yield of oil on distillation, that it was the foundation of a new industry, and that operating costs were then relatively low.

In framing estimates of present-day reserves, different minimum figures of thickness have been adopted by different authorities. For example, the First Royal Coal Commission on the Coal Supplies of Great Britain (1871) framed its estimates on coal included in seams of one foot and over in thickness to a depth of 4000 feet, and this basis was also adopted for the purpose of the 1913 Congress Report; for seams between 4000 and 6000 feet a thickness of 2 feet was taken. M. R. Campbell (1917, page 24), in estimating the coal reserves of the United States of America chose 14 inches as a minimum workable figure, and a depth of 3000 feet. These thickness figures would seem, however, to be too low for general adoption. Coals between 12 and 18 inches thick have been worked in places in Great Britain, Belgium, America, and other countries, but only those of particular value and easily accessible. Instances also occur where the variations a coal so often shows bring it for a time within these limits. But in dealing in a broad way with the question of reserves under present-day conditions, it would appear desirable to regard 2 feet as a minimum figure and to include all coals between 1 and 2 feet in a separate category. This does not imply the exclusion of thin seams from consideration. It merely means that their value as additions to reserves cannot be fully gauged without a detailed knowledge of particular local conditions; they may well be important in considering conservation problems, as several authorities have pointed out (see, for example, J. F. K. Brown, 1917). These remarks apply, of course, only to the better grade bituminous coals and coals of higher rank. It may be noted that according to the 1913 Congress figures, some 53 per cent of the world's reserves consists of bituminous (or "soft") coal, about 6 per cent of anthracite (or "hard") coal, and 41 per cent of subbituminous coal, brown coal and lignite. When dealing with the inferior coals in the last category, the figure of minimum workable thickness would have to be raised. It is certainly neither practical nor economical to extend to subbituminous and lignitic seams the minimum lower working limit used for high-ranking coals.

LOSS IN MINING

Mining engineers accustomed to operate seams of moderate and uniform thickness, in fields free from faulting and of moderate gradient and favorable conditions generally, may find it difficult to appreciate the loss in mining that does actually occur in fields where such favorable conditions do not exist. Should any mining engineers find themselves in that dilemma, the best reply would be to invite them to cross over to Scotland and operate a colliery in the Midland Valley. In addition to the geological factors to which I have referred, there are other considerations that contribute—often very seriously—to loss in mining. Thus areas of coal necessarily left in as surface support lower the extraction percentage, while in undersea workings much coal may have to be left intact as a precautionary measure. Extraordinary or unmanageable thicknesses of coal lead to loss. Equally serious is the loss due to workings on the pillar-and-stall system, where the stoops or pillars are not extracted in an approved manner.

What deductions are we to make, then, for such varying and unequally operating factors (geological and other) in framing estimates of the reserves of a coal field? M. R. Campbell (1913, Vol. 11, page 539), in estimating the coal reserves of the United States, deducted from his final figures the amount of coal produced up to the date of his survey and added to this an additional 50 per cent for waste in mining. Later, in 1919, he modified this, and added to the total production up to the end of 1918 from 20 to 50 per cent "to cover waste and loss in mining," probably 50 per cent for the earlier years and 20 per cent for the later years. W. A. Tarr (1938, page 373) states that the loss in mining bituminous coal in America "is estimated at ½ ton for every ton mined."

Percentage extraction figures may be on one of two bases: (1) percentage extraction from underground area actually being mined; and (2) percentage extraction from the entire coal field.

Percentage Extraction from Area Being Mined

In seams of moderate thickness worked by the longwall method, the percentage of extraction should be well up towards 100 per cent. If, however, the workings are mechanized on the three-shift system, this figure drops, and frequently does not exceed 90 per cent. In seams 6 feet or more worked on this system, the loss is still greater, and 80 per cent frequently is not attained. Reference may be made to the Thick Coal of Staffordshire and Warwickshire, in the English Midlands, which is 16 to 24 feet thick, and has long been the subject of special study. A very special method of working this seam was described by D. S. Newey in a paper read before The Institution of Mining Engineers (*Trans.*, Vol. LVIII, 1919–20), in which an extraction of nearly 100 per cent was obtained. The seam, however, is normally wrought by square work, longwall retreating in three sections or longwall advancing in the top section and leaving 5 feet as a roof for working the bottom section. Under favorable circumstances, 90 per cent extraction has been claimed, but 80 or 85 per cent is more usual, and where underground fires occur the figure naturally deteriorates considerably.

In pillar-and-stall working, the method of dealing with the pillars is the determining factor. I cannot do better here than quote the words of the American authority H. R. Wheeler, with whom I have fully discussed the matter:

> Successful pillaring with a high rate of extraction is dependent upon three important principles, namely: (1) advance and retreat work should be scheduled so that pillaring is started immediately the advance is completed; (2) pillars should not be allowed to stand;

(3) the removal of each individual pillar must be scheduled in relation to the removal of all other pillar cuts, so as to maintain a straight roof control line.

Pillaring of this nature has seldom been resorted to, as a few examples from different parts of the world will show. Thus, in Southern Rhodesia, working plans reveal square miles of workings where no pillars have been extracted. It may well be impossible to extract these now. In India, seams 20 feet thick are worked in two lifts, and here the extraction percentage is given as 50 per cent.

In the recent Report by the Commonwealth Board of Inquiry into the Coal-Mining Industry of Australia, 1945–46, it is stated that it is not the practice to work out any pillars and so 60 to 70 per cent of the coal is left untouched. I have examined the working plans and agree personally with this conclusion.

In Scotland, the Dysart Main Coal of Fife reaches a thickness of 24 feet. Many years ago, areas were worked by taking out as much as possible in the first working and leaving the pillars, which are now, in certain places, lost as a result of spontaneous combustion. Gemmell, a very eminent authority, gave an extraction figure of 50 per cent to the Royal Commission on Coal Supplies in 1905, but from my own knowledge of certain areas, even this figure is too high. It may here be mentioned that a very successful application of pneumatic stowing in this seam was published in *The Colliery Guardian* of Feb. 10, 1939. This described the extraction of one panel of coal in this seam (Dysart Main) at Wemyss. The percentage extraction obtained was 98 per cent. The seam was 17 feet thick, the stowing material washery dirt, and the stowing machine was of German origin. The tonnage of coal in the panel was calculated to be 210,300 tons, of which, as mentioned, 98 per cent was brought to the surface, 19 hundredweight of dirt being stowed against each ton of coal extracted. Pillars of solid coal are left surrounding the extracted area, but these pillars will be mined later. This case is exceptional. No figures were given as to cost per ton or capital cost of plant required, and in the case of thick seams, apart from difficulty in extracting pillars, where leaves or beds of different qualities occur, it is the practice in all countries to extract only the better coal and leave the inferior in the ground.

Percentage Extraction from Entire Field

The percentage extraction from an entire coal field must include losses of coal that has to be left as supports for winding shafts, main roads and staple pits, coal left as barriers against fire or water, coal left on the boundaries, and coal left as a support for important buildings, rivers, canals and railways. These factors exist to some extent in every field and cause "loss in working" in addition to the losses in the actual mining of the seam in any prescribed area. An example of what these factors may amount to *in cumulo* is to be found in the Regional Survey Report on the Durham coal field (1945, paragraph 57). The total reserves in 1942 are there estimated to be 3000 million tons, and the amount of coal left in place is set out as follows:

	Tons
Coal left for the support of railway permanent way, viaducts, bridges, etc	35,172,000
Housing estates	66,752,000
Highways, sewers and water pipes	6,496,000
Coal left voluntarily for support of property	278,683,000
Coal left in barriers and for support of working shafts or as protection against inundation of water	350,659,000
Total (24 per cent of total reserves)	737,762,000

Much of this coal might be worked if satisfactory arrangements, engineering and financial, could be made for the support of the surface by stowage. No one can forecast the future accurately, but the amount of coal in danger of being permanently lost represents a large proportion (actually 24 per cent) of the total reserves in this case.

A second example is taken from the plans of a colliery that had been closed as "exhausted." The plans were carefully examined, and the total coal originally estimated to be contained in the coal field was compared with the quantity left, for one reason or another. It was found that out of 13,100,000 tons estimated in the field originally, 4,410,000 tons remained when the colliery was declared to be exhausted. Allowing for possible errors in estimations, it appears that more than 30 per cent of the resources was left unworked. It was found that: (1) one seam was too near the surface and the working threatened to admit inundation of water; (2) another seam split into thin sections separated by bands of stone, and became unworkable; (3) another seam thinned out to 26 inches, with an 8-inch band, and could not thereafter be worked; (4) another seam developed a bad roof and had to be abandoned; (5) faults and geological disturbances affected many areas; and (6) pillars for four winding shafts, main roads, and other purposes accounted for the remainder.

This section is intended to indicate that sweeping deductions must be made from estimates based on geological data only, in assessing the resources of coal that can be brought to the surface economically by mining engineers, by methods known to the industry at the present time. Mechanization is not helpful in this matter, and the problem is urgent. Where Nature is most bountiful, her gifts are most likely to be wasted. An intensive study of each coal-producing country is necessary to determine even approximately the degree of loss, but the waste certainly is greater than is generally supposed.

Conclusion

The limits of workable depth and thickness of seam adopted in computing the world's coal resources require fresh consideration and amendment, in the light of experience and knowledge gained since last computation in 1913. The deductions from the mathematical computations of tonnage, to allow for geological disturbances and difficulties by which the mining engineer is obstructed in his efforts to exploit the coal fields, particularly the thick seams, are insufficient.

GEOGRAPHICAL ISOLATION AND INACCESSIBILITY TO WORLD MARKETS

In competition with other sources of heat and energy, coal suffers from the difficulty of extracting it from its natural bed and also of transporting it to market, especially over land. The establishment of a colliery on a coal field requires much capital, much time in development, and, despite mechanization, a large number of skilled workers.

The geographical distribution of the coal fields therefore is an important factor in the assessment of available reserves. This is a world problem rather than a series of unrelated or unconnected parts.

The immediate practical concern is not a question of tonnage, but what proportion of the tonnage can be made available at the required place and time to compete successfully against all competitors. Climatic conditions or absence of social amenities may militate against coal development to a much greater extent than against oil development, but the most serious handicap is the transport of the produce to market. Comparison with oil, gas, etc., in this respect is too obvious to mention, and indeed many coal fields may be rendered valueless by isolation, inaccessibility, or adverse climatic conditions.

Large reserves of coal, for example, doubtless exist in Alaska, in the Yukon, in northern and northeastern Siberia, in Spitzbergen, and at other places (Carboniferous, Mesozoic and Tertiary), but, apart from the fact that the coal fields are as yet little known in general, their location precludes development on any large scale. All the fields mentioned lie close to or within the Arctic Circle, where the rigors of the climate, the difficulties of establishing a sufficiently large and trained mining personnel, and the short period of the year during which shipping is possible, are inimical, and indeed overriding, factors in their possible exploitation. Spitzbergen (to take one instance) lies in latitude 76° to 80° north, and access to its inhospitable shores is prevented by pack ice, except during a few months each year. The July temperature is given as 38° to 40°F. Shipment may be possible during six months, but actually the "summer" extends over only three months (Cadell, 1920). Since the islands came under Norwegian control in 1925, some half a million tons of coal has been despatched annually, chiefly to Scandinavia, and at irregular intervals. Spitzbergen must be regarded, however, as negligible from the point of view of reserves for general world use.

Of coal fields remote from large centers of industry and lying far inland, there may be cited as instances those of Central and South Central Siberia (the Kuznetsk Basin, the Angara River fields, etc.) and the great coal fields of interior China. It may be estimated that the great bulk of China's resources in coal is in provinces remote from navigable waterways—certainly the largest deposits are several hundreds of miles distant from a seaport. A vast amount of prospecting, exploratory and mining work must be done and formidable transport obstacles overcome before these reserves can be regarded as falling within the ambit of actual, available world supplies, and the long overland transport would still remain a difficulty. Other examples of a similar character will readily suggest themselves to readers.

There are instances of a less striking but none the less important nature. Canada, for example, suffers from the fact that her two most heavily industrialized and populous provinces, Quebec and Ontario, possess no resources of coal (apart from a little lignite in the latter) and must draw their home supplies of coal either from the Maritime Provinces of Nova Scotia and New Brunswick or from the Alberta fields of the far west. To bring coal from Alberta, however, means transporting it a distance of some 2000 miles. The development of the Alberta coal field is retarded to some extent perhaps by low quality, but to a much larger extent because of its geographical isolation. Transport cost renders it impossible for Alberta coal to compete with coal from the great fields in the northern United States. Although in 1913 Canada was estimated to contain some 16 to 17 per cent of the world's coal resources, yet nearly half her requirements were imported from over the border.

The South African coal fields have been developed since 1880, and the geographical isolation is being to some extent overcome. The industry of the Union is now well organized, and the output approaches 23 million tons per annum—19 millions from the Permian Witbank of the Transvaal and 4 millions from Natal. Apart from local sales, the chief market is the bunkering of passing steamers.

The Rhodesian coal field is completely isolated from the outside world by inaccessibility to markets. The sales are confined to local needs, and to the smelting of copper in Northern Rhodesia and the Congo, and of chrome ore in the rich mineral field of Southern Rhodesia.

In South America, the coal resources generally, except in the coastal regions of Colombia and Chile, have remained unexploited on any large scale because of inaccessibility to markets.

If a new investigation into world coal reserves should be set on foot, special consideration should be given to the geographical factor. It should not be too difficult to group the major coal fields in some such categories as the following:

1. Coal fields geographically accessible:
   a. Coal fields long exploited and/or well known.
   b. Coal fields in which little exploitation has as yet been done.
2. Coal fields geographically isolated or remote.

There is nothing permanent, of course, in such a category; it would merely express the conditions relative to world markets and world requirements existing at the particular time the census or compilation was made.

Summary

The Twelfth International Geological Congress Report was for many years a standard world authority, and indeed must still rank as a monumental work of the greatest value, but after the lapse of 34 years of intense world progress in every sphere of activity, much revision has become necessary.

From the practical and economic, if not from the geological and scientific viewpoint, sweeping reductions in the tonnage are inevitable. The minimum workable thickness and the maximum depth of mining require revision. It is significant that 33 per cent of European reserves are below 4000 feet in depth.

"Actual" and "probable" reserves should be more clearly defined. Low-rank coals of Cretaceous and Tertiary age, even if altered to some extent by postdepositional agencies, should be clearly differentiated from coals of Carboniferous age. It is noteworthy that 80 per cent of prewar production was of Carboniferous age, and the Carboniferous formation contains less than one half the world's total reserves.

Further deduction must be made for loss in extraction, which is due partly to inefficiency in mining technique and partly to geological conditions. Practical considerations further suggest deduction in respect of geographical isolation and inaccessibility to markets.

The time has come for a new appraisement of reserves on a standardized quantitative and qualitative basis, with particular reference to the reserves that can be made available economically to meet the industrial competition of other sources of heat and power. Detailed surveys of coal resources are being carried out in various countries. It does seem imperative that these should be worldwide and compiled on a common basis, giving also some consideration to the factors set forth in this paper under the heading Reasons for Modification of Tonnage Estimates.

On such a basis, I venture to predict that the world reserves, instead of being stupendously large, will be found to be perilously small, calling for greatest possible conservation alike by mining engineers and consumers.

Acknowledgments

In addition to the authorities named in the text, acknowledgments are gratefully accorded for valuable assistance in the compilation of this paper to: Dr. Murray MacGregor, Glasgow, formerly Assistant Director (Scotland), Geological Survey of Great Britain; Mr. Dugald Baird, M.I.M.E., The Wemyss Coal Co. Ltd., East Wemyss, Fife; Mr. R. S. Barrett, F.S.I., M.I.Min.E., Newcastle-upon-Tyne; Mr. Laurence Holland, M.I.M.E., J. P., Birmingham; Mr. T. Hornsby, Regional Controller, Northern B Region, Ministry of Fuel and Power, Newcastle-on-Tyne; Dr. Walter Vogel, formerly Chief Mining Engineer to the Rhenish and Westphalian Mine Owners, Germany; and the Chairman and/or Directors of the following Companies: Chinese Engineering and Mining Co. Ltd.; Durban Navigation Collieries Ltd., South Africa; Mountain Park Collieries Ltd., Luscar Collieries Ltd., and the Jasper Collieries Co. Ltd., Alberta, Canada; and Wankie Colliery Co. Ltd., Rhodesia.

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The Philosophy of International Atomic Energy Control

BY JOHN M. HANCOCK

IN beginning my remarks, may I make it entirely clear that since January 4, 1947, I have not been a member of the United States Delegation to the United Nations Atomic Energy Commission. I am speaking, therefore, in purely a personal capacity.

Because of the interest of the engineering profession with reference to uranium, and because of the title assigned me for this talk, I am going to assume that you know what the United States Plan is for the control of atomic energy. At best, in the limited time, I could only summarize, at the risk of giving undue emphasis to the items mentioned, and at the risk of omitting many important parts of what seems so far to be a complete and well-rounded Plan for meeting the problem. I will aim to comment upon those aspects of the Plan that continue as problems and involve apparent, or obvious, misunderstandings and contrary views.

JOHN M. HANCOCK
Industrial organizer and administrator, Mr. Hancock is a partner in the firm of Lehman Brothers and a director of twenty large American corporations. As representative on the U. S. Delegation to the United Nations Atomic Energy Commission, he was right-hand man to Bernard Baruch in developing the United States Plan for international control of nuclear energy—either in peace or war. His knowledge of the subject is intimate and first-hand.

The control of atomic energy represents not only a problem but a challenge—both faced by all the peoples of the world. It involves a new approach to the problems of the kinds that arise between nations, problems that have not ever been solved even by international treaties in their efforts to outlaw weapons of war. These efforts range from the Kellogg-Briand treaty to outlaw war, and its obvious failure to prevent World War II, to the interdiction by the Pope of the use of the crossbow in the days of the Crusades. All previous plans have been failures—that makes the challenge to set up a plan that will work, or will at least give timely warning of its breakdown. I must confess that I have never seen another problem quite so intriguing or quite so difficult. Most of the jobs I have tackled revealed their limits after some examination. In this one, however, I found, whenever I got to what I thought might be its limits, that its confines had been extended several leagues. The basic problem is to set up a control to secure the good from the use of atomic energy and also avoid the risk of its sudden use for war. That is not too difficult by itself, but it is difficult to fit such a control into existing concepts of the responsibilities of nations.

As the United States proposals have now gone into history, and they now stand with the support of nine other nations, it would seemingly be more accurate to think of them as the views of the United Nations Atomic Energy Commission. In other words, eleven other nations have had the chance to become familiar with the U. S. Plan, and of these eleven, nine do understand it and do approve it.

United States Plan

Taking up events as they have developed, the U. S. Plan, as proposed, is based on a choice among three courses that had been given consideration.

1. The first, and a somewhat natural one, was the retention by the United States of the monopoly of atomic energy, and particularly of the atomic bomb. This did not seem a wise objective, because it is clear that we cannot retain our present monopoly beyond a limited period of years, if another nation should have the will to break it. The simple fact is that we have a practical monopoly for several years ahead and we are offering to give it up.

2. The second possible course was a world state. This seemed too ambitious a program to undertake in the present state of world opinion, for there were many evidences of lack of faith of the people in their own governments, and the people saw no more chance of good results from understanding a still larger field for government.

3. The third course, and the one adopted, was the creation of an atomic energy commission to be set up by the Assembly of the United Nations for the purpose of recommending a treaty to deal with the problems raised by the discovery of atomic energy. This plan was the setting up of a rule of law in the atomic energy field.

This general plan of approach to the problem was supported by the Washington Declaration, late in 1945, of President Truman and Prime Ministers Attlee of the United Kingdom and MacKenzie King of Canada. Later their plan found support in the Moscow Declaration issued by the representatives of the Soviet Union, the United Kingdom and the United States. The ideas of these three Great Powers were embodied in the January

24, 1946, resolution of the General Assembly of the United Nations. It is significant that this Act of the Assembly recognized the basic problem in attaining a control of atomic energy, for it admitted the existence of a general lack of confidence among the nations of the world. It provided for progress by stages, each of which will develop the necessary confidence in the world before the next stage is undertaken. If there had been general confidence at the time, these words would have been unnecessary and presumably would not have been used.

It seems clear enough from what one can observe that the requisite confidence for a treaty to provide for the control of atomic energy is not now in evidence. If one were to judge only by current developments, he would say the attainment of such a treaty would be a miracle. This lack of confidence evident to the United Nations was the background against which the specific directions to the Atomic Energy Commission were pointed. That resolution directed the Commission among other things to make specific proposals "for *control* of atomic energy *to the extent necessary to ensure its use only for peaceful purposes, for the elimination from national armaments of atomic weapons,* and for *effective safeguards* by way of inspection and other means *to protect complying states against the hazards of violations and evasions.*" It is important that the five Big Powers used these words, and it is clear that they must have understood their meaning. Their support of these words constituted some obligation to go ahead on the lines there laid down.

The United States proposals represented only a carrying out of these directions calling for effective control and effective safeguards, including inspection, to protect complying states against the hazards of violations and evasions. They were not sprung on an unsuspecting world as something new and different from what all the nations had been led to expect. I believe every one of these words as I have emphasized them in my reading carries a full content. I believe the conscience of the world wants exactly the kind of plan outlined in those words. I do not believe the Assembly wanted the drafting of a mere treaty in which nations would exchange promises. Otherwise there was not any reason to go to the extent the Assembly went in describing exactly what the United States Plan is aimed to do.

Earlier Failures Considered

It would have been so easy for the Assembly to follow the old practice for handling such problems among the nations of the world. It would have been easy to require the Commission to draft a resolution simply outlawing atomic bombs. Apparently the Assembly had in mind all the efforts over the years to outlaw various implements of war, all of which had proved their dismal ineffectiveness without a single exception. These earlier plans failed because the treaties put a complying nation at the mercy of the violating nation in the event of war, thus forcing the complying nation to produce and possess the prohibited weapon in anticipation of its need. The resulting difficulty has been that, when a war once started, nations have felt compelled to resort to every tool of warfare whose use they thought would be to their advantage. It becomes necessary to prevent the production or possession of a particular weapon during peace, as otherwise it will be used in war. That is why it is necessary to make every effort to prevent the *start* of a war, rather than merely to prevent the use of any particular tool of war.

Let it also be understood that merely preventing the production and possession of atomic bombs during peace will not be enough to prevent the starting of a war. It is idle to argue that the bomb should be outlawed for the reason that it is only a tool of aggression—aggression, the prevention of which is the primary purpose of the Charter of the United Nations. No matter how people may persist in this argument, it must be equally clear that it is a tool of war that can be used for the prevention of aggression and, if necessary, for its punishment—both within the spirit of the United Nations Charter and the conscience of the world.

The principal reason for starting with the bomb—rather than tackling the whole problem of disarmament—is the hope that an effective plan of control of atomic energy can be worked out and that this plan may show the world the way to control (1) other weapons of mass destruction, (2) all weapons, and, (3) hopefully lead the way to peace. It has been clear from the start that the least that can be sought is an adequate warning to the world of any planned evasion of an atomic energy treaty, and that this warning should be timely enough to protect the world against a surprise attack.

Purpose of the Plan

There is a natural question as to why the United States proposed any treaty at all to cover the control of atomic energy when the nations of the world are bound by the present Charter of the United Nations to prevent aggression. Nothing could be added to the Charter by a promise not to use the bomb for aggression, and there never was any reason why this nation should not be free to use the bomb and any other tool of war for the prevention of aggression. If this nation is going to break its earlier promise regarding acts of aggression, why should any one assume it will be bound by a later promise? The whole purpose obviously was to set up the plan of control as the basis for outlawing not only the use of the bomb but its construction or possession, and to attain the greatest possible assurance that no other nation could use it without giving timely warning.

The fundamental instinct of man is self-preservation. The fundamental concern of nations—their primary responsibility—is also self-preservation, and nations have sought it in the concept of absolute national sovereignty and national power. National power has given a measure of security but only up to the point of clash between what nations consider to be their vital interests and aspirations. These clashes have come with increasing frequency, and when they occur they end only in war.

While in no sense a complete guarantee of self-preservation, at present reliance on national power is a nation's only final choice. It will not and cannot be relinquished until a more effective means of assuring self-preservation is found. It was clear from the start that this international control would be an interference with present conditions in the several nations to the treaty. It was frankly laid out at the start. It was expected that there would be plenty of attempts to prescribe limitations on the power of the international agency. We in this country had had experience with administrative law and we saw the need of restraints upon arbitrary judgments of a governmental agency, but we were determined that the treaty must be effective rather than palatable.

A New Pattern

This treaty offered by the United States is to follow a new pattern, something never attempted in the world before, but something made necessary by the failure of all previous attempts and by the existence of the atomic bomb. This is to be a treaty aimed to be kept, a treaty that the world will know is being kept, or is not being kept, thus enabling the punishment of the violators at an early date and preventing an atomic age war of nerves, or "saber rattling." Quite obviously, the nations of the world recognize that governments change and that peoples' views change over fairly short periods of history. No one needs to be reminded today that when Italy and Japan signed the Treaties of Peace at the end of World War I they expected to keep those treaties. It is clear that the objectives of those countries changed during a short period of about fifteen years, and that similar changes in objectives of government may take place in the years ahead.

In the past, treaties were good as long as they worked, and a treaty was a satisfactory procedure as long as no great harm was done when it was broken. In that kind of a case promises were enough. In the case of atomic energy there had to be steps taken to prevent and deter nations from breaking the treaty and to punish them if they broke it.

Can anyone argue that our recent enemies—Germany, Japan and Italy—were restrained from breaking a treaty by any moral sense or by national conscience? While it is argued that gas warfare was not employed to any appreciable extent in this latest war, it seems clear that the only reason this was not done was the fear of retaliation in greater measure. It is noteworthy, too, that this nation did not sign the treaty outlawing gas warfare. Apparently its conscience was as powerful as its promise. It is also to be noted that even the nations that agreed not to resort to gas warfare did produce gas for use in war. This made it necessary to prohibit not only the use of the atomic bomb, but to prevent the means of constructing one in a hurry.

That is the reason a mere exchange of promises is not enough. If the United Nations is to succeed, there must be more faith and confidence among nations than exist at present. Faith and confidence can be built up primarily through a willingness of nations to submit to inspection of their atomic energy activities. Without such inspection, promises are likely to be worthless. If confidence and good will can be established in this field, it can be a definite step forward to world confidence in all fields, to the building of faith in the given word.

A Rule of Law

In one manner of expression, the United States Plan—now the plan of ten nations among the twelve on the United Nations Atomic Energy Commission—is nothing more in its general concept as to enforcement than the establishment by treaty of a rule of law in the field of atomic energy, setting up specific crimes with certain penalties, with an international control body able to detect violations before disaster strikes, with power established by treaty to punish violations—a rule of law that excludes any political favors on the part of any nation toward any other nation that violates the law.

In a more concrete manner of expression, the United States has proposed an international authority with unequivocal power to exercise full and effective control over atomic energy from birth to death, so as to realize the potential for good and to avoid the use for war, along with a system of swift and certain punishment for violations, which shall be stigmatized as international crimes.

The willingness of nations to submit to an effective inspection and control by an international body is the best evidence of honorable intentions not to use the bomb and also to make only the proper peacetime uses of atomic energy. Nothing less can provide a safeguard to complying nations. Unless the control agency has power to know what is being done, to report infractions and to initiate punishments to follow such violations, the whole international control plan will be mere words, and become a fraud upon the people of the world.

One reason for an international control rather than a national control is that the national control would place too great a temptation before a nation, too great a strain on its conscience. No nation would report to the world its intention to violate a control treaty, and there would be no timely warning of the kind needed to provide safeguards for the rest of the world. There must be a chance for nations to prove their good faith by their conduct. No plan that fails to meet this test should be accepted by this country. It must be obvious that in referring to international control this country means not only an actual effective control but also one international in its scope, or worldwide in extent, as well as international in character—one in which the international body may see for itself and not be bound to accept the word of any nation as to what is going on within its borders with reference to atomic energy, but also one bound together for enforcement of the control.

More than Outlawing the Bomb Required

It will be interesting to see what reasons can be offered for arguing for a convention or treaty merely outlawing the bomb and going no further. A frank statement of such reasons by those who take this position should help to clear the air quickly—what would be the basis for hope on the part of the rest of the world that there would be a later agreement as to an effective control, when that is the only purpose back of the offer to surrender the present monopoly. This is not the kind of a problem that can be handled in segments. It must be handled as a whole, or not at all.

There is one fact based on the technology of atomic energy processes that must be thoroughly understood if anyone is to have any views about this problem that are worth while. If the problem were solely to prevent the use of bombs, the job would be easier, but the world wants the peacetime benefits of atomic power. If the problem were solely to foster the use of atomic energy for peaceful purposes, the job would be easy—if there were not the risk that the material needed for peaceful uses can readily be diverted to the purposes of war. The difficulty lies in doing both. The process of making and using fissionable material in peaceful pursuits is, up to a certain point, identical with its preparation for use in bombs. At the forking point, the only difference is that the man in control in the one case plans to use the material only for peaceful purposes, while in the other he decides to use it for war purposes. His decision alone governs whether the use of atomic energy shall be for peaceful industrial purposes or for war uses. That is why the problem is difficult and that is why the entire chain of events, starting with the removal of uranium and thorium from the ground, must be under such an effective system of control that atomic warfare will be prevented if possible, and if not prevented, then at least a timely warning will be given to other nations of any impending violation. While the United States Plan aims at prevention far more than at punishment, it would seem fantastic to assume that in no possible case could the controls be violated. In that event, the world should not have to rely solely upon a mere treaty, without any effective organization and means for taking the offender in hand.

The attitude adopted in developing the United States proposal was that it must be a fair-minded plan—fair to us and fair to all other nations. The United States Delegation would not have proposed it—and I am sure that the American people would not support it—if it were not. It is a plan of self-preservation, not for ourselves alone but for the entire world. Misunderstandings persist, but on examination of the proposals it is easy to see that there is no attempt to seek a preferential position for this country on account of its present possession of the bomb. There is throughout an absolute equality of terms and, as a matter of fact, this nation alone will have many of the obligations from which other nations will be free for several years. No nation will be free to do anything that any other nation may not likewise be free to do, and, similarly, all will be equally bound. Nations are now free to go ahead as fast as they wish with the development of atomic energy for their own purposes, and again I emphasize, they will remain so unless a specific agreement is made by treaty to the contrary.

Under the plan of the treaty this nation will be transferring its plants to the international control agency, presumably long before any other nation has a similar obligation. If any nation wishes to go ahead with any act at any time, provided only the act is not prohibited by the treaty, it should be free to do it, if we are to be free to do it. No nation is prevented today from scientific research and it is proposed only that scientific research on atomic explosives be a monopoly of the international control agency, only for the purpose of its keeping abreast of the developments in that field, and not with any purpose of producing or using bombs. All national control plans would seem logically to be subject to international controls and not to be regarded as in substitution for them, the same for us as for all other nations. So far as the right of any nation is concerned, it is free to accept or reject the proffered treaty.

Conditions for Control

There is nothing strange about the fact that atomic energy was first used widely for war purposes. It is now being used for purposes of health just as fast as possible. Tremendous work is being done to develop it for use as power, but unless the treaty should provide to the contrary, any nation is free to go ahead on these developments, or any part of them, without any restraints from the United Nations or any member of it.

We have at no time proposed that we turn over our knowledge of atomic energy *only* when the international control and inspection system is working "to our satisfaction," nor have we proposed to dispose of our bombs only "at our unfettered discretion." We have proposed, specifically, that when an adequate system for control of atomic energy, including the renunciation of the bomb as a weapon, has been agreed upon (by all) and put into effective operation and condign punishments set up for violations of the rules of control, which are to be stigmatized as international crimes, then and under those conditions we propose that:

1. Manufacture of atomic bombs shall stop.
2. Existing bombs shall be disposed of pursuant to the terms of the treaty.
3. The Authority shall be in possession of full information as to the know-how for the production of atomic energy. We have at no time proposed any release of information regarding the bomb itself.

We must proceed in the full knowledge that nations might prove unwilling to move toward world security at the price of a modicum of pride and position. The United States plan fully recognizes this possibility by providing for a step-by-step establishment of the Atomic Development Authority with requisite safeguards at every stage. These steps and these safeguards must be specifically defined in the treaty itself.

The stating of these steps and these safeguards will be difficult. It will require time and patience as well as care and precision. But if the nations of the world should decide upon an international authority with full responsibility to prevent the making of a bomb, while at the same time giving full impetus to the peaceful uses of atomic energy; if they will give an international organization the requisite powers to discharge this responsibility, with the right to know what is going on in the atomic energy field anywhere in the world, without being expected to take any nation's word regarding its activities, with power to enforce its everyday operating decisions, with power to bring offenders before a bar of international justice for a finding on the facts and a finding of guilt, and with the creation somewhere in the United Nations organization of adequate power to punish; if these decisions can be made, it should not be too difficult to state when or under what conditions the United States will cease making bombs, and, ultimately, when and under what conditions it will dispose of its existing stock of bombs and bomb materials. The logic of the proposal is so obvious that the plan should be accepted by the world in principle, subject to its being put into the form of an international treaty, and then offered to the nations of the world for their acceptance and ratification.

However, it seems futile even to discuss the conditions under which these two events—the ceasing of bomb manufacture and the disposal of existing stocks—would take place unless a decision has been arrived at to create an effective plan of controlling atomic energy, the minimum essentials of which are in the United States proposals.

The Question of the Veto

There has been a great deal of discussion about our idea concerning the veto. There seems to have been an entirely unwarranted assumption that we were making a general attack upon the veto, now in the power of the Big Five members of the Security Council. Nothing could be further from the fact. From the start, we have insisted on only two points, which would come into being after the treaty has become effective:

1. That the veto power now in the Security Council must not be used to protect violators of the treaty setting up the crimes, which we describe in general terms as the production, possession, or use of an atomic bomb, and which would include such preparatory steps as unwarranted possession of atomic material suitable for use in a bomb; seizure of any plant belonging to the Authority; or any willful interference with the Authority's operation. Not all these crimes are such as would certainly lead to war in all cases. There seems nothing controversial about setting up these acts as crimes and providing a certainty of punishment for them. All we ask is that no nation be free by use of the veto to protect a violator from the penalties established for his crimes.

2. One other field of operation likewise should not require unanimous consent. The day-to-day operations of the International Authority should not require unanimous approval and should not be thwarted by the desire or determination of any one nation.

This argument about the veto comes down to this—we may maintain the sanctity of the present veto or the sanctity of the proposed atomic energy treaty. The United States asks only that the sanctity of this treaty be maintained. It asks only that no one of the Big Five nations be free to excuse a violator from the punishment assigned to the violation. It asks that if a nation signs the treaty, it does not do it with its fingers crossed.

Let me cite an illustration well within your own experience. Let us assume that a village board passed an ordinance prohibiting the parking of automobiles in front of the only exit from the village fire hall, but that the ordinance carried a provision—like the veto provision of the United Nations Charter—that any member of the village board could veto the proposed punishment of himself or any of his friends. Can you think of such an ordinance as effective?

In all my search to get at the root of the questions about the veto, I have not found a satisfactory ground for objection to the United States Plan. I know the claims are made that the veto issue is not relevant and that it was bad timing to raise this question so early in discussion. Let me dispose of the smaller objection first.

We knew perfectly well that the suggestion would not be welcomed by all the world, but, realizing the necessity for it and seeing no valid objection to it, we proposed it frankly at the first session of the United Nations Atomic Energy Commission. It would not have been good faith to have raised it later, for if we had raised it later, we would have been accused rightly of attempting to "chisel" in the course of our negotiations.

Now, as to the other argument that the discussion is not relevant. Can it be argued that provision for effective punishment is not a relevant part of an effective treaty for the purpose we have in mind? Should any one of the Big Five nations be able to erase all moral responsibility for a violation of such a treaty, by some procedural device such as a veto? Admittedly the volume of discussion has been greater about this one element of the United States Plan than about other equally important parts of the Plan. This discussion, both in the public press and in the sessions of the Atomic Energy Commission, has resulted in focusing public attention on this one element of the Plan. It is no more important than many others, but it is a necessary part of a complete and effective control plan.

It is obvious that many nations having deposits of uranium and thorium would never consent to turning these materials over to other nations if the nations receiving the materials were left free to decide the use to which they would put the material, and, particularly, if the nation receiving the material were to be free from punishment at the whim of any one of the Big Five. Perhaps the confusion comes from a failure to understand that this treaty governing atomic energy is to be a treaty of a different nature than any treaty the world has so far known. It is to be a treaty that will not depend on the conscience of any nation for its observance. The world will know whether the treaty is being observed, and, in the event of failure, will be able to take appropriate action. Under the old pattern of treaties, it would be perfectly right to say that the veto was not relevant to the present discussions. But this is not to be that kind of a treaty.

It is being argued that the United States is attempting to break down the whole structure of the United Nations through its insistence regarding the veto question. Ask the proponent of that argument whether the maintenance of the right of veto would not inevitably lead to the creation of five alliances, each built around the use of the veto by one of the Five Big Powers? Would not that likelihood do more to destroy the United Nations than the surrender of the veto in the limited field of crimes to be clearly defined in advance and agreed to as a part of the international treaty for the effective control of atomic energy? That's the whole position on the veto.

Interest of Mining Engineers

While your immediate interest as professional men will relate to the mining aspects of the control plan, you will realize that a great deal more work must be done on this problem. It is not intended, however, that the international control body shall be required to own the mines or to operate them, though there may be warrant for their doing both in a few cases. In general terms, "free enterprise" should control this field, even though the only buyer of the product will have to be the international control agency. There will arise questions as to the methods to be allowed for securing production of uranium ores required to meet the needs of the world. My strong personal preference is to provide for these questions specifically in the terms of the treaty and to set up only those powers within the international control agency as will prevent the misuse of atomic energy, leaving its powers required for the development of peaceful purpose within the framework of a free economic system so far as possible consistent with an effective control. This will be a natural field of debate, in which this group should properly take an active interest.

No attention has been paid, in the record so far made, to the financing of this international control agency. It will likely be an expensive organization. Its financing on a stable basis will be all-important, as otherwise the available funds for control some years ahead will permit the employment of forces too limited to permit of its being effective. It will therefore be necessary to avoid giving those powers, or functions, that would likely involve tremendous financial resources. This, too, will be a field in which you will be interested.

Your greater interest will be in an estimate of prospects for securing such a treaty as I have outlined. Being convinced of the extreme fairness and even the liberality of the United States proposals and their logic, I have believed that in the end these proposals wouldbe accepted. As of the moment, they are acceptable to ten out of twelve of the nations on the Atomic Energy Commission of the United Nations, and they are opposed by the Soviet. The latest arguments of the Soviet delegate show some misunderstanding of our proposals and firm opposition to certain elements which, speaking personally, I would regard as essential. The misunderstanding will be removed in the usual course of further discussion. The logic will have a chance to assert itself, but the opposition may still remain.

Again speaking personally, I hope no one will get "hot and bothered" about the present objections. The problem is difficult, its solving will require more time and patience than had been hoped for and expected, and even then it may not be solved. There is no reason to be irritated, no reason not to be even more patient for a time. A treaty may not result from all the expenditures of time and effort, but the expenditure is warranted.

In the meantime, it is best to go ahead with the manufacture of as many bombs as the country can produce. It is a hard philosophy, but it is safer than war itself. For myself, I shall never want them used as a tool of aggression, but I will not oppose their being used to prevent aggression.

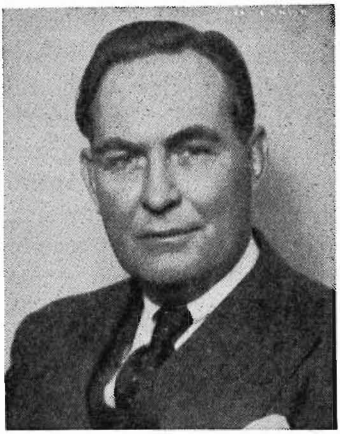
General Disarmament

For a moment, may I divert your attention from the atomic energy problem to the general disarmament problem now under consideration by the Security Council of the United Nations. A satisfactory conclusion of the problem of the control of atomic energy seems prerequisite to any agreement on general disarmament. If disarmament in the field of atomic energy should be found impossible, general disarmament seems far more likely to be impossible. In the field of atomic energy, we alone possess the tool of war. We have offered to prevent its use and have named the conditions under which this prevention should be effected. If disarmament in the field of atomic energy cannot be secured, though the only possessor of the bomb is willing to give it up, then general disarmament seems hopeless—for all nations will have to give up weapons they possess and are apparently unwilling to give up in the field of general disarmament. At least, up to now, no other nation has proposed to give up under any conditions even so much as its most unimportant tool of war.

May I close by stating my belief that the United States plan represents the minimum that is required to prevent the misuse of atomic energy for destructive purposes, while making possible its use for the benefit of mankind. A sound solution to this problem does not ensure solutions to the many other problems that beset nations. Their solutions, too, require patience and understanding. But if we fail in this most critical problem of our time, other problems become mere details in the world's struggle for peace and security.

The Role of the Engineer in the Development of Atomic Energy

BY P. C. KEITH



P. C. KEITH

Prior to becoming President of Hydrocarbon Research, Inc., Mr. Keith was for many years Vice President of the M. W. Kellogg Company in charge of engineering and research. He directed the development, design, and construction of the gas-diffusion plant for separating the uranium isotopes at Oak Ridge, for the Manhattan Project. He has to his credit about twenty-five important patents relating to oil refining and is now building plants to convert natural gas into 90-octane gasoline.

It is difficult to talk about atomic energy and the engineer without repeating a number of phrases that have been worn smooth with use. Mr. John M. Hancock has spoken to you of the two-sidedness of atomic energy; one useful, and the other destructive. If a control plan of the type that he has outlined is adopted it will be perfectly possible to go ahead with the peacetime development of atomic energy. Failing the adoption of such a plan, emphasis will of necessity be placed upon the perfection of atomic energy as a weapon of destruction. I want to speak, however, in the hope that atomic energy will be developed for peacetime use; and speak about the role of the engineer. Before I can do that I must outline the framework within which the engineer must work, and then I would like to go back and tell of some of the things that he has done, in the hope that that may throw some light on what he may be expected to do in the future.

Last year the McMahon Committee—the Senate Committee charged with drafting domestic atomic-energy legislation—held extensive hearings in an effort to strike a balance between the negative attitude of what to do *about* atomic energy and the positive attitude of what to do *with* it. Out of these hearings grew the United States Atomic Energy Act, calling for a civilian commission to exercise control over all atomic-energy activities in this country. As you know, this Commission has been in being for some time, but its efficient functioning has been delayed, unfortunately, by lack of Senate confirmation. Its primary functions are: (1) to prevent the misuse of atomic energy within the United States and, (2) to encourage the development of useful applications of atomic energy. I should like to outline the work of this Commission because, as far as we in the United States are concerned, it is the Commission that will determine the role the engineer is to play in the development of atomic energy, and how he is to play it.

The Atomic Energy Commission

The Commission is a great deal more than a government bureau as we have known government bureaus; it will be America's atomic-energy industry. Its authority starts at the mining level and carries through to the level of application, whether it be in the laboratory or in the field. Its activities will be many and various:

1. It will own and operate all fissionable material mines and refining installations and will allocate the refined materials to such agencies as it may authorize to work in the atomic energy field.
2. It will own and operate all so-called "dangerous" installations; that is, plants that handle fissionable materials in sufficient amounts and in high enough concentrations to be readily diverted to dangerous uses. For example, "dangerous" installations would include isotope-separation plants producing enriched uranium 235.
3. It will exercise supervision and control over such private interests as it may authorize to operate "safe" installations; that is, plants that would have to undergo major changes before they could be diverted to dangerous usage.
4. It may own and operate or lease extensive laboratories through the medium of which it is hoped it will keep in the forefront of developments in the sphere of nuclear physics and directly related sciences.
5. It may encourage work on key problems; for example, the development of atomic engines for ships and the development of large atomic power plants for industrial and city purposes.
6. It probably will supply medical centers and the like with radioactive materials needed for research on cancer and other diseases, as well as for research of a fundamental nature; i.e., "tracer" studies in biochemistry.

The picture, then, is one of an extensive and interrelated enterprise radiating out from the Commission and extending over the entire country. From the standpoint of free enterprise, such a system might seem to have its disadvantages—it is certainly government-controlled. On the other hand, it has the very definite advantage of making the national security of this country paramount.

The Place of the Engineer

Where and how does the engineer fit into this picture? It is obvious that the Commission could decide to conduct all its research and development within "ivied walls," thereby relegating the engineer to a relatively minor role, or it could assign to him an essential position.

If the Commission chooses to rely entirely upon pure science, the only engineers required will be "handbook practitioners"—steel and concrete empiricists—who would be called in at the final stage to sweat out the job of translating the scientist's sketches into working blueprints and living machinery. On the other hand, if the Commission assigns to the engineer an essential role, "creative engineers" will be required—men whose job it will be to work side by side with the scientist and whose responsibility it will be to see to it that engineering keeps pace with science.

It is highly improbable that the Commission will rely entirely upon pure science. Germany tried this procedure and failed to produce an atomic bomb. This country assigned to the engineer an essential role and succeeded.

The reason the Germans made this mistake is that they have always misunderstood the role of the engineer. In Germany—and throughout continental Europe, for that matter—the chemical engineer has always been regarded as a glorified pipefitter; there the development function is the monopoly of the scientist. The weakness in this system is that the scientist is never close enough to industrial reality to realize what can or cannot be done on the large scale. A mistake in either direction is equally fatal. In one direction, it leads to waste of time and effort on processes that are inherently impractical of large-scale attainment. In the other direction—and this is what happened in the German atomic bomb fiasco—it results in the scientist failing to realize when an infant process *is* industrially feasible. Almost invariably, the German industrial plant is simply a blown-up version of what is done in their scientific laboratories. The Germans simply do not take into account the fact that going from the laboratory scale to the industrial scale involves more than a multiplication factor.

Here in America, on the other hand, we have learned that when a laboratory process is taken into the field, things change. What gives trouble in the laboratory may not give any trouble at all in the field, and vice versa. America has developed engineers whose business it is to anticipate these changes and allow for them in plant design.

In recent years, as processes have become more and more complex, the American process engineers have had to revert more and more to basic scientific principles in order to transpose laboratory technique into successful field performance. Today, the creative American engineer must understand the fundamentals of the process with which he is concerned, whether it be an intricate chemical system or the reactions involved in nuclear physics. Engineering has become a science in its own right.

Early in the American development of atomic energy, the Office of Scientific Research and Development, headed by Vannevar Bush—as great a scientist as he is an engineer—recognized this fact and appointed a Planning Board comprising engineers and industrialists to pass on the feasibility of the processes then under development, and to anticipate the bottlenecks that might be encountered in going from the scientist's theory to reality. Later, when the Army took over the Project, General Groves recognized the soundness of this approach and continued and fostered it. It is more than probable that the Atomic Energy Commission will recognize the essentiality of this approach. Assuming that that is done, we might get some idea of what the engineer can do in the future by looking at some of the accomplishments that he has been responsible for in the past.

Contribution of Engineers in Developing Manhattan Project

No one disputes the fact that in designing and constructing the four great bomb-production centers—the thermal and gas-diffusion plants and the electromagnetic plant at Oak Ridge and the transmutation plant at Hanford—the engineer accomplished a Herculean task. However, many people seem to think that that is all he did—that the research and development upon which process design was based was the work of the scientist. Now, it is not my intention to take credit from the Manhattan scientists, but I do not think it is an exaggeration to say that without the engineer these processes could not have been developed in time.

I should like to support this statement with a brief review of the kind of contribution the engineer made in the research and development stages of the Manhattan Project. I will take my specific illustration from K-25, because that is the plant with which I was most closely associated.

The gaseous diffusion process is a method for the separation of uranium isotopes by means of a porous screen. The plant, designed to isolate uranium 235, is a complex interconnected system comprising thousands of centrifugal pumps, thousands of special diffusers containing acres of diffusion barrier, hundreds of miles of special piping and tens of thousands of valves and control and indicating instruments. The process requirements made it imperative that this plant should be made vacuum-tight and, though highly corrosive uranium hexafluoride is handled by the ton, virtually noncorroding. With its complex and unusual process machinery and its robot control mechanisms, the plant is one of the most remarkable industrial machines that has ever been built.

It requires little imagination to picture the types of problems that were encountered in taking the gaseous diffusion process, which at the start of the war was no more than a theory, and putting it into successful large-scale operation in three years' time. To mention only a few of the many problems that were solved by the engineers:

1. There was the problem of developing a suitable porous screen and manufacturing it on a large scale. This material had to be uniformly porous with an average pore diameter less than the wave length of visible light; it had to be virtually noncorroding in the presence of the hexafluoride; and it had to be strong enough to serve as a material of construction. The magnitude of this task can be appreciated when I say that there are more than seven thousand miles of porous tubing built into the Oak Ridge plant.

Engineers recruited from a chemical company, a metallurgical company, a paper company, a construction company and an oil company collaborated with engineers of a manufacturing concern catering entirely to the automobile industry to solve this problem.

2. There was the problem of designing a suitable process pump and fabricating it on a large scale. This pump had to be noncorroding and nonleaking, and utterly dependable. As a centrifugal machine, its counterpart had never been built. For this problem, engineers came from the oil industry and a university. Collaborating with the engineers of a steel company and a compressor manufacturer, the problem was solved. Of interest is the fact that the solution to one difficult problem was suggested by the engineers of a publishing company.

3. The engineers and chemists of an automobile company, working with a chemical company, found the answer to the general corrosion problem.

4. Really leakproof valves were the contribution of a team composed of an engineer working primarily with a naval architect's firm, an engineering executive in the utility field, and the engineer of a large valve company.

5. The development of the special chemicals required was the contribution of engineers and chemists of a number of commercial chemical companies and university research groups.

6. A system for predicting the pressure waves and operating characteristics of a rapid speed system having some thousands of interconnected operating units was the work of a group of mathematical process engineers.

These were only a few of the problems that had to be solved by engineers before the gaseous diffusion plant became a reality. These problems embraced practically every field of technologic endeavor—chemical, mechanical, electrical, structural, metallurgical, mathematical. And what was true of the gaseous diffusion plant was equally true of the electromagnetic plant and the transmutation plant.

The success of the atomic bomb rests at least in equal measure with the American engineer as with the American scientist.

The fact that an engineer from a publishing company would work with an engineer from an oil company on the solution of a compressor problem should make it clear that in America the engineer and industry are synonymous. Because of the caliber of the Commission, I am sure that it will wish to maintain the very closest collaboration with industry. This will be done by bringing the engineers into the early stages of the peacetime development of atomic energy. Only by so doing can the Commission be sure that the engineer will be making his maximum contribution to the development per se and that industry will be in a position to make prompt use of the fruits of the development.

Engineer's Role in the Future

But I have said enough about what engineers have done in the past—the work on the development of the bomb. Let us look ahead and see what the engineer, if he is given the opportunity, will do in the future. Mr. Winne doubtless will elaborate on some of the points I will make; but I must mention some of them in order to give an accurate picture of the engineer's role in the future.

I shall confine my remarks to work on the constructive uses of atomic energy. On the basis of what is known today, the most fruitful avenues for the useful application of atomic energy are: (1) its use as a tool in medical and fundamental scientific research, and (2) its development as a useful source of power. The engineer's role in the former program will be restricted to the design and engineering of the equipment needed to provide the necessary research materials. The research itself is the province of the scientist. However, it is likely—more than that, it is probable—that out of this research will emerge as yet unknown applications of atomic energy that will in turn impose new and more compelling demands upon the engineer. On the other hand, the latter program—the development of useful atomic power—will be predominantly engineering.

The indications are that the kind of reaction that will supply the atomic energy of tomorrow is the same type of reaction or fission that takes place in the "piles" built at Hanford. However, the Hanford piles were built to produce plutonium from uranium. Since operations at low temperatures simplified many of the engineering problems, these piles were designed to operate at a low temperature and are not suited for the production of power. Before atomic energy becomes a useful source of industrial power, piles must be designed to operate at high temperatures. I might explain that, as presently visualized, the role of the atomic pile in a power-generating unit is precisely that of a furnace or firebox in the conventional steam-electric power plant; in other words, it is simply a source of heat. More or less standard equipment is required to transform this heat into useful power. Hence, to be economic, this heat must be generated at a high-temperature level.

The design of a high-temperature pile poses for the engineer problems at least as difficult as those encountered in developing the bomb. In the past, aside from cost, the engineer picked his building materials simply on the basis of strength, resistance to corrosion and/or erosion and thermal properties. The materials entering into a pile must satisfy not only these requirements but also a neutron-capture specification, and in the high-temperature application must also satisfy the specification of nondisintegration. New metallurgical techniques are indicated. Further, an economic and dependably controllable high-temperature pile will require the removal of heat per unit of volume at a rate hitherto commercially unknown. Additionally, it would be highly desirable if the dangerously radioactive operation, which is self-poisoning, could be made continuous. All the foregoing problems are rendered more complex and more difficult of solution by the necessity for providing heavy shielding to protect personnel against radioactivity. Finally, compacting the atomic-power plant to drive a ship may be almost like the straw that broke the camel's back.

These, then, are *some* of the problems the engineer will meet in the development of useful atomic power. They are no less difficult than those of 1941, and their complete solution looks about as hopeless. But fools rush in where angels fear to tread: that is why engineers are busy on the problem today.

But the power project must be buttressed by other projects. There is the project of developing more efficient methods of mining uranium and thorium; the project of designing more efficient isotope-separation plants and transmutation plants to feed enriched materials to the power piles; the project of developing superefficient materials, accounting instruments and procedures to ensure that fissionable materials shall not be diverted to dangerous uses; the project of designing versatile nuclear laboratories.

I could go on indefinitely. These are the kind of problems the engineer will have to solve in the future—and, as in the past, I am confident that he will solve them by going to the great industrial enterprises of the country and enlisting their cooperation and enthusiastic support.

But when the engineer has done all of that—assuming that the Commission assigns these tasks to him—he has a still larger and more important responsibility:

1. He will be responsible for keeping industry abreast of the needs of the atomic development.

2. He will be responsible for shaping the widely various techniques encountered into a systematic technology; in other words, for placing nuclear engineering on the same footing with chemical engineering, mechanical engineering and the like.

3. Finally, he will be responsible for seeing to it that the knowledge gained is so diffused through the whole framework of American industry as to raise the level of American technology generally.

This, then, will be the role of the American engineer in the peacetime development of atomic energy if the Commission sees fit to utilize his services to the utmost.

Application of Atomic Energy to Industry

BY H. A. WINNE AND B. R. PRENTICE

HARRY A. WINNE

Starting as a "student engineer" with the General Electric Company in 1910, Mr. Winne in 1941 was made Vice President for engineering design, and four years later was put in charge of engineering policy for the company. One of his assignments was to the State Department's Advisory Committee on Atomic Energy. He is in charge of General Electric's new Nucleonics Project and is thoroughly posted on the use of nuclear energy in peacetime industry as well as in war.

THE announcement of this World Conference on Mineral Resources briefly traced the development of the metals industries over the past 75 years. The various phases were characterized as iron and steel for the railroad era, then copper and the electrical age, through alloy steels to the age of light metals in World War II, ending with the curtain rising on the atomic age at the end of the war.

The interests of mining and metallurgical industries in the atomic age may perhaps be divided broadly into three groups: (1) production of the special materials required by atomic-energy installations and processes; (2) use of atomic power in the mining or refining of materials; (3) use of radioactive isotopes and radiation in metal and chemical processes both for laboratory study and in the production of materials for use in any field.

In the production of special materials, the mining and metallurgical, scientific and industrial groups have already contributed much to the start of the atomic age. The mining, refining and fabrication of the basic uranium to a degree of purity and form suitable for production of plutonium in the Hanford Engineering Works is just one example. The production of graphite for the Hanford piles, sufficiently free of neutron-absorbing impurities to allow a chain reaction with natural uranium, was a signal achievement. These, together with many other difficult materials problems solved in the production of the atomic bomb, are, however, just a beginning.

The use of materials in a nuclear chain reactor or "pile" involves consideration of their "nuclear properties."* Previous uses of engineering and construction materials have been based only on external physical and chemical properties. The addition of suitable nuclear properties to the list of requirements portends many changes from the engineering materials that have become common. The periodic table contains many elements whose possibilities as useful engineering materials have never been thoroughly explored because of scarcity, cost, difficulty of processing, or other reasons. Many of these have attractive nuclear properties, but production methods for refining, reduction, alloying, working, and various other treatments have not been developed. Beryllium is an example mentioned by Smyth,[1] which is valuable as a moderator because of its low atomic weight. The production of metallic beryllium essentially free of neutron-absorbing impurities is still almost a laboratory process.

The industry can look forward to increasing demands for metals of very high purity, including many now considered rare, for use as structural materials, high-temperature fuel,† alloying elements, moderators, liquid metal heat-transfer fluids, and for radiation shields. Some of the multitude of metallurgical problems that must be solved to bring the benefits of atomic power to our society are outlined in the following pages.

The potential uses of atomic power plants for various special purposes, such as ship propulsion, mining mineral deposits in remote parts of the world, providing a source of power where none now exists—that is, supplementing our present power sources—have been mentioned by many writers. However, the atomic power development as a whole is a long and difficult program, as shown in the following pages.

The use of radioactivity and radiation in chemical and metallurgical fields has been possible on a very limited scale for a good many years. It has not been widely exploited; largely, no doubt, because of the scarcity and cost of radioactive elements. The development of atomic energy makes possible the production of radioactive isotopes of great variety and on a considerable scale. This, together with widespread interest and education in the fields of radiochemistry, radiation chemistry and nuclear physics, should stimulate activity in using these unique and potent tools.

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* By "nuclear properties," we mean properties that make materials good for slowing down neutrons (moderator) or low in absorption of neutrons or suitable to withstand radiation of neutrons in a pile (radiation stability), and so forth.

[1] References are on page 721.

† The term fuel is used in the sense of "atomic fuel," such as U-235 or plutonium.

Atomic Power

One point of view from which we wish to consider atomic power is: What are the problems that the metallurgical and mining industry can help to solve? This involves some consideration of why the problems arise; therefore we approach a detailed discussion of the problems by first reviewing an atomic power plant in broad outline.

Fig. 1 shows schematically a possible atomic power plant. The heart of the plant is the nuclear reactor, which generates heat by the conversion of mass to energy. The heat is converted to electrical energy by extracting it from the nuclear reactor with a heat-transfer fluid that boils water in a heat exchanger to make steam for a conventional turbine generator.

The nuclear reactor must be surrounded by an adequate radiation shield to protect power-plant personnel from lethal neutron, gamma and other radiation. The heat exchanger and primary heat-transfer fluid probably will need a moderate amount of shielding.

Into the nuclear reactor goes the atomic fuel, one of the known fissionable materials, such as U-235, and if we wish to generate new fuel at the same time we are consuming the charged fissionable material, a fertile material, such as U-238, may also be charged. A material is called fertile when it can be transmuted to a fissionable material by the capture of neutrons.

Discharged from the pile are the partly burned fuel, and the irradiated fertile material, which contains some new fissionable material. Later use of the unburned fuel and the new fuel both require chemical separation from any other structural materials, containers, and from the fission-product wastes.

An optional phase of operation of an atomic power plant is the production of radioactive isotopes. This is shown on the chart as the adding to the pile of a by-product charge of some "parent" material such as nitrogen, from which a radioactive isotope such as carbon (C-14) is produced by the capture of neutrons.

PRINCIPLES OF THE NUCLEAR REACTOR

Occasion frequently will arise for reference to some of the nuclear principles of the chain reaction in the nuclear reactor. They are briefly reviewed in the following:

Energy is released by the fission of the nucleus of a fissionable atom, say U-235. The two nuclear fragments vary in the number of protons and neutrons contained in each. In general each fragment is the nucleus of a radioactive isotope of some element ranging from atomic number 35 to 65.

The two fragments fly apart with tremendous velocities. Their kinetic energy constitutes most of the energy released at the expense of a loss in mass of one thousandth of the original mass. The fragments will collide with adjacent atoms, giving up energy by increasing the vibration, amplitude and velocity of the surrounding atoms. We recognize such atomic agitation as the temperature of the material. Thus the energy appears almost immediately as sensible heat in the fuel itself and within a few thousandths of an inch from where the fission occurred.

Fission was caused by the capture of one neutron by the U-235 nucleus. This neutron, when added to the 92 protons and 143 neutrons present, caused the group of particles to be violently unstable and to break immediately into the two unequal fragments.

The entering neutron was the trigger. It has been absorbed and is now lost to the process. If the reaction is to proceed at a constant rate, another neutron must trigger another U-235 nucleus, and so on at equal intervals of time in a continuous chain. The characteristic of U-235 (and also Pu-239 and U-233) that makes it suitable for such a chain of fissions is that two to three free neutrons are released as part of the debris at fission in addition to the two main fragments. Thus there are available more than enough triggers for the next fission.

The fact that *more than one* neutron is released per fission permits some losses or nonprofitable absorptions of neutrons without killing the chain reaction (an obvious necessity in practice). The fact that on the average *more than two* neutrons are released per fission permits several choices in the use of the extra neutrons that are available in addition to the one required for a continuous, constant-rate chain reaction. Of course, some of these extra neutrons escape from the reactor and are wasted in the shield or otherwise, but some can be put to useful purpose.

The extra neutrons can be used to expand the reaction, essentially doubling it at each generation. This may result in a bomb. They can be absorbed in a suitable material to produce radioactive isotopes for chemical, biological or therapeutic use. Of most significance to power, however, is the use of these neutrons to make new fissionable atoms; for example, to transmute U-238 to U-239, which changes spontaneously to neptunium N-239, which in turn changes spontaneously to plutonium Pu-239. Pu-239 is a suitable atomic fuel. Every neutron that can be used in this way replaces the U-235 atom burned with a new Pu-239 atom and so helps to replenish the atomic fuel supply. Another example of fuel replacement is the production of U-233 from thorium.

The neutrons in any nuclear reactor are valuable. Their loss or waste on reactions extraneous to the purpose of the pile is a permanent economic loss. Therefore, pile design for high neutron economy is important.

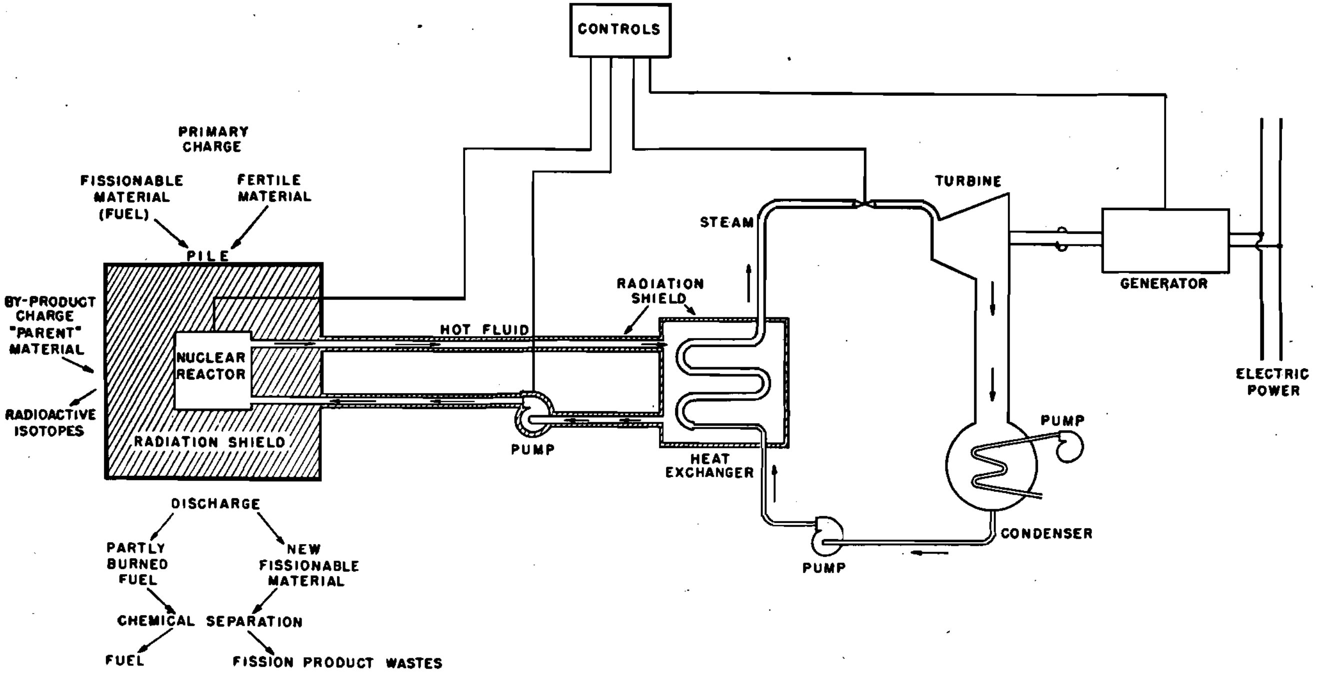

FIG. 1—*Diagram of atomic power plant.*

By controlling the neutron flux, the power output of the pile is regulated. To hold constant power level in a slow neutron pile, rods containing an excellent neutron absorber such as boron or cadmium may be inserted to absorb some neutrons so that equal numbers are available to produce fission each generation. To increase power, the rods are withdrawn so that a small fraction of the excess neutrons are available each generation to produce fission. The power then accelerates exponentially. It will continue to accelerate, except for variations in reactivity produced by temperature, expansion of materials, or change of their nuclear properties, until the control rods are again pushed in to absorb the excess neutrons. After the control rods are returned to an equilibrium position the reaction continues at a constant but higher rate. Power is reduced by the reverse of this procedure.

The time between one generation of the neutrons emitted instantaneously at fission (prompt neutrons) and the next generation is very, very short. This is true even in slow neutron piles, where each neutron is forced to lose almost all of its energy by a multitude of collisions with the light nucleii of the moderator before the next fission. The time is so short that acceleration, even with small changes in reactivity, would be too fast for the control mechanism to be effective were it not that about 1 per cent of the neutrons is not emitted promptly at fission, but is delayed from 0.01 second to a minute or more. The delayed neutrons provide a time constant of exponential acceleration long enough to permit control, provided the excess reactivity is never allowed to exceed the margin of delayed neutrons.

The fission products include many radioactive isotopes, which give off quantities of very intense radiation, and some of them continue to do so for thousands of years. Provision may be made to contain them within the fuel. If some are allowed to migrate out of the fuel they must be prevented from entering the heat-transfer fluid, else the fluid system must be designed to handle the accumulated radioactive isotopes.

All the materials in the pile are subject to high neutron and X-ray or gamma radiation, which may affect chemical and physical properties. Furthermore, almost all pile materials will become radioactive in greater or lesser degree after extended operation.

DEVELOPMENT OF AN ATOMIC POWER PILE

A scientist or engineer, looking at the principles and associated properties of a nuclear reactor, is forced to recognize a number of fields in which extensive research and development work must be done to facilitate the design and construction of a high-performance atomic power system.

Perhaps we should first define a high-performance system. Considering land-based plants, proposed primarily for power, a prime consideration is economic use of fissionable materials, including replacement of burned fuel by transmutation. Second, losses in the transformation of heat to, say, electrical energy should be as low as the current knowledge of materials and processes will allow. This requires temperatures as high as practicable.

Considering how the energy is released, one recognizes that the heat must first be removed from the body of the fuel to its surface. This may entail thermal stresses. It certainly involves a knowledge of the thermal conductivity of the material, and its stability and strength after a reasonable percentage of the atoms have disintegrated into a wide variety of pairs of new atoms. The percentage of the fuel that can be consumed before it must be removed and reprocessed will depend on these factors, and also on the neutron physics of the pile for, in general, as the fuel undergoes fission, and the fission products accumulate, the pile reactivity will decrease. The frequency of reprocessing, including its cost and the accompanying losses, may have a profound effect on the economic use of fissionable material.

Such fuel problems cannot be solved by simply consulting a handbook. The metallurgy of fissionable materials is a new and only partially investigated field. Possible alloys and mixtures include many metallic elements that may be valuable because of low absorption of neutrons but that are comparatively new to the metal-processing industries. Conversely, many well-known alloy or mixture components have high neutron absorption and are not suitable. The fuel designer may wish to consider ceramics to obtain very high temperature. If he decides to prevent fission products from contaminating the heat-transfer fluid, he must also develop a suitable barrier between the fuel and the fluid. This barrier cannot be a heat barrier, so bonding or joining techniques, again using materials that are stable under radiation and that do not absorb too many neutrons, will need investigation. As emphasized by the Smyth report, this barrier, or "canning" problem, turned out to be one of the most difficult of solution for the Hanford piles.

Just to develop a fuel that will function in the pile is not enough. The effect of fuel assembly materials on the cost and efficiency of the chemical reprocessing plant must be considered. As the whole pattern of atomic power plants, fuel-supply facilities and fuel-reprocessing facilities develops, national and international security may require centralized reprocessing plants. Then standardization of fuel elements may be a factor. The mechanical form of the fuel should preferably permit charging to and discharging from an active pile, storage and transportation of the radioactive fuel packages with suitable protection for personnel, and so forth.

The purpose of discussing the problems of fuel design so extensively has been to emphasize the many detailed but important research and engineering problems that must be solved on just one component of a high-performance pile. Related problems must be solved on almost all components. We can hardly overemphasize the fact that achievement of the probable vast benefits of atomic power entails an integrated and orderly solution of a multitude of problems. Furthermore, these problems include factors new to design engineers, only recently introduced in scientific research, such as:

1. Material stability under radiation, including physical, chemical, electrical and thermal properties.
2. Neutron-absorption characteristics of materials.
3. Effect of contamination within the body of the materials by transmutation and fission.

Finally, the experimental techniques for determining many of these nuclear properties of materials are relatively new, some are difficult, some approximate, and in most cases the experimental facilities are currently very limited.

It is important to remember too that in the design of the fuel package, and in fact in the design of all parts of a pile, reliability must be achieved to a degree that transcends most of our experience. This is due to possible radiation hazards from failures, and the extreme difficulty of inspection and repair of a "hot" (in the radioactive sense) pile.

In addition to the problem of fuel design, there are many other features of a nuclear reactor for power purposes that pose some nice questions for the engineers and scientists. These are not necessarily less important or difficult than the fuel problems, and involve many of the general considerations and details mentioned in the foregoing. Some of these are reviewed briefly in the following paragraphs.

Heat-transfer Fluid

The selection of a fluid to carry the heat from the nuclear reactor to the heat exchanger in which it may be converted to steam or a hot gas is a vital matter. Gases, liquids, and liquid metals must all be considered. The medium must have low neutron absorption. It must be reasonably stable under intense radiation. It must, of course, have good heat-transfer characteristics, must be noncorrosive, preferably nontoxic and nonexplosive. Availability and cost are important.

If the medium is to be allowed to boil in the reactor, the neutron-absorption characteristics of the vapor must be approximately the same as those of the liquid. Otherwise a sudden flashing to vapor of a part of the liquid might result in such a sudden change of nuclear characteristics in the pile that the control mechanism could not compensate for it.

Radiation Shield

The shield for protection of personnel from the lethal neutron and other radiations is an absolutely necessary part of any power pile. If research and development can considerably reduce the volume and weight of shield required, it will be very helpful in facilitating the application of atomic power plants to ships, and elsewhere where weight and size are of great importance.

Control

The reliability of the control system must be absolute, in that any failure must result in safety rather than to permit a runaway. It must be able to handle all possible variations in reactivity of the pile, either normal or accidental, gradual or fast, such as result from the slow consumption of the fuel or the sudden loss of part or all of the heat-transfer fluid. It must be effective at all times, under any possible set of conditions. It must make it impossible for the "nuclear boiler" ever to explode. These requirements are rigid, and *must be met.*

We believe enough has been said to indicate that many new technical problems are involved in the design and construction of a high-performance atomic power plant. Many of them are of a metallurgical or chemical nature, of particular interest to many members of this Institute. That they can and will be solved in the course of time the authors have no doubt.

AN ATOMIC POWER SYSTEM

Now let us consider what a land-based atomic power system of the future might comprise. In all our discussion is implicit the fact that today we foresee no possibility of obtaining usable electric power directly from an atomic pile. The atomic energy will appear as heat, which, when converted into steam or hot gas, will feed conventional turbogenerators. In other words, from the steam-supply pipe on to the consumer the system will be similar to present systems using coal or oil. The nuclear reactor and heat exchanger, however, will replace the boiler. There will be involved components comparable in function to present fuel and ash transportation, storage, preparation and disposal installations, but vastly more important from the points of view of economics and security.

The system may include both "primary" and "secondary" reactors. A primary reactor is one that produces not only power but fissionable material as well. The reactors at present operating at Hanford, since they produce heat (at present dissipated in the Columbia River) and plutonium, are by this definition primary reactors. Under the international control plan, which our country has proposed to the United Nations, such reactors would be under the control of the international authority.

A secondary reactor is one that consumes but does not produce fissionable material. If the fuel charged into such a reactor is "denatured" so that it could not easily be converted to bomb use, the international control plan would permit such a reactor to be under national or private authority.

The system would include a chemical reprocessing, or fuel-reclamation plant. When the fuel in the reactor has reached a certain state of depletion, it will have to be removed and passed through a remote-controlled shielded process for removal of the fission products, and put into suitable form for further use. Here again the international control plan would require operation by the international authority because of the possibility of diversion of atomic fuel.

It is obvious that consideration of national and international security will have a large bearing on how such operations will be conducted, how fuel will be stored and transported, even on geographical location of plants.

Here again are many factors that will have a profound effect on future developments—factors that we cannot evaluate with any degree of accuracy today.

ECONOMICS OF ATOMIC POWER

Treatment of this subject has been placed after the preceding sections purposefully. It is the opinion of the authors that estimates of economy and cost of atomic power sufficiently accurate to predict where or when or if atomic power will be in competition with other fuels are not feasible in view of the multitude of unknown technical and economic factors, which will be established only as research and engineering produce results. It is the equally strong opinion of the authors that the long-term future prospects for competitive and economic atomic power are bright. The magnitude of the potential ultimate gains to society are so great that research and development must proceed vigorously on a wide front.

Quantitative statements that can be made with a considerable degree of accuracy are:

1. Since an atomic power station or system will be similar to a coal-fired or oil-fired station in all parts from the turbine steam pipe on to the consumer, the investment and operating costs for this part of the station will be essentially the same as for coal or oil.

2. The nuclear reactor and heat exchanger in an atomic plant will probably be somewhat higher in first cost than the boiler installation in an ordinary steam plant. So it is probable that an atomic plant's opportunity for reducing cost of power to the consumer lies in the cost of fuel only. In modern public utilities, cost of fuel represents, on the average, only about 20

per cent of the total cost of power to consumers. So atomic power can affect only this percentage of the total cost to the consumer.

Some of the significant unknowns, or unavailable data, which make it impossible in our opinion to estimate accurately the overall cost of atomic fuel today are first cost of atomic fuel in suitable concentration and form; cost and efficiency and frequency of chemical extraction, reprocessing, and final preparation, plus waste disposal, all of which are ultimately chargeable to the consumer. Also included, but on the credit side, are the gains from sale of radioactive tracers, by-products for research, and use of facilities for test and research. These latter gains are estimated by the Carnegie Endowment Committee on Atomic Energy[2] to be small compared with revenue from power. Another unknown factor is the extent to which the national or world interest may require the production of fissionable material by national or international authority for any reason, and perhaps regardless of cost. In this event, atomic power is a by-product and its production and sale at competitive rates simply replaces expense for cooling otherwise required by such installations and pays for some, perhaps all, of the cost of the plant and its operation.

APPLICATIONS OF ATOMIC POWER PLANTS

There has been much speculation, some of it unwarranted, as to possible uses of atomic power.

The heavy protective shielding required on any such plant precludes its use where extremely light weight is required. The shield would crush an automobile or a truck. Atomic power on inhabited aircraft is extremely unlikely, at least for a long, long time.

It may ultimately prove possible to design an atomic plant for a locomotive, although this does not look feasible now.

Atomic plants for naval and large commercial ocean vessels look definitely possible, and attractive from the standpoint of making refueling extremely infrequent. This may well be the first real commercial application.

Atomic power plants for land use are certainly technically feasible, and probably will be attractive first where fuel is scarce and high in cost.

So far this paper has been devoted to a discussion of power as distinct from industrial uses and benefits of other aspects of atomic energy, tracer chemistry, radiation chemistry, and others. These are reviewed more briefly in the following pages. Such emphasis should not be construed as an opinion that power is any more important to industry than other benefits—other aspects may prove more important to the generations yet to come.

Radioactivity and Radiation

In discussing this and following phases, the authors have drawn much upon material published in references 2, 3 and 4. In particular, the predictions of future possibilities in these fields by such authorities as Arthur H. Compton, Zay Jeffries, James Franck, and Milton Burton are recognized.

INDUSTRIAL USE OF RADIOACTIVITY

The prime characteristics of radioactive tracers that make them of value are two: (1) extremely small quantities can be detected by registering the particles or radiations emitted at each disintegration on a suitable radiation detection instrument; (2) by the same means it is possible to detect and to measure the amount of tracer present quite accurately without removing it from the compound by chemical separation or even without removing or sampling the compound from its process container.

Perhaps the surest widespread industrial uses are in the chemical laboratories. Since chemically and physically the radioactive isotope of an element acts exactly the same as the stable isotope of the same element, analytical techniques can determine the amount of a given element in the final product or at an intermediate stage if a known amount of radioactive isotope of that element is added to the bulk at the start. This can be of value when quantitative analysis or spectrographic methods cannot be used.

Some of the scientific advice given to the United Nations Atomic Energy Commission by the Office of the United States Representative, which has not received wide national circulation, is quoted from reference 3:

> The availability of a variety of radioactive tracer elements will afford possibilities for answering questions hitherto difficult to answer. By the use of instruments sensitive to radioactivity, the radioactive atoms of a given element, which always travel with their non-radioactive brothers, may be used as indicators of the travel of the latter, a phenomenon often difficult to follow by ordinary methods. Particularly important are questions as to how, and how fast, atoms transfer from one molecule to another or from one place to another in the course of a chemical process, including such processes as corrosion, diffusion, absorption of molecules on surfaces, and formation and destruction of colloids.
>
> The use of radioactive tracer atoms holds much promise for the study of the composition of liquids and vapors in equilibrium with each other, and for studying the performance of distillation columns and other equipment used in chemical engineering, for example, in the oil industry. Particularly important as a tracer in the oil industry and wherever carbon compounds are concerned will be the carbon isotope C-14.
>
> The radiations from the fission chain reaction are capable of inducing chemical reactions which cannot ordinarily be carried out, since one effect of radiation is a sort of catalysis of thermodynamically possible reactions. . . .

Metallurgy

In metallurgy, the use of radioactive tracers has many possible applications. Some of these are as follows:

1. Diffusion of an element into itself and into alloys in which it is a component could be followed if the diffusing atoms are radioactive.
2. Inclusions could be identified by adding a radioactive form of a suspected component to the melt and photographing by microradiographic techniques.
3. Positive identification and location of minor constituents, which often markedly affect the properties of metals and alloys, could be made by microradiographic methods; such information is usually very difficult to obtain by microscopic methods.

The previous discussion has envisaged adding the radioactive tracer to the material. A very different analytical technique is based on producing radioactivity in all susceptible elements of a sample by subjecting the sample to a known amount of radiation in the neutron flux of a pile. Then the presence of minute traces of impurities can be identified by observing the half lives and type of radioactive emanations after removal from the pile. The amount of impurity present can also be estimated.

Tracers may find widespread use in production processes. Here, however, additional limitations enter. Cost in repetitive use becomes more significant. The Carnegie Endowment Committee on Atomic Energy[2] estimated that for radioactive carbon (C-14) to be attractive to industry, it should be produced at about $500 per gram, to reach mass use in petroleum, coal-tar and similar large-volume production. This assumed that a milligram (50 cents) could tag a ton of material at an additional cost of 50 cents for incorporating the tracer in the process, making the total cost $1.00 per ton. The 1946 price of C-14 from the Manhattan district was about $400,000 per gram.

The Committee estimated that the market might pay around $10,000 per gram for C-14 used in bulk organic chemicals, $100,000 per gram for use in pharmaceuticals and similar uses.

Actual use, however, may develop unexpected advantages, and, of course, cost is bound to come down as production increases.

Another critical problem in production as distinct from laboratory use is the question of widespread distribution of all sorts of products and materials containing traces of radioactivity and the effect on sensitive materials such as photographic film; and on living things, owing to continual intimate exposure or possible ingestion by unwarned people or animals. Some believe that this problem will limit production uses to those isotopes with short half lives of, say, a few days. Then a period of storage of products before shipment could virtually eliminate all radioactivity. Such considerations may limit the list of possible tracers. For example, C-14 has a half life estimated at 6000 years. Two other carbon isotopes C-10 and C-11 have impractically short half lives of 8 seconds and 20 minutes, respectively. Thus no carbon radioactive isotope is known that could be used if radioactivity of the product is objectionable. Such questions can be settled only as we gain in experience and knowledge and when proposed uses are specific rather than hypothetical. The need for elements with short half lives either in production process or laboratory may well require a wide distribution of isotope-production facilities near industrial and population centers.

It is also possible that experience will show that the amount of radioactivity required for tracer purposes in many products is so small that long half-life tracers can be widely used in metallic, organic and other materials. Then industry may be faced with radioactivity in materials purchased for further processing, in scrap for remelting, and other processes. Such background radioactivity if not controlled might interfere with the further use of tracers. Thus in years to come we may find materials specifications containing minimum tolerances for radioactivity.

The number of industrially important elements for which potentially useful radioactive isotopes, those with half lives longer than a half day, are not known is limited but includes oxygen, nitrogen, magnesium, aluminum and silicon.

Some production uses do not require the presence of the radio isotope in the product. Included are separation processes where the radio isotope is one of the elements rejected, also processes involving catalysts. For example, in some oil-refining processes, a catalyst is diffused through a reaction vessel. Certain malfunctions may cause it to segregate or to migrate out of the vessel. If the catalyst were tagged with a radioactive isotope, its concentration and location could be registered continuously through the walls of the tank.

RADIATION CHEMISTRY

The infant field of radiation chemistry, relating to the use of radiation to produce or catalyze chemical reactions, is perhaps too new to warrant extending our speculations far. However, the use of ultraviolet radiation to produce vitamin D in ergosterol is a well-known and related reaction.

Franck and Burton[4] have examined the possibilities and reported to the United Nations the following "groups of processes where application of radiation chemistry appears promising:"

> We may anticipate economic advantages in the vast field of polymerization processes which are now so successfully applied in the manufacture of plastics, rubber, etc.; in this field, in fact, initial successes have already been obtained. In a similar connection, studies even prior to the war on the effects of radiation on some of the constituents of natural gas indicate that they may be converted, via the medium of radiation chemistry, into indus-

> trially important products. Their present uses (e.g., in the production of carbon black or for fuel) are economically unsound. Related to such processes in a certain sense is the low-temperature cracking of oils, which should be intensively studied. Radiation chemistry here presents the opportunity of a new technique which may produce new and very interesting products.
>
> A host of rare but medically important drugs, until now synthesized only by plants but not *in vitro* will probably be by-products of the utilization of radiation chemical processes. Very interesting preliminary photochemical effects on viruses have been reported; viruses may be made to lose their virulence while still retaining their ability to produce antibodies. Progress in this important field is limited by the lack of penetration and the specificity of the rays which must be used; radiation chemistry should promote such work at an accelerated pace. The chemical aspect of the large field of biologicals is a portion of the field of radiation chemistry which we are now just beginning to tap. Some notion of the vistas which lie before us, when we begin to understand primary effects a little better, is indicated by the suggestions of the medical use of specifically absorbed radioactive dyes and of the possible large-scale production of vaccines. . . .
>
> In the fields of inorganic chemistry and physics the production of new phosphors and of inorganic polymers should be studied. Possible hardening of metals by radiation and a host of new enterprises made possible by the interesting process of dislocation of atoms in solids may become important.

In this field, chemists point out that often, when a reaction is discovered by the use of radiation, continued investigation leads to thermal or catalytic means to make the reaction "go." In general, the latter are much cheaper for production. Such progress does not, however, minimize the significance of an original discovery using radiation to produce the reaction.

In the field of ultra complex molecules as antibiotics such as penicillin or streptomycin, new and improved strains are often cultivated from mutations. Radiation may be a tool that can produce a variety and extent of mutations in such molecules of many times the diversity and rate at which they occur in normal evolution.

Chemists may learn much about the stability of chemical bonds by breaking them with alpha, beta, gamma or neutron radiations. While such radiations have been known for many years, they have been available only in the form of a few rare natural radioactive materials or in connection with the limited output of "atom-smashing" accelerators. The vast spectrum of radiation intensities now beginning to become available makes widespread research in these fields possible.

Conclusions

A great many of the statements in this paper are necessarily hedged with "if," "but," "possibly" or "probably." This merely emphasizes the newness of the field we have been considering, and the tremendous possibilities ahead.

Atomic energy is not yet producing commercially useful power. We are certain such production is technically possible. It is probable one or more experimental or demonstration plants will be in operation within the next two to four years.

We believe such production is economically feasible, at least for many special applications. However, the development of economically competitive atomic power is in our estimation a long-term project, possibly requiring decades—and its advent will be gradual. We feel atomic power will supplement, but not supplant, present power sources.

What may be termed the by-products of atomic energy—radioactive isotopes, radiation chemistry and metallurgy, fission products—may well prove of more importance to society than atomic power itself, and we shall probably realize many of their benefits more quickly.

It is quite evident that in order to reap all the potential benefits, a tremendous amount of research and development must be carried on, and much of this lies within the scope of members of the A.I.M.E. We are sure it will be done.

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Petroleum and Natural Gas; Uses and Possible Replacements

BY ROBERT E. WILSON AND J. K. ROBERTS

ROBERT E. WILSON
Scientist, technologist, and industrialist, Dr. Wilson is Chairman of the Standard Oil Company (Indiana). In 1929, he took charge of research and development, in which post he earned great credit for the expansion of the company. He advanced rapidly to his present position. A chemical engineer by profession, he is a speaker and writer of unusual ability; and is the possessor of numerous medals and honorary degrees.

IN order to make clear the reasons for the basic importance of petroleum and natural gas in the world today, and the problems faced by our scientists and technologists in using efficiently these great natural resources and finding possible replacements for them, it will be necessary to present a brief discussion of hydrocarbon chemistry.

The most important use of petroleum products is as fuel, particularly for the various forms of the internal-combustion engine. There are, of course, hundreds of thousands of chemical compounds that give off heat when they burn; that is, when they combine with the oxygen of the air. If a capable chemist were assigned the problem of finding the ideal volatile liquid fuel for use in an engine, he would probably begin by referring to the tables that give the heats of combustion of the chemical elements.

Of all the ninety-odd elements, hydrogen shows up with by far the highest heat of combustion—about 52,000 British thermal units per pound. Unfortunately, however, hydrogen is a very light gas, which can be liquefied only at very low temperatures. To burn it as fuel in an automobile would require a balloon about as big as the car to hold the equivalent of a gallon of gasoline; or, the hydrogen could be compressed in heavy steel cylinders, but this would require about 125 pounds of steel per pound of hydrogen. Obviously, then, hydrogen itself cannot be considered a satisfactory and convenient automotive fuel, though in chemical combination it is an essential constituent of all important motor fuels.

Of the common chemical elements, the one having the next highest heat of combustion is carbon, with about 14,500 B.t.u. per pound. Carbon, however, is a solid, which cannot be vaporized to any appreciable extent at temperatures below 6300°F.—so, the second best element from a heat standpoint is again far from being a suitable fuel for an internal-combustion engine.

Hydrocarbons the Best Fuels

Since all the other common chemical elements have heats of combustion far lower than those of hydrogen and carbon, a chemist would readily predict that the most promising possible fuels for automobiles would be found among the many thousands of compounds of hydrogen and carbon and particularly among the compounds that are richest in hydrogen. A survey of such compounds abundantly verifies this prediction. There are hundreds of hydrocarbons, rich in hydrogen, which are liquid at ordinary temperatures, readily vaporizable to give combustible mixtures with air, and which have heats of combustion slightly above 19,000 B.t.u. per pound—more than 50 per cent above that of coal.

If we searched the entire catalogue of several hundred thousand known chemical compounds, we would not find any having a higher heat content and more desirable other properties than certain hydrocarbons present in petroleum. It is therefore extremely fortunate for our whole economy that we have plentiful supplies of petroleum from which almost ideal liquid fuels can be obtained at costs that are of the same order of magnitude (before taxes, of course) as the delivered price of good domestic coal per unit of energy content, and much less than that of bottled spring water! The only other substantial present source of hydrocarbons at all suitable for this purpose is coal tar, but the total United States production of benzol and similar products from coal tar last year was less than 0.5 per cent of the total gasoline production.

The great convenience of liquid hydrocarbons, as well as their other properties, has made them preeminent in the entire field of internal-combustion engines, whether Otto cycle, diesel, gas turbine, or jet. Hydrocarbons are becoming steadily more important as fuel oil for homes and industrial plants; but mobile equipment remains the greatest present and prospective user of petroleum products.

Secondary Uses of Petroleum

The most important secondary use of petroleum products, as lubricants, is largely based on the fact that hydrocarbons are noncorrosive, immiscible with water, relatively nonvolatile, and possess "oiliness," the property that distinguishes a true lubricant from other liquids of the same viscosity. Oiliness is related to tendency to be adsorbed on the surface of metals and thus to prevent metal-to-metal contact. Another outstanding property of petroleum-base lubricants is their adaptability to conditions that would cause rapid and troublesome deterioration of most other types. Petroleum oils can be made quite stable, and resistant to high temperatures—a property that renders them particularly advantageous for use in internal-combustion engines, steam turbines, and similar equipment.

In the lubricating field, as in the fuel field, the wide variety of available hydrocarbons is important, since it permits many special requirements to be met. Generally what is wanted is a material of suitable viscosity, so as to provide adequate protection for the rubbing surfaces, and one that has a low volatility, so that the oil will not evaporate from the part being lubricated. A low pour point is often necessary, so that the oil will not solidify at low temperatures. Because of the many different kinds of mechanisms, as well as the different operating conditions for any one kind—for example, summer and winter automobile driving—oils of a wide range of viscosity are required.

It is really only a coincidence that the fuel that drives automobiles and the oil that lubricates them both come from the same petroleum. It has been very convenient, however, for the processors of crude oil to have their two principal markets combined into one. The ability to concentrate in studying the customers' needs has been advantageous to the user as well as helpful to the oil industry in finding uses for its products.

There are, of course, a rapidly growing number of other uses of various petroleum products—as solvents, insecticides, asphalts, road oils, waxes, emulsifying agents, rust preventives, and chemicals, but in total they account for only a very small percentage of total volume.

Natural Gas

Natural gas, being composed principally of hydrocarbon molecules smaller than those present in oil, also finds its greatest use as fuel. Since its cost at the well is much lower than that of petroleum, and it can be burned without refining, it can be widely distributed through pipe lines in spite of the fact that the transportation cost per British thermal unit per mile is several times that for petroleum. Natural gas is used widely also as a raw material for chemicals and for manufacture of carbon black.

For both gas and oil, the uses as fuel so far exceed all others that they should be considered first. The data given above on hydrocarbon heating values show why gas and oil will continue to be used in increasing quantities in these fields as long as their price stays in the present general range.

Competition from Atomic Energy

A potential long-range competitor might be atomic energy. However, it has already been pointed out by a number of authorities that for several reasons atomic energy is not likely to compete with liquid fuels for most transportation and other small-scale uses; therefore there seems no need to go into this question in any detail. It might merely be said in passing that there is nothing in sight to indicate that it would be possible to build a small, mobile atomic engine without surrounding it with several feet of concrete insulation to prevent the escape of dangerous radiations. This problem will not be solved for a long time, if ever; and if it is solved, there will then arise the equally difficult problem of whether this small mobile atomic engine can be built for anything like the $2 per horsepower the motorist now pays for an average light car engine.

We believe we are justified in assuming that we can forget about atomic energy as a competitor for petroleum products, except possibly for certain naval vessels and large stationary power plants. As regards the latter, atomic energy would be competing principally with coal. With modern cracking methods, the petroleum industry no longer need market heavy fuel oil in competition with coal, except where the convenience, cleanliness, and labor-saving characteristics of oil justify a substantial premium.

Consumption and Utilization

To indicate the growing importance of petroleum and natural gas, let us consider the growth in consumption. Since 1900, the energy used in the United States has come from the sources indicated in Fig. 1, data for which were collected principally by the Bureau of Mines.

If the ratio of 1945 volume to the volume in 1900 is calculated, the following figures are obtained: coal, 2.3; water power, 5.9; natural gas, 16.3; petroleum, 27.2. Oil has shown by far the greatest relative increase, with natural gas a good second. Oil has grown from about 4 per cent of total United States power sources in 1900 to 30 per cent at the present time. The uses of natural gas may be grouped under the four principal headings shown in Table 1.

Although the use for carbon-black manufacture is the smallest of the four, it has shown the greatest rate of growth.

The principal products made from petroleum, as regards quantity, have been gasoline, kerosene, and fuel oil, as shown in Table 2.

The percentage of crude oil turned into gasoline has risen from 10.3 per cent in 1904 to more than four times as much at present. The percentage made into kerosene has dropped to less than one tenth of that used for this purpose in 1904, though the total volume has doubled!

Some of the fields of utilization of oil also increased more rapidly than others and for both oil and natural gas the reason behind the increase was a technological development—or perhaps several technological developments, which supplemented one another.

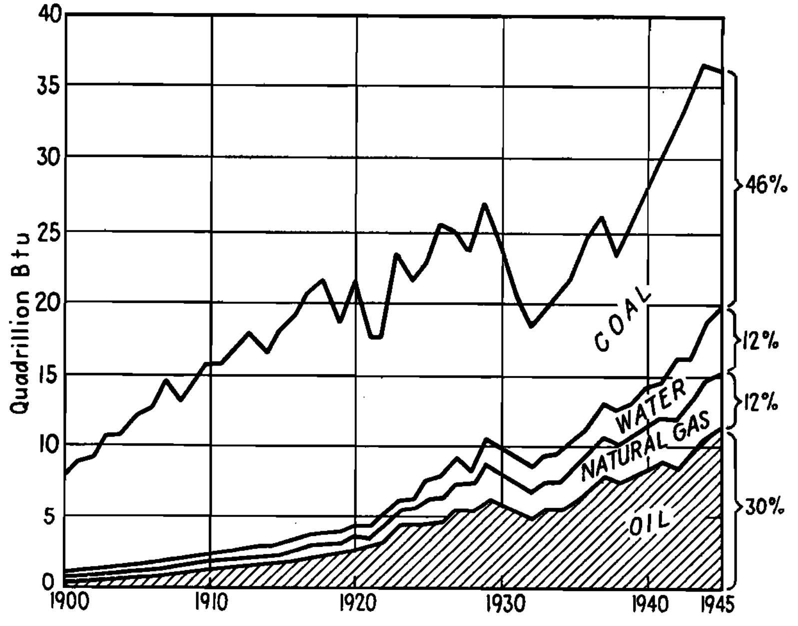

FIG. 1—*The sources of power in the United States.*

The use of natural gas for carbon black grew more rapidly than other uses because of the discovery that carbon black greatly increased the strength and durability of rubber tires. Gasoline became a large-volume petroleum product because it was needed for the increasing number of automobiles; and the automobiles increased in number as rapidly as they did partly because the cost of gasoline was lowered—and quality was improved—by a number of technological advances: oil cracking, scientific methods of exploration and production, the solving of the knock problem, and so forth. At the same time the use of kerosene grew less rapidly because of the many inventions in the electrical field, which substantially eliminated its use for lighting and relegated it to the field of fuel.

The interrelationship of the natural gas, petroleum, automotive, and rubber industries is evident. This relationship has taken the form of close

TABLE 1—*Consumption of Natural Gas in the United States*

BILLIONS OF CUBIC FEET PER YEAR

Year	Domestic and Commercial	Use in Oil or Gas Fields	Carbon Black	Other Industrial Uses
1920	286	202	41	269
1925	272	424	140	352
1930	376	723	267	575
1935	413	580	242	675
1940	579	712	369	996
1944	806	860	370	1,731

cooperation between the technical men of the related industries, with considerable effect on the products, particularly as regards quality. The automobile engine has improved as technological advances in the oil industry made higher quality gasolines and motor oils available at reasonable prices. The greater reliability of modern tires assisted this trend, since it increased the driving speeds that could be considered reasonably safe.

This close cooperation between the technical men of seller and buyer is continuing, as competitive companies carry on constant detailed research, so as to make their products just a little better than those of others and thus get a larger share of the business.

Future Requirements

In any discussion of the future of gas and oil, it is obvious that we must consider the normal growth curve and also the possibilities of new tech-

TABLE 2—*Production and Yields of Principal Petroleum Products*

Year	Gasoline		Kerosene		Fuel Oils	
	Production[a]	Percentage	Production[a]	Percentage	Production[a]	Percentage
1899	18	12.9	82	57.7	22	15.5
1904	19	10.3	88	47.8	34	18.5
1909	35	10.7	109	32.9	117	35.4
1914	79	18.2	126	24.9	244	48.1
1920	310	26.1	151	12.7	576	48.6
1925	657	32.4	164	8.1	998	49.3
1930	1,067	42.0	135	5.3	1,022	40.2
1935	1,254	44.2	153	5.8	986	37.3
1940	1,632	43.1	202	5.7	1,365	38.6
1945	2,123	45.1	222	4.7	1,969	42.0

[a] Thousands of barrels per day.

nological advances of the type that so greatly influenced utilization in the past. Predictions of future demand necessarily become more and more speculative the farther they are projected, but for the purposes of this paper it matters little whether a given level of consumption is reached in 1970 as projected or in 1965 or 1975—the important fact is that the demand curve for almost all petroleum products still trends sharply upward.

If we plot the probable growth of passenger-car registration as calculated by our Sales Research Department from United States Public Roads Administration data, we obtain a curve that indicates that the number of passenger cars will increase from the present 27,000,000 to about 43,000,000 by 1970.

If we examine the figures for annual consumption of gasoline per passenger car (Table 3), as given by the Bureau of Mines, we find that this figure has risen rather steadily. We believe it can be expected to level out somewhere around 17 barrels per car per year. This rise has occurred (and would normally be expected to occur in the future) in spite of the great improvement in the quality and potential efficiency of the gasoline. The customers have elected to take the improvement in the form of larger cars, faster acceleration, higher top speeds, and more comfortable driving rather than in the form of greater mileage per gallon. Another factor leading to increased usage per car has been the decreased cost of gasoline, as compared with the '20s. Still another has been the steady improvement in roads, which has tended to increase both average speeds and annual mileage.

TABLE 3—*Projected Annual Consumption of Gasoline*

Per Passenger Car		Per Commercial Vehicle	
Year	Barrels per Car	Year	Barrels per Vehicle
1925	10.6	1926	20.5
1930	13.3	1930	24.6
1935	14.4	1935	26.6
1940	15.1	1940	32.9
1970	16.8	1970	37.0

Similar curves show that truck and other commercial vehicle registrations can be expected to increase in number at an even faster relative rate than passenger-car registrations, and should rise from a present figure of about five million to about seven and a half million by 1970.

The number of gallons of gasoline used per truck can be expected to rise from the 1940 figure of approximately 33 barrels per year per vehicle to about 37 barrels by 1970 (Table 3).

In calculating the total gasoline consumption by commercial vehicles in 1970, however, we have introduced a reduction for probable conversion to diesel power. In the figures calculated for farm tractors, a correction must be introduced for use of tractors powered by distillate fuels. These assumptions result in final figures as shown in Table 4 for total gasoline consumption in 1970.

TABLE 4—*Estimated Gasoline Consumption in 1970*

	MILLIONS OF BARRELS
43,000,000 passenger cars	720
7,100,000 commercial vehicles	263
3,000,000 tractors	46
Aviation gasoline	65
Naphthas	25
Miscellaneous	32
Total	1,151

In addition to this considerably expanded use of gasoline, we anticipate even more pronounced increases in the use of certain other petroleum products. Some of the uses of distillate fuels are still in their infancy. Even oil heating of homes still has great growth ahead of it as part of a gradually rising standard of living.

In 1940, only 9.4 per cent of the one-family and two-family homes in the area where central heating is desirable had oil heat. At that time approximately two million oil burners were in operation. On the basis of past growth of oil heat and the growth patterns and future expectancy of competing fuels, it is anticipated that the number of domestic oil burners will rise to four million by 1950 and to five and one-half million by 1970. At this level approximately 22 per cent of the one-family and two-family homes in the colder areas will be heated by oil.

Since fuel-oil consumption per burner averaged approximately 45½ barrels per year in the prewar period, it is estimated that domestic fuel-oil demand will be approximately 250 million barrels by 1970.

Diesel fuels also will be used much more widely by railroads and other users. In spite of the greater original cost of diesel locomotives, railroads are buying them in increasing numbers because of their manifest advantages as compared with steam locomotives: lower operating costs, reduced maintenance, faster acceleration, smoother operation, elimination of track pound, and freedom from dirt and cinders. The present rapid increase in the number of diesel locomotives is occurring particularly in the large sizes—freight and passenger locomotives that use from 4000 to 8000 barrels a year of diesel fuel, as compared with the 1000 barrels used by the small switching diesels now in such common use.

We can also expect a substantial increase in the proportion of marine diesel power, which in the United States has not kept pace with the growth of marine diesel power abroad. Currently, the proportion of diesel-powered vessels is increasing. About 10 per cent of the large ships built during 1946 were driven by diesels, and we expect this percentage to rise. Other diesel uses will also increase—farm tractors, electric-power plants, smelters, and miscellaneous.

Road oils and asphalts will be used more extensively. In fact, it is hard to see a drop in demand for any petroleum products except residual fuels. Some of the increases in distillate and diesel fuel consumption will cut into the market for residual fuels, but they will continue in demand for many heating or power installations where their advantages will justify a probably increasing premium over coal. Our best guess is that total demand for heavy fuel oil will drop slightly.

Table 5—*Estimated Demand in 1970 for Products Now Made from Petroleum*

Product	1970 Demand, Millions of Barrels	1970, Per Cent	1946, Per Cent
Gasoline:			
Gasoline and naphthas	1,086	41.8	42.6
Aviation fuel	65	2.5	
Kerosene	161	6.2	5.7
Diesel fuel	242	9.3	15.8
Domestic heating oil	250	9.6	
Residual fuel oil	464	17.8	23.7
Others	332	12.8	12.2
Total	2,600	100.0	100.0

The foregoing figures take into account the probable range of future prices. While the industry is now confronted with the major problem of apportioning the limited amount of virgin gas oil available in a barrel of crude between gasoline, heating distillates, and diesel fuel, it is our belief that technological developments in refining and product utilization will resolve the attendant price difficulties and hold the prices of these products at levels that will permit the increased use predicted. Likewise, the cost range now anticipated is under the price ceilings imposed by competing forms of power, and the costs are likely to remain below these price ceilings even if the gasoline and diesel fuel have to be made from alternative sources, such as coal. We therefore believe we are safe in our forecast of a rapid growth in the demand for these liquid fuels without regard to source of supply.

Adding up all these anticipated demands, it looks as though we shall have in 1970 the demand shown in Table 5 for products now made from petroleum. The 2,600,000,000 barrels of crude oil, or its equivalent, needed to supply the demand in 1970 compares with a consumption of 456 million barrels in 1920, 926 million in 1930, one billion 327 million in 1940, and one billion 773 million in 1945.

Improvements in Quality

In considering future utilization, we must consider not only quantity but also the changes that will occur as regards quality. When science turns out improved products, the new achievement always seems to convince the customers that still better products will be along shortly; and so far, science has always managed to come through. Each new advance in a well-explored field becomes a little more difficult than the last, however, and something of this sort has happened in regard to petroleum products.

The automobile manufacturers are working on cars that will have higher compression ratios and will require gasoline of higher octane number. While radical changes in engine design will be required as compression ratios go up high enough to require octane numbers appreciably above 85 A.S.T.M. —or about 90 research—there seems no doubt that the designers will solve the many problems eventually and will turn out cars that make efficient use of gasoline of 95 research octane number, or even higher. These cars will go farther on less gasoline, but as was indicated earlier, we feel that there will be more use of each car; and since there will also be more cars, total gasoline consumption in the country will rise. We shall therefore be faced with two simultaneous demands—for higher quality gasoline and for more of it. Such a situation always presents rather serious problems.

From the early '20s until the early '40s it has been possible through a series of technological advances to *decrease* the cost of gasoline while steadily *increasing* the quality; but it seems clear that the time has come when further substantial increases in quality will cost real money. During the war it was possible to make relatively large amounts of 100-octane gasoline and some with even higher performance. This was done, however, by skimming the cream of the components present in virgin and cracked naphthas and adding ingredients that in many cases were produced by expensive synthetic processes. The 100-octane aviation gasoline sold for about 14 cents per gallon at the refinery, against about 6 cents for the regular grades. Also, it was necessary to lower the octane number of motor gasolines in order to obtain enough of the high-quality ingredients for aviation fuel. Since we produced about three times as much regular gasoline as 100-octane, the arithmetic mean, which would not be too far from the blending result, would be about 78 A.S.T.M. octane number. When the average for all the gasoline produced in the country has to be raised to 95 research octane number or above, it will mean upgrading most of the present components by high-cost processing; and while we can allow a certain amount, as always, for technological improvements in refining, the cost of the gasoline must certainly go up, along with the quality.

We can also expect—with certain exceptions—a tendency to increase some of the quality requirements of high-speed diesel fuels. For many years the diesel engine was popularly considered an omnivorous device, which would operate on anything that could be pumped through a nozzle, and on some things that could not. Now, however, principal interest centers in *particular* forms of the diesel engine, from which high speeds and output are exacted, and which we find are anything but omnivorous. The problems of fitting fuels to diesels are likely to increase; but with further research, it may turn out that fuels can be used that are not now employed in high-speed diesels. It appears, for example, that cetane number has been overemphasized and that performance of a diesel engine in service is by no means determined by cetane number as now measured. The actual variables to be reckoned with include both engine and fuel characteristics. Many of the conditions exist only in the service engine itself and must be evaluated in that engine. The question of using catalytically cracked fuels in locomotive diesels, for example, is a part of this problem. Some results have already been obtained in service tests which indicate that catalytically cracked diesel fuels may be expected to give entirely satisfactory operation.

Effect of Developments in Equipment

Thus far we have been assuming that present engines of various kinds will go on being used and that changes will come about only through gradual evolution. Gradual changes usually can be predicted with some accuracy. However, in the history of natural gas, and also the history of petroleum, outstanding new inventions such as the electric light substantially changed the course of development. It seems well to stop and consider whether any far-reaching changes seem likely to loom up over the technological horizon today.

Two new developments in mobile equipment have already appeared—the gas turbine and its near relative, the jet engine. We must ask ourselves whether these inventions will radically change the situation concerning petroleum and natural gas, and perhaps will eliminate some of our present large markets.

There seems to be little doubt that jet-propulsion fuels will largely supplant high-octane gasolines for military aircraft, particularly for fighters. Where extreme speed is the primary consideration, the piston engine cannot compete. It will be a long time, however, before anything as extravagant with fuel as present-day jet propulsion can be used for commercial airplanes, and even when it is used we must remember that normal aviation use will probably remain small compared with the volumes required by ground equipment. Just as use of 100-octane gasoline dropped at the end of the recent war, so would we expect use of jet fuels to remain minor in peacetime, compared with other fuel uses of liquid hydrocarbons. Granting that the present jet engine can do things that other power plants cannot, there is still much room for improving its efficiency and reliability; for example, it operates at compression ratios of only about four to one, and at quite prodigal excess air ratios. Its thermal efficiency is low and its overall propulsive efficiency is unattractive until the plane gets up to speeds that are inherently expensive, and that can be justified only for very special service. Further, though the engine is light, the fuel loads for long-range operation are quite certain to be high.

The gas turbine comes closer to the efficiency of present prime movers, and should become increasingly important. Because the blades of the gas turbine are particularly vulnerable to the harmful effects of ash and corrosion, a clean liquid or gaseous fuel seems certain to be required for most uses. The quality of this liquid fuel is unlikely to be critical as long as clean distillates are used. Since combustion may occur quite far removed from the turbine, there will in most cases be adequate opportunity to install devices that improve the burning qualities of almost any hydrocarbon or other liquid —though such devices must operate at very low pressure drops and of course should not impose peculiar problems of their own.

In general, we find that there are likely to be new engines but that most of them will involve liquid fuels. Any reasonably expectable new inventions will change merely the type of hydrocarbon fuel required and supplied. We will still look first to petroleum and second to natural gas to supply the need. But where will we turn next as we use them up?

Sources of Liquid Fuels

The prediction of demand for liquid fuels over the next 25 years is hazardous; and a guess as to the sources for that period may seem little less than foolhardy. However, the question is so important that the most likely alternatives should be discussed in detail.

Our immediate and most important source, of course, will be the present proved liquid hydrocarbon reserves, now estimated at about 24 billion barrels, an amount almost as great as the total amount used in the whole past history of the petroleum industry. If we examine the chart showing our crude oil reserves during the past, we find that, except for slight decreases during one year of World War II and two other short periods, our proved reserves have steadily increased rather than diminished; that is, in most years discoveries and further development of old fields have more than equaled production.

Since consumption has been increasing in geometric progression during most of these years, and since every oil field discovered means one less still to be found, merely to hold our own on reserves would represent a real achievement—though it would not give us an adequate backlog for growing demands. The principal factor that has brought about continued increase of these reserves is the application of technology to every branch of our business. Something of the romantic story of these applications of technology to the search for oil—deeper drilling, better methods of produbtion, new methods of secondary recovery, more efficient methods of refining and utilization—has been set forth in a paper by one of the authors.[1]

To give just two brief examples, the maximum depth of wells has gone from 69½ feet in Colonel Drake's well to 5700 feet in 1909, 9800 feet in 1930, and 16,655 feet today. Whereas before 1920 we had to rely entirely on surface geology to indicate where oil might be found, today we have amazing instruments that give accurate indications of structure four or five miles deep in the earth.

It should be noted, however, that while these instruments permit successful wildcat drillings—that is, drillings in unproved territory—to be made six times as frequently as without the instruments, the present percentage of successful wildcat wells is no higher than it was in the old days, when these remarkable exploring instruments were not available. In other words, the easily found oil has already been found; that which is left is harder to find, and the difficulty in finding it has recently been increasing more rapidly than the improvements in exploration methods.

More serious is the fact that the cost of wildcat wells has approximately trebled during the past 10 years. The cause of this is partly the higher costs of labor and materials, but even more the fact that to find new reserves wildcat wells must be drilled to greater and greater depths and in more and more remote places. Even this might not be too serious if it were not coupled with the fact that the number of barrels of oil discovered per wildcat well is averaging only about one half what it did 10 years ago. While the costs fluctuate from year to year with the opening of new areas, everything points to the fact that the cost of finding new reserves is around six times what it was

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[1] R. E. Wilson: Technology as a Multiplier of Our Natural Resources. *Chem. and Eng. News* (1944) **22**, 784.

10 years ago, and is still on the upward trend. Moreover, unless we develop some major improvement in our methods of finding oil, or unexpectedly discover large new areas underlain by important deep oil deposits, the recent trend to higher costs is not likely to be reversed.

In view of the greater difficulties in finding new oil reserves and the increased costs of production, we cannot remain complacent when we view the growing demands facing our industry. Without doubting the fact that technology has not exhausted its resources, and that we shall find many, many billions of barrels of oil over the next few years, we would be derelict if we did not give increasing attention to possible alternative sources of the liquid hydrocarbons, which play so vital a part in our civilization.

One source will be imports. We can hardly expect to go on indefinitely producing 65 per cent of the world's oil from 30 to 35 per cent of the world's proved reserves, in 15 per cent of the favorable land area. Imports doubtless will tend to increase, but must not be allowed to depress the domestic industry, discourage the search for additional reserves, or interfere with the development of synthetic substitutes from domestic sources.

The foreign source about which we hear most at present is the oil of the Middle East. We are inclined to think, however, that our imports will come predominantly from South America, and that the Middle East will gradually replace South America as the principal source of supplies for the European area. If there should be another war we could not depend on our ability to keep open our communication lines to the Middle East, but if we retain our Caribbean bases we should be able to keep open our supply lines to northern South America.

Though all of us sincerely wish it, permanent world peace has not been assured. We must therefore make sure that we have a strong, vital industry, with the bulk of its reserves within our own sphere of influence. This means, first, building up our reserves while using those which American ingenuity has discovered elsewhere; and second, development of synthetic processes from other domestic raw materials. Both of these important objectives can be realized only if government policies are sufficiently far-sighted.

SYNTHETIC PROCESSES

Gasoline from Natural Gas

The most promising of the synthetic processes is that by which gasoline and other liquid fuels are produced from natural gas, by use of a modified Fischer-Tropsch synthesis, which we term the Synthol process.* In the carry-

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* Various other names, such as Hydrocol, are also being used for essentially the same modified Fischer-Tropsch process.

ing out of this process the first step may seem to be in the wrong direction. The gas is partially oxidized with oxygen to obtain a mixture of hydrogen and carbon monoxide. The mixture can also be obtained by an alternative process, in which the natural gas is reacted with steam and carbon dioxide at high temperature over a catalyst.

The so-called "synthesis gas," obtained by one or the other of these methods, is passed over a finely divided fluid catalyst, which may be primarily iron. Under proper conditions the hydrogen and carbon monoxide react to produce liquids that range in molecular weight all the way from gasoline to heavy distillate fuels and wax. As is evident from the fact that two 6000-barrel-per-day plants are now in the final stages of engineering—one to be built at Brownsville, Texas, by Carthage Hydrocol, Inc., and one in the Hugoton field of western Kansas, by Stanolind Oil and Gas Co.—this process has reached the point where, under favorable conditions, gasoline made from it can compete successfully with gasoline made from crude oil. The octane number of the gasoline produced, after suitable finishing operations, will be about 80 A.S.T.M., before addition of tetraethyl lead. For each 6000 barrels of gasoline, the process also produces about 1000 barrels of distillate fuels and another 1000 barrels of oxygenated compounds that are valuable as chemicals. The most abundant of these oxygenated compounds is ethyl alcohol, but there are also substantial quantities of other alcohols as well as aldehydes, ketones, and organic acids.

To make one barrel of synthetic crude oil by the Synthol process, about 13,500 cubic feet of natural gas at standard conditions must be charged to the plant. Since our total natural gas reserves are estimated at 160 trillion cubic feet, processing of *all* this gas to liquid fuels would make available some 12 billion barrels of oil to supplement our present 24 billion barrels of known liquid hydrocarbon reserves. While no one thinks that by any means all of the gas will be used to make liquids, it is apparent that we have here a considerable reserve on which to draw; especially since, as we drill deeper, we tend to find a higher proportion of gas and less oil—also, a barrel of volatile fuel is worth more than a barrel of crude. Use of a portion of the gas to make gasoline is especially desirable from the standpoint of national economics, because gas from certain fields contains a high proportion of nitrogen and therefore is not well suited for long-distance transportation to the usual markets.

Gasoline made by the process will cost somewhere around 6½ cents a gallon, about the present refinery cost of gasoline. It now appears that for about 3 or 4 cents per gallon more a modified Synthol process can be used to make gasoline from coal. Since lower grade coals such as lignite and subbituminous can be used, mining costs can be minimized by strip-mining techniques. An interesting experiment, which may favorably affect the economics of gasoline from coal, is the present work being carried out by the Bureau of Mines in cooperation with the Alabama Power Co. on underground gasification of the coal. Synthesis gas for the process may possibly be prepared by partially burning the coal, preferably with oxygen, while still in place in the original seams. The gas made by this process might also be piped to consumers, as a replacement for present natural or manufactured gas.

From the standpoint of reserves, the proved feasibility of the Synthol process starting with coal should end all serious concern anyone might have had about the outcome of future exploration for new oil pools. There is enough coal in the United States to supply gasoline for more than a thousand years. The availability of gasoline from coal also places a ceiling on the price to which crude oil can go as it becomes scarcer and harder to recover.

Other Synthetic Processes

Another process, which may enter the picture ahead of gasoline from coal, and which will help to extend our present crude supplies by making better use of them, is hydrogenation of cracked cycle stocks and residues. It is possible to restore the hydrogen to these stocks by hydrogenation processes similar to those well known in other fields, thus making them more suitable for further cracking or for use as end products. While this process appears to be more expensive than the Synthol process that uses natural gas as the starting material, it will become economically desirable as the price of crude oil rises. Alternatively, the heavy residues could also be used as starting material for the Synthol process, by conversion to carbon monoxide and hydrogen.

A comparison of the most important of these processes by our research workers has resulted in the following estimates of the dates when we may expect to see them in substantial commercial operation:

1. Synthol (using natural gas)	1948
2. Hydrogenation of heavy oil residues	1965
3. Synthol (using coal)	1970

Obviously, technologic improvements in processes 2 and 3 could bring them into operation sooner, and major new gas and oil discoveries would tend to postpone them. The schedule is based on the costs by the best present processes, calculated against anticipated future prices of crude oil. It might be changed, for example, if a satisfactory process can be developed to prepare synthesis gas by partially burning coal underground. It should be noted, however, that cost of the coal represents only about 25 per cent of the cost of

Synthol gasoline, and there is therefore a limit to the economies that can be obtained by underground gasification.

HYDROGENATION OF COAL

In the forecast of dates just given, we slighted a process that was used extensively to make gasoline in Germany before and during the war; that is, the hydrogenation of coal or lignite. It is used even in peacetime in Europe, but the cost of the gasoline, according to the most recent report from the Bureau of Mines, is from two to four times the cost of gasoline in the United States. The Bureau of Mines is not neglecting the possibility that improvements can be made, either by obtaining higher throughput in the present high-pressure process or by developing a new process involving moderate pressures and minimum consumption of hydrogen. Since compressed hydrogen represents about 50 per cent of the net cost, however, there is a rather strong floor under the possible reduction that can be made.

OIL SHALE

Another possible source of gasoline was omitted from our timetable—oil shale. In the days just after World War I, when the alarmists were pointing out that the reserves of crude oil could not possibly last another 10 years, a number of oil companies became much interested in oil shale, and some bought large acreages of these deposits. It may yet turn out that they were right, but on the basis of what we know at present, gasoline from oil shale will in general cost more than gasoline from coal. Only the richer and more favorably located deposits seem likely to be developed, to supply certain territories where there is a freight advantage.

The primary difficulty with oil shale is that a fairly rich deposit will contain only about one barrel of oil per ton. Since the only feasible method of obtaining the oil is by heating the shale, more than three-fourths of a ton of ash must be handled for every barrel of oil obtained. While the process is simpler than the Synthol process, and at present involves lower investment cost per barrel of oil produced, the resultant product must undergo expensive refining operations to produce commercial products.

In spite of the fact that at present oil shale does not promise to overtake coal in the economic race, shale is a possibility that should not be overlooked. So the Bureau of Mines is preparing to build and operate a 200-barrel-per-day recovery plant in the Colorado field. We agree that a certain amount of work should be done to determine the potentialities of our large reserves of oil shale, and that this work is properly one for the government rather than for private industry, but we believe that such work should be in the nature of surveys of deposits and study of mining methods and costs, rather than large demonstration plants for recovery and refining of shale oils.

Tar sands, of which there are very large reserves in North America, are in much the same position as oil shale, economically. While the oil can be recovered by extraction instead of by retorting, it does not seem probable that the costs will be brought down to a level sufficiently low to compete with gasoline from coal, especially in view of the rather remote location of the tar-sand deposits, and the poor quality of the recoverable oil.

FUELS FROM FARM PRODUCTS

Occasionally we hear the proposal that liquid fuels be made from surplus agricultural products, particularly from farm wastes. Furfural and furans from corncobs are one suggestion, but the usual suggestion is ethyl alcohol produced by ordinary fermentation with yeast. Bacterial fermentation could be used to produce butanol and acetone.

All these fuels have serious disadvantages. Alcohol, for example, has only about two thirds the heating value of present-day gasoline. There are other reasons why gasoline containing ethyl alcohol is not a satisfactory motor fuel; but the greatest objection is the price. Even with corn at 50 cents a bushel, alcohol costs around 31 cents a gallon. It is estimated that each bushel of corn processed into alcohol and sold to the American people for use in motor fuel would cost either the taxpayer or the consumer 50 cents in addition to the cost of the corn itself.

The present situation is that alcohols made from waste products, or from valuable grains, cannot compete in cost with the same alcohols obtained by synthesis from petroleum or natural gas. Alcohol from agricultural sources would become a factor only as a result of large government subsidies to encourage production or use of alcohol. Enforced use of alcohol in gasoline would simply be a direct method of taxing automobile users for the benefit of other groups. Some urge the use of alcohol fuels as helpful to the national defense, but in every war foodstuffs tend to become scarce and should certainly not be diverted to making motor fuels when there are so many other adequate sources of these materials. We can logically expect these fuels to come from petroleum, natural gas, and coal, with oil shale as a substitute sitting on the bench, eager to enter the game.

Lubricants

Lubrication, the smaller but equally important job done by petroleum products, must also be considered in any general survey. The important point here is that we could use around 10 per cent of the crude oil to make satisfactory lubricants, and are now actually using less than 3 per cent. So, there will be plenty of crude oil to make lubricants for a long time. The Synthol process does not produce satisfactory lubricating oils directly, but if the need arises some of the Synthol products can be put through further synthetic processes and converted into lubricants. During the .war the Germans made some of their lubricants by this method.

Other practical processes exist for synthesizing lubricating oils from petroleum hydrocarbons. There are already on the market synthetic motor oils that are obtained by chemical synthesis from refinery gases. In spite of their hydrocarbon origin, these oils are not hydrocarbons, and they have certain disadvantages in comparison with present oils. While they also have certain compensating advantages, their price is high, and we anticipate that for most uses petroleum oils will continue to serve as the lubricants.

New Uses

In addition to the increased use of fuels and lubricants, we can feel sure that there will be an increase in the demand for other products now made from petroleum—the present familiar by-products and also some entirely new products. A tremendous chemical business has already been built up based on the conversion of refinery and natural gases into chemicals. Early successful research by the Carbide and Carbon Chemicals Corporation led the way to the large-scale commercial production of glycols, alcohols, amines, and many other derivatives from refinery gases.

During the war, when butadiene for synthetic rubber had to be obtained regardless of cost, a large part of it came from alcohol and another large part from petroleum. Practically all of it now comes from petroleum. Even during the peak of the war demand, it amounted to less than 0.5 per cent of the petroleum industry's total products. Nylon is now on the way to obtaining its carbon and hydrogen atoms from petroleum instead of from coal, and many other products can be made as easily from petroleum as from coal tar. The hydroforming process turns naphthenes and straight hydrocarbon chains into compounds containing the versatile and useful benzene "ring." Toluene, 99.7 per cent pure, came from the petroleum refineries in 10 times the quantities available from coal in World War I. Availability of aromatic compounds of this purity makes possible production of the aromatic chemicals that are so important to us as dyes and pharmaceuticals.

Some rather interesting other compounds of various types seem to be in the offing—for example, it would be a great benefit to have drying oils that are not esters. If the drying-oil molecules could be built up by attaching long-chain hydrocarbons with conjugated double bonds to benzene, it should be possible to produce a drying oil that would not undergo saponification by the alkalies present in washing compounds or by the metallic oxides present in bricks and concrete.

In the plastics field, ethylene is already being used as a starting material, and we can expect that other olefins will also be polymerized for this purpose. Orthoxylene has become a significant competitor of naphthalene for manufacture of phthalic anhydride. Detergents are being made by sulphonating alkylated aromatic compounds and in some cases by sulphonating olefins. A new industrial chemical, which recently became available from our own laboratories, is a mixture of alkanesulphonic acids of low molecular weight, which appears to have desirable properties in electroplating baths and for a number of other uses.

A little simple arithmetic will show that these developments are on a sound basis and will continue. At the present average price of crude oil, there is available an organic raw material costing only a little more than ½ cent per pound. Even the complicated and expensive processing carried out in refineries increases the price to only about one cent per pound for gasoline, f.o.b. the refinery. With our fundamental knowledge of hydrocarbon chemistry enabling us to do more and more with these once stubborn and intractable molecules, we can expect that an increasing proportion of chemicals will come from petroleum. In terms of the requirements of the chemical industry, the supply is practically inexhaustible. The 1945 figures for petroleum and some other large industries are as shown in Table 6. So the supply of organic material is there, and the organic chemists are making more and more use thereof.

TABLE 6—*Production of Petroleum and Similar Products, 1945*

Industry	Millions of Pounds per Year	Factory Sales, Millions of Dollars
Petroleum products	544,200	$7,150
Organic chemicals	13,483	1,463
Plastics	1,172	380
Paints and varnishes		640

Economics

All the developments we anticipate depend upon maintaining the proper environment. This means an economic and political system in which research and development are encouraged and in which progressive companies have an incentive to invest the tremendous amounts of capital involved. No one can deny that the oil industry as a whole has done an amazing job of bringing science and technology to bear on its problem of supplying the consuming public with products of ever increasing quality. The gasoline we buy now at the filling station for 15.8 cents (ex taxes) is far better than that we bought in 1920 for 29.7 cents.

It is instructive to look at the prices of petroleum products, compared with those of other products as shown in Fig. 2, using the latest available wholesale price indices compiled by the Bureau of Labor Statistics (for January 1947). The year 1926 is taken as 100. These figures in themselves prove that the petroleum industry is a highly competitive one, constantly seeking to lower the cost of its products and pretty generally succeeding.

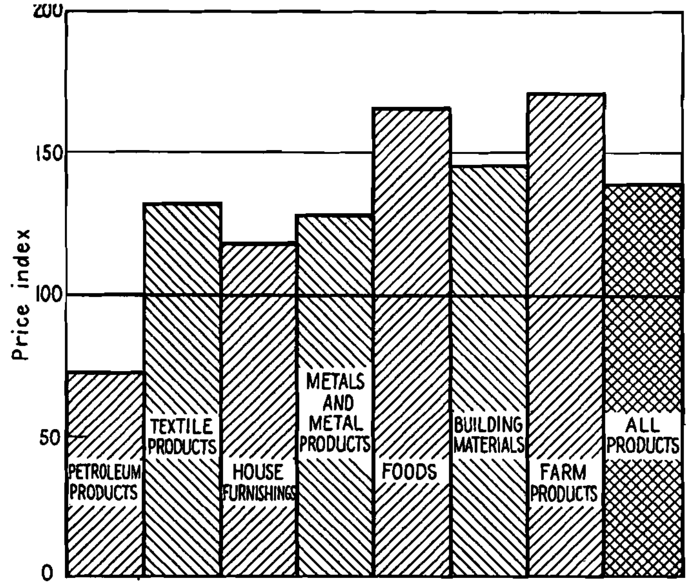

FIG. 2—*Wholesale price index for January 1947.*
Compiled by the Bureau of Labor Statistics. 1926 = 100.

These achievements have required large amounts of capital and will require even greater outlay in the future. According to figures presented by Eugene Holman at the last meeting of the American Petroleum Institute, the average oil company has a capital investment of $22,600 per employee, compared with $9,000 for the coal industry, $8,400 for the foods-processing industry, $5,600 for the metal-products industry, and $6,000 for industry as a whole. As we go to substitute sources for liquid hydrocarbons, the trend of increasing capital requirements will be intensified. This is indicated by the relative figures on the costs of various types of refining processes (Fig. 3).

From time to time the oil industry has been accused of being monopolistic because some of its units have become very large. Without desiring to draw invidious comparison, we should like to direct attention to some of the differences between the petroleum and coal industries.

The petroleum industry, with some very large companies and many small and medium sized ones, can and does spend the large amount of money on research and development necessary to ensure progress; it has or can secure the large capital requirements needed to go into new fields; it has the technical ingenuity and the energy to embark on new enterprises, no matter how large. Technical developments are freely licensed for reasonable royalties, and small operators in all phases of the business are recognized as essential to the overall success of the industry. Intensive competition among the many units, and also with other industries, is the keynote.

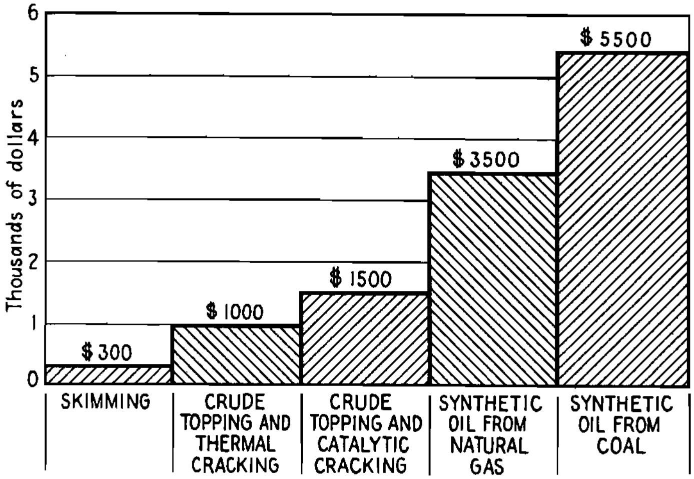

FIG. 3—*Investment costs for refinery units, per daily barrel of capacity.*

The coal industry, to paraphrase the March issue of *Fortune*, is made up of a large number of small operators practicing so-called "perfect" competition against one another but *not* effectively competing with other industries and technologies that have gradually taken much of its business away. The relative contribution the two industries have made to the more abundant life is so apparent that he who runs may read. Extensive research and development work, and adequate capital and courage to put promising developments into operation, are the essentials of a progressive industry, and only recently has the coal industry shown signs of bestirring itself along these lines.

The petroleum industry is in reality a liquid-fuels industry, and supplying liquid fuels will continue to be its job even though its starting materials eventually may be gases or solids. In deciding upon national policies that will affect the future, it seems only fair to judge any industry by its past record of accomplishment. Given the right environment of freedom, the petroleum industry is entirely confident that it can and will maintain the country's supply of vitally necessary liquid fuels and lubricants at reasonable costs for many generations to come.

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South Africa

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U. S. A.

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England

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Société Géologique de Belgique
Belgium

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University of Oslo
Norway

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Institute of Ceramic Engineers
U. S. A.

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Association Luxembourgeoise des Ingenieurs et Industriels
Luxembourg

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Chemical, Metallurgical and Mining Society of South Africa
South Africa

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Canada

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England, Scotland

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Lingnan University
China

E. DE GOLYER
American Association of Petroleum Geologists
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England

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Belgium

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Nova Scotia

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Eidgenossische Technische Hochschule
Switzerland

AXEL EKWALL
Svenska Teknologföreningen
Sweden

CADWALLADER EVANS, JR.
The South Wales Institute of Engineers
Wales

S. A. FALCONER
University of British Columbia
Canada

N. H. FISHER
Bureau of Geology, Geophysics and Mineral Resources of Australia
Australia

JEAN M. GOGUEL
École Nationale Supérieure des Mines de Paris and *Société Géologique de France*
France

STANLEY N. GRAHAM
Queen's University
Canada

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Mining and Metallurgical Society of America
U. S. A.

H. H. HENLINE
American Institute of Electrical Engineers
U. S. A.

WILLIAM O. HOTCHKISS
Society of Economic Geologists and *Geological Society of America*
U. S. A.

P. Y. HU
Ministry of Economic Affairs and Tangshan Engineering College, Nan Yang University
China

BASIL RAWSON JACKSON
Institute of Petroleum
England

LINDSEY JENKINS
Australasian Institute of Mining and Metallurgy
Australia

M. S. KRISHNAN
The Mining, Geological and Metallurgical Institute of India
India

MANUEL B. LLOSA
Sociedad de Ingenieros del Peru and *Escuela Nacional de Ingenieros*
Peru

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Montecatini, Societa Generale
Italy

HANS LUNDBERG
Geologiska Föreningen i Stockholm
Sweden

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American Society for Testing Materials
U. S. A.

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Instituto Geologico Minero
Spain

HENNING MARSTRANDER
Norges Geologiske Undersokelse and *N.T.F. Bergingeniorenes Avdeling*
Norway

EMILIO A. MAULME
University of Cuenca
Ecuador

JULIO A. MELNICK
Copiapo School of Mines
Chile

A. R. MUMFORD
The American Society of Mechanical Engineers
U. S. A.

A. B. NEWMAN
American Institute of Chemical Engineers
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Canada

CHARLES M. PARKER
American Iron and Steel Institute
U. S. A.

RUSSELL J. PARKER
Institution of Mining and Metallurgy
England

ADRIAN PAULEN
Ministerie van Verkeer en Energie, Bureau Mijnwezen
Netherlands

ERNESTO PELUFO
Instituto Sudamericano del Petroleo
Uruguay

GEORGES PERRINEAU
Ministère de la Production Industrielle
France

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Suomen Geologinen Seura
Finland

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Instituto de Geólogia
Mexico

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Sociedad Geólogica del Perú
Peru

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Catholic University
Belgium
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Geological Society of London
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Direccao Géral de Minas e Servicos Geologicos
Portugal
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Pan American Institute of Mining Engineering and Geology
Chile
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American Society for Metals
U. S. A.
RENE TAVERNIER
Société Belge de Géologie, de Paléontologie et d'Hydrologie
Belgium
W. B. TIMM
Department of Mines and Mineral Resources
Canada
MATEO H. TUPAS
Bureau of Mines
Republic of the Philippines
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B. H. VAN DER LINDEN
Koninklijk Institute van Ingenieurs
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China
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Acknowledgment

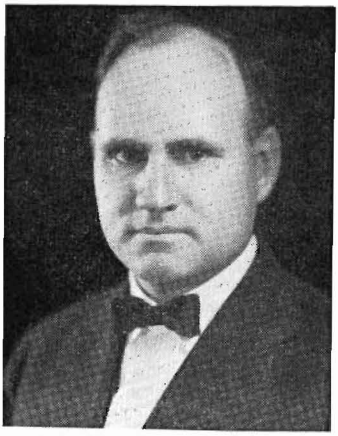
This volume would be incomplete without special mention of the contribution made to it by two members of the Institute staff. Charlotte Carlsen Einersen prepared the foregoing lists of delegates and committee members; she "dug out" from many sources, and compiled, the biographical material regarding the officers of the Institute; and she was particularly diligent in searching the official minutes and other records for much of the important data included in the History of the Institute. Katharine S. Lovell did the detailed editing and read the proofs for the entire volume. She is doubtless the only person who will ever be able to say, with truth, that she has read every word in the book—and she has read them twice. The volume itself attests to the high quality of her work.

Index

Metals and Alloys of the Future

BY ZAY JEFFRIES

THE metallic products of today represent the temporary end point of the efforts and interplay of thousands of years of the human struggle for existence, for pleasure, for conquest, for defense, for improvement in the standard of living, and for the satisfaction of that irrepressible urge to discover and utilize the materials and laws of nature. Each metal has gained its place in the sun in severe competition with all other materials, be they metallic or nonmetallic. Each serves better than any other for certain purposes.



ZAY JEFFRIES

Vice President of the General Electric Company, Dr. Jeffries is not only a distinguished metallurgist but an author, economist, and industrialist. He is noted for his forward-looking conception of metals and metallurgy. For many years he was associated contemporaneously with the Aluminum Company of America and the General Electric Company. He received the James Douglas Medal, A.I.M.E., in 1927 and the John Fritz Medal in 1946, for his notable achievements in metallurgy.

The compromise between cost and properties usually determines the selection of a metallic product for a given use. There are exceptions, as in wartime when the availability at a certain place at a certain time may far outweigh the ordinary economic considerations. In many instances superior properties are vastly more important than cost. If this were not so, the metal industry, for practical purposes, would be the iron industry. The use of 38,000,000 metric tons of newly produced nonferrous metal during the five-year period from 1940 through 1944 is ample evidence that the special properties of these many metals have great economic value.

In fact, our extensive industrial advances would have been quite impossible without the great range and variety of properties and combinations of properties of the nonferrous metals. This observation is not made to detract in the slightest way from the dominant role played by iron and steel. During the past century the production of pig iron has constituted well over 90 per cent of all the new metal produced in the world. Copper, lead and zinc have accounted for more than 90 per cent of the new metal production aside from pig iron.

Fig. 1 shows the world production of pig iron compared with the new production of all nonferrous metals for the past 60 years. The nonferrous production is plotted on a scale 20 times that of pig iron. The 20 to 1 ratio was maintained approximately up to 1925, but since then the pig-iron production has been only about 15 times that of the nonferrous metals.

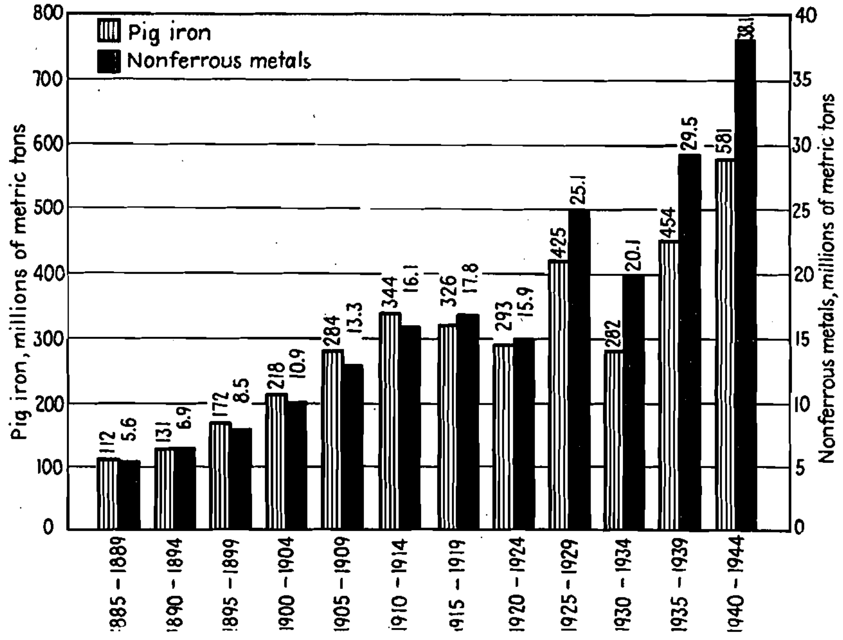


FIG. 1—*World production of pig iron and nonferrous metals.*

While manganese and chromium are nonferrous metals, their manufacture and use are so closely associated with the iron and steel industry that their tonnage production is included in the pig-iron figures as "ferroalloys." These ferroalloys include also several other nonferrous metals. The figures in this chart deal only with new metal production. Actually the metal industry uses all the scrap and secondary that is economically available. The annual production of steel ingot, for example, is considerably larger than that of pig iron. This comes from the use of accumulated scrap and the remelting of large tonnages of scrap and waste from current production. In general the steelmakers use all the available scrap, and pig iron is used to supply the deficiency. Among the nonferrous metals the scrap recovery varies greatly. Secondary copper and aluminum are big businesses, while the recovery of tin is minor. A large percentage of the gold used in industry is ultimately recovered. In the long run we have only the new metal production to work with, but the future of any of these metals may be greatly affected by the ease or difficulty of their recovery for re-use. The new metal may be lost by use beyond economic recovery, like the aluminum employed in the manufacture of steel, or a high recovery may be practical, as in copper electrical transmission lines or iron and steel parts in thousands of machines and structures.

From the tonnage standpoint, seven nonferrous metals have had annual outputs of more than 100,000 metric tons. Table 1 shows the maximum production in any year of each of these metals. Pig iron is included for comparison.

TABLE 1—*Maximum Production of Several Metals in a Single Year*

Metal	Production, Metric Tons	Year
Pig iron	123,000,000	1942
Copper	2,700,000	1942
Aluminum	1,875,000	1943
Zinc	1,840,000	1941
Lead	1,722,000	1939
Tin	245,000	1941
Magnesium	222,000	1943
Nickel	142,000	1943

Ordinarily copper, lead and zinc are far ahead of aluminum, but the war activities brought aluminum to third in tonnage and, because of its low specific gravity, second only to pig iron in bulk volume. While many other metals are vital to our economy, such as cadmium, cobalt, mercury, antimony, silver, gold and the platinum group metals, their combined production in weight is insignificant. Their dollar value, however, is great. In some years the value of the gold output alone has been greater than that of pig iron.

Looking ahead we can be certain that there will be no drastic changes overnight. They should be evolutionary rather than revolutionary, especially the changes in tonnages. One can therefore be reasonably sure of the following conclusions:

1. During the next 20 years the tonnage production of pig iron and ferroalloys will constitute more than 90 per cent of all new metal production.
2. During the next 20 years the tonnage production of copper, lead, zinc and aluminum will constitute more than 90 per cent of the new metal production exclusive of pig iron and the ferroalloys.

I have not so far tried to distinguish between "metals" and "alloys." It is the final metallic products in which we are interested, whether or not there has been intentional alloying. In many instances quite pure metals are needed, and commercially pure metals are produced in considerable quantities, especially the nonferrous ones. But in use well over 95 per cent of all metallic products are alloys. Also, some nonmetallic elements and near metals are vital parts of certain alloys. For example, carbon, a near metal, makes it possible to produce steel from iron. Our great industrial civilization could not have been built without alloys, which provide scores of thousands of combinations of properties not attainable in any other way. It is a rare occasion now when a new metal makes its commercial debut. New alloys, on the other hand, and old ones with new combinations of properties are flowing steadily from the many laboratories of the world.

Of the 90 odd elements around 70 in the elemental state are metals. To the eight metals named in Table 1 should be added chromium and manganese to comprise the list of major metals from the standpoint of tonnage production. Among the minor industrial metals may be mentioned calcium, sodium, titanium, vanadium, cobalt, arsenic, columbium, molybdenum, silver, cadmium, antimony, tantalum, tungsten, gold, mercury, bismuth, uranium, platinum and palladium. Among the rarer metals used in small amounts or available for laboratory study are lithium, rubidium, cesium, beryllium, strontium, barium, gallium, indium, germanium, zirconium, thorium, some of the platinum group and the rare earth metals.

With all of these metallic elements available for use as such or in alloys, and with nonmetals and near metals also available to modify properties, it does not seem strange that there are so many thousands of combinations of properties. But there are strange and wonderful results nevertheless, because many of the properties of the alloys could not have been predicted from the properties of the constituent metals. A few of these unexpected results are mentioned merely by way of example:

1. Producing glass-hard steel by quenching certain iron-carbon alloys from a red heat.
2. Alloys of nickel and iron that do not expand over a considerable temperature range on heating.
3. Alloys exhibiting the property of permanent magnetism.
4. Alloys having much higher electric resistivity than any of the component metals.
5. The age-hardening of many alloys.
6. The softening of high-manganese steel by quenching.
7. Making alloys of nickel and iron resist many kinds of corrosion and high-temperature oxidation by adding chromium.

8. Profoundly modifying the electron emission of tungsten by mixing with it a little thorium dioxide.

9. Making copper hard enough for many tools by alloying it with a little beryllium followed by proper heat-treatment.

10. Making large pieces of steel harden throughout by the addition of certain alloying elements in relatively small amounts.

Hundreds of such examples could be cited, including unexpected properties relating to final uses as well as to fabricating processes. Many of these are old and, in general, they have become part of our heritage from the arts of our forebears.

The Quality Phase of Metal Industry

Around the middle of the last century a revolution in the art of steelmaking was started by the bessemer and open-hearth processes. For 50 years or so it seemed at times that the demand for ordinary steel could never be met. It seems logical to refer to this period as the quantity phase of the metal industry. The quantities, however, were met and more than met. This gave rise to severe competition in the quality of metal products and thus was ushered in the present or quality phase. The chart in Fig. 1 itself supports the view that the quality phase was underway as early as about 1925. This phase is characterized by several changes, among which is the increased use of nonferrous as compared with ferrous metal. Other factors are the increased use of alloy steel; the use of more heat-treated steel; production of special alloys for ease of machining, ease of forming, ease of welding, etc.; the use of a host of alloys with special electrical characteristics; the increased use of high-cost metals; more combinations of metals and nonmetals; increased use of sheet and plate, and in general the practice of supplying tailormade alloys to fit various requirements.

It is significant that the quality phase has been spearheaded by metallurgical science. Metal science is beginning to precede metal art for the first time in history. It will probably give rise to no controversy to say that metal science is only in its infancy and where it will lead the metal industry of the future no one can foretell. Perhaps we should not be too much concerned with the unknowns of the longer future anyway. On the basis of the past and present, however, I shall try to point out some of the things that seem probable in the future.

As far ahead as one can now foresee, iron will continue overwhelmingly to dominate the tonnage metal industry. Constituting 5 per cent of the earth's crust, there is no possibility of exhausting the supply. The richer and more available ores will supply less and less of the requirements as time goes on, but lower grade and less accessible ores will then be mined. The reservoir of iron scrap will always be great and its utilization in the future should be a more important factor than in the past. The iron alloys are peculiarly fit for man's needs and the science of modifying the properties by alloying and by processing is progressing at a rapid pace.

TABLE 2—*World Production of Copper, Lead and Zinc by Decades*

THOUSANDS OF SHORT TONS

Period	Copper	Lead	Zinc
1880–1889	2,356	5,006	3,217
1890–1899	3,909	7,510	4,516
1900–1909	7,227	10,491	6,990
1910–1919	12,077	12,230	9,721
1920–1929	14,268	15,398	11,443
1930–1939	17,761	16,225	14,272
Total 60 years	57,598	66,860	50,159

The old nonferrous standbys, copper, lead and zinc, will be wanted by man in even greater quantities than in the past. Table 2 shows the production by decades since 1880. Unfortunately, the quantities of these metals are limited. The earth's crust is supposed to contain about 0.01 per cent copper, 0.004 zinc, and 0.002 lead. In the longer future, the prices of these metals should go up relative to iron and thus they can be conserved for the uses for which they serve better than any other materials.

Nickel, tin, antimony, cadmium and cobalt are also relatively scarce metals. Although there is twice as much nickel in the earth's crust as copper, the ore concentrations are rare. In general, these metals should tend to increase in price relative to iron. Such a trend should be looked upon with favor because this is an automatic way to properly conserve these valuable assets.

Manganese and chromium come in a somewhat different category. There is about four times as much chromium and ten times as much manganese in the earth's crust as copper. Both metals can be made available in larger amounts than in the past and both can be used to a greater extent for alloying. There should also be high-manganese or manganese-base alloys in the longer future. Such a future cannot be written off for chromium either because it has favorable high-temperature properties not approached by any other metal. Also, chromium, especially in partnership with iron, nickel, cobalt, tungsten, molybdenum or titanium or certain combinations of these, seems to be essential for high-temperature alloys such as are needed in gas turbines and for jet propulsion. We may therefore look for expanding uses of manganese and chromium.

Aluminum and magnesium, the light-weight metals, are available in various parts of the world. Magnesium can even be produced from sea water. With aluminum constituting about 8 and magnesium more than 2 per cent of the earth's crust, there is no possibility of exhausting the raw-material sources. The future cost of these metals should decrease relative to most other metals, and this will be a favorable factor for both their increased use and the needed conservation of the scarcer metals. Probably the normal place of aluminum in tonnage production is still fifth, even though it did reach third place in 1943. Its normal place now in cubic volume production is probably second only to iron and it should gradually work its way up to second place in weight production. It would seem probable that it will be a strong contender for second place by 1970. It may take several years for magnesium to exceed its wartime production, but this is sure to come, after which it should enjoy a healthy growth.

More attention should be given to the utilization of some of the more abundant but more intractable metals and near metals. Silicon, a near metal, is used in large quantities as an alloying element in cast iron, steel, aluminum and certain other alloys. It is so abundant that any major structural use to which it can be put will be welcomed from the standpoint of conservation. Powder metallurgy seems called for to solve problems as yet unsolved, to make such uses extensive. Titanium is abundant. Its metallurgy is difficult, but we must try to solve some of these difficult metallurgical problems if the more abundant metals are to come into general use. Calcium is available in unlimited quantities and if some one can find a way to keep it from slowly burning up under ordinary conditions, there is hope for its future use as a structural metal. Zirconium is another metal that is about three times as abundant as copper, but only a small amount of it is used in the metallic state.

The noble and seminoble metals sell at high prices because they are so valuable and so scarce. Books have been written about gold and perhaps wars have been fought over it too. I can provide a sure formula for the quick settlement of the South Pole region—an authentic report that placer deposits and ledges rich in gold have been found there. Fortunately, a high percentage of the noble metals put to use in the past has been or may be recovered for re-use. The world of the future needs these noble metals badly. They, in general, represent the extreme in quality for their special uses. Their future would appear to depend on how much can be produced. Much greater quantities would be used if they could be made available at lower prices.

Among the rarer metals some are important to a much greater extent than either the quantities or prices reflect. Cesium for photoelectric cells, lithium to "solidify" hydrogen, cerium for cigarette lighters and zirconium in photoflash lamps are merely examples. Many new and valuable uses of the rare metals are sure to be found as science marches forward. In fact. it is probable that their field of usefulness has been but barely scratched.

THE ROLE OF TUNGSTEN

It is an amazing fact that one minor metal, tungsten, has played the dominant role in three great industrial advances since the beginning of this century. The first was high-speed steel. Iron was the basis of the alloy but tungsten was the main alloying element. The important contributions of chromium and vanadium to the improved qualities is a splendid example of the value of multiple alloying. Molybdenum can be substituted for part or all of the tungsten, a fact that was taken advantage of during World War II to conserve the tungsten. This possible substitution also makes it certain that the valuable properties of high-speed steel will be available for a very long time.

A prominent mechanical engineer estimated that high-speed steel made possible the production in five days what otherwise would have required six. This significant contribution was achieved with the use of only about $50,000,000 worth of the alloy annually.

The second advance began in 1904 with the substitution of tungsten for carbon in lamp filaments. By the middle of the 1920s the lighting levels had so increased that it would have cost the people of the United States $2,900,000,000 per year extra to have the same amount of light with carbon filament lamps, yet the annual cost of the tungsten to do this was only of the order of $100,000. The saving in cost of light effected by the use of one pound of tungsten was around $300,000.

The third of these great advances was cemented tungsten carbide. Here cobalt or its equivalent in minor quantities was a necessary partner. This material has been with us for only 20 years, but it is now a fairly safe prediction that within the next 10 years it will make possible an increase in production over high-speed steel as great as the latter did over its predecessors. Furthermore, it should do this by using not more than $10,000,000 worth of tungsten per year. Molybdenum cannot be substituted economically for any significant amount of the tungsten in the present state of the art. Small amounts of titanium, tantalum or columbium carbides greatly improve the cemented tungsten carbide, especially for steel turning. This is another example of the value of multiple alloying elements and the great economic value of minor metals.

Many other examples can be cited of the great economic value of some of the minor metals, but if a few thousand tons of tungsten per year can do so much for mankind in a half century, may we not expect unforeseen significant developments among other minor metals in the future?

Quality Need Not Reduce Quantity

These examples prompt me to make another observation. The advent of high-speed steel did not reduce the use of ordinary tool steel. The equivalent of the older tool steel is made in much greater quantities than before. Neither did cemented carbide reduce the tonnage of high-speed steel or its approximate equivalent. We need all these materials—yes, and the new ones that will come—to enrich our industrial civilization.

Of course we all know that we cannot predict the future, but I wish to cite an important development to indicate that at any given time we may even be pointed in the wrong direction. For the first 30 years of this century probably more laboratory work was devoted to the discovery and improvement of lamp filaments than to any other one thing. First came the carbon, then the osmium, then the tantalum filament and finally tungsten. While the many improvements were being made on tungsten there was a persistent and extensive search for metals, nonmetals, alloys, compounds, or anything that would stand up at higher and higher temperatures. In the past this had been the road to a more efficient conversion of electrical energy into light. Paradoxically, the big improvement came by using, not the metal with the highest melting point, but the one with the lowest—mercury. The very efficient fluorescent lamp produces the equivalent of the needed high temperature in the mercury arc instead of in a solid filament.

Although we are now in the quality phase of the metal industry, the quantities are markedly greater than they were before 1925. A greatly increased standard of living masks the more efficient use of metallic products. The figures for the past 10 years also include much metal for war and preparation for war. About all that could be produced was consumed. During the next 10 years the quality phase should gain further ground, but the chaotic state of much of the world casts a cloud of uncertainty on the ability to produce and on the capacity to consume. It now seems probable that the world production of new metal will be less from 1945 through 1949 than in the previous five years.

If it were not for the light-weight metals, it is likely that the ratio of 15 to 1 of pig iron to nonferrous metal would change toward more pig iron within a decade or two. Looking still farther into the future, such a change would be inevitable. This change will be accelerated as the world outside the United States increases its standard of living. If the whole world enjoyed our standard, something like seven times the present metal consumption would be required. Iron and the light metals can keep pace with such expansion but many of the other metals cannot. In the past 60 years the production has increased a little over five times. The time when another sevenfold expansion may obtain is surely a long way off. But at even twice the present production many of the nonferrous metals cannot keep their place. So if we try to anticipate the conditions during the next half century it seems probable that iron and steel will grow faster than the heavy nonferrous metals. The latter, however, will be available in ample quantity to provide a rich industrial economy.

Will the light-weight metals grow as fast as pig iron? I believe they will grow faster. They are adaptable to many uses, and being children of science their expansion will be led by science. Whether the light-weight metal growth will make up or more than make up the probable deficiency in the heavy nonferrous metals, I do not care to hazard a guess. Suffice it to say that the light-weight metal industry is headed for great expansion.

I wish to mention briefly some aspects of the use of metallic elements in nonmetallic products. The amount of metallic aluminum in use is but a handful compared with that contained in nonmetallic products such as brick and cement. But the amount used in nonmetallic products originating from the raw materials and processes incident to the production of metallic aluminum is increasing. In a broad sense, such products may be regarded as part of the aluminum industry. There is so much aluminum that the size of the ceramics industry need not affect the size of the aluminum industry. This is not so with many other metals. Lead and zinc, for example, are used in large quantities in nonmetallic products, such as glass and paint, the materials for which must come from the same relatively exhaustible sources as the metals. The future of these and several other metals for use in metallic products will be proportionately affected by the amounts used in nonmetallics.

You may be wondering why I have so glibly projected the expansion of the metal industry when plastics may come along and steal the business. Plastics will expand greatly. They have replaced metal and they will replace more. The biggest plastic is rubber and its use increases the use of metal, as exemplified by the automobile. Metal replaced wood in the past, but we have a hard time to get enough wood today. We will continue to have severe competition among the available materials. At times one may be the most popular for a given use and at other times another may enjoy first place. Such changes are going on all the time. Metals too will be used in the future where nonmetals are now used. But nothing on a broad front can take the place of metals. The science of metals is keeping pace with other sciences, and since now science is leading art in many instances, the metals relative to other materials should find their competitive place in the future economy. My opinion is that it is toward substantial overall expansion.

Nuclear Fission

The crowning example of the quality phase of metallurgy is the atomic bomb. It is also the best example of an art that has been not only guided but literally created by science. The probable importance of the future of atomic energy has been recognized by giving the subject an important place on the program of this seventy-fifth anniversary meeting. One would nevertheless be guilty of shirking a responsibility if some of the possible impacts of this great achievement on the metals and alloys of the future were not given at least brief consideration.

After all, the two atomic bomb materials, uranium-235 and plutonium, are metals. The source material, uranium, comes from ore deposits, the discovery and commercial working of which constitute part of the field this great Institute was founded to promote.

Although the bomb is the hottest political potato of all time, and as such may have a more important influence on the metals and alloys of the future than anything mentioned earlier or later in this paper, I will proceed on the assumption that our great industrial civilization is not at an end and that the stage will in due time be set for peacetime utilization of atomic energy and its by-products.

The new thing is the discovery that certain atoms can be split in two by bombarding their nuclei with neutrons, resulting not only in the release of a stupendous amount of energy but also in the liberation of more free neutrons. These are the requirements for an atomic chain reaction and so far the only element found in nature that meets these conditions is uranium-235. Natural uranium contains about 0.7 per cent of this isotope. The large plants at Oak Ridge, Tennessee, separated the U-235 from the U-238, thus effecting the separation of one metal isotope from another on an industrial scale for the first time in history. Who can tell to what extent similar separations in connection with other metals may be needed in the future?

The concentrated U-235 cannot be handled like ordinary uranium. When a certain amount, referred to as the critical mass, is exceeded, an uncontrolled chain reaction takes place. This is an atomic bomb.

During the war natural uranium was treated in another way. Piles were made containing uranium and graphite. When a certain amount of these materials arranged in a special way is exceeded, a chain reaction also begins, but this can be controlled by inserting or removing material having a high capacity to absorb neutrons. Such a pile can generate large amounts of heat, which can be removed by a coolant such as water. The heat is generated by the same nuclear change as that in the U-235 bomb. The nuclei are broken in two by neutron bombardment. Each time an atom breaks in two it generates millions of times as much heat as an atom of carbon burning with oxygen. In addition, two or more neutrons are set free at high velocity. In the bomb these new neutrons hit more nuclei and these in turn release still more neutrons, and so on, till the amount of energy released within a given space and time is incomparably greater than man has been able to achieve before.

When a U-235 atom is split in a pile there are 139 U-238 atoms around to each U-235 atom, and some of the released neutrons strike the nuclei of the U-238 atoms. When this occurs the most likely thing to happen is the making of a new kind of nucleus, which by its own radioactivity changes into plutonium. The plutonium can be separated by chemical means from the uranium, making a new material available, which can be used for atomic bombs, but which we ardently hope will be used for other purposes. Thus at Hanford, Washington, a new synthetic metal was made for the first time in history on an industrial scale.

What a strange thing this is! There is no combustion in the pile, yet if 0.1 kilogram of plutonium per day is produced, the heat generated is equivalent to 50,000 to 150,000 kilowatts. The plutonium produced is also a heat generator, a fuel if you will, more potent than man has heretofore dreamed of.

A uranium-graphite pile produces, besides heat and plutonium, direct radiations including strong fluxes of neutrons. It also produces fission products, which are atoms near the middle of the atomic weight scale, representing the units into which the heavier atoms have been split. Some of the fission products are strongly radioactive. By separating fission products, or by using the neutron flux of a pile to bombard other atoms, radioactive isotopes of various elements can be made available in quantities far exceeding those which would be practical by the use of cyclotrons or other known means.

When most of us studied chemistry there were supposed to be only about 90 kinds of atoms. Well, there are 90 from the chemical standpoint—but there are 600 now known with different kinds of nuclei, and more are on the way toward positive identification. Nearly 500 of these are metals. We cannot cope with the problem of nuclear energy without taking into account many of the 600 different kinds of atoms.

The Hanford piles produce from pure uranium a most complex alloy. When a uranium slug has been in a pile long enough to produce the desired concentration of plutonium, it is removed and replaced by a new slug. The removed slug not only contains plutonium but dozens of isotopes of the fission products. The slugs are so radioactive that they must be allowed to stand for a prolonged period before the chemical separation is begun. Even the residual radioactivity after such standing is so great that the operating personnel must carry out the steps by remote control from behind thick radiation shields.

In the nuclear energy plants of the future, new metallic products must be developed to meet the new requirements of construction and operation. In turn, still more new metallic products will be made available for man's use. New techniques will be made available to metallurgists, which can be used to promote both the old and the new arts. By using radioactive tracers and controls, for example, the effects of minute amounts of impurities in metals can be learned, the good can be utilized and the poisons can be eliminated, or made less harmful.

We can speculate without end on the future of this field, but no one knows what is ahead. Metallurgists, however, will not have performed their obligation to their profession until they have given their best toward the solution of the many problems incident to making nucleonics a servant and a benefactor of mankind.

Indicated Trends in Quality Metallurgy

Some of the indicated trends in quality metallurgy are: (1) There will be more efficient utilization of the metals, (2) high-cost metals will be used more in combination with low-cost materials, (3) alloys having long life will be given a high economic rating by designers and users, (4) engineers will be able to analyze the stresses in machines and structures so much better than now that safety factors can be greatly reduced, (5) structures will be built up by forming sheet and plate and joining by welding or furnace brazing to provide light-weight, stiff and strong assemblies, (6) tens of thousands of new combinations of properties will be provided by alloys of the future, each combination serving some particular use better than any other. Some of these combinations will be designed primarily for ease of manufacture and others for better engineering fitness. Some are bound to be volume production items and many others will have but limited use.

We may expect a steady campaign toward greater strength with less weight coupled with high resistance to ordinary corrosive conditions. When the base metal does not have the necessary corrosion resistance, metallic or nonmetallic protective coatings will be called for. We may expect great advances in the effectiveness of such coatings. Better permanent magnets and soft magnetic alloys are reasonable expectations in the not distant future. Our industrial economy can be greatly affected by using higher temperatures in power plants and in chemical processes. The drive for alloys that will stand the stresses and corrosive influences at these high temperatures must not only continue as in the past few years but it must accelerate. There can now be no doubt about the result. Such alloys will be forthcoming.

The fulfillment of these hopes depends in part on the advances in metal science. The universities and colleges are better geared today to give fundamental training in both the physics and chemistry of metals than at any previous time. The body of solid science is accumulating at a rapid rate. The younger generation of metallurgists excels not only in numbers but in knowledge of the tools and methods of research and engineering. Industry is conscious of the need for research as the only way to unlock nature's secrets and thus lay the foundation for their use.

Obviously we cannot realize these possibilities if we put our great industrial machine in a strait jacket and dissipate much of our energy in fighting futile and illogical class wars. Not only is our potential surplus production needed abroad to rehabilitate shattered economies, but even more needed for the sustained hope of millions of people tottering on the brink of political chaos is the shining example, within our power to provide, of freedom with abundance. Putting our house in order at home would give help and encouragement to many war-torn peoples and do more than any other one thing to start the world on the road to peace and plenty. If statesmen can keep pace with science and industry, we are even now on the threshold of a great advance in the metal industry.

Techniques of Mineral Exploitation of the Future

BY LOUIS S. CATES AND HOWLAND BANCROFT

LOUIS SHATTUCK CATES

President of the Phelps Dodge Corporation since 1930, Mr. Cates is one of the leading figures in the world copper industry. He is credited with having made the Phelps Dodge an integrated enterprise for mining, milling, smelting, fabricating and marketing the metal. He has been awarded honorary Doctor's degrees by the Michigan College of Mining and Technology, the University of Arizona, and Columbia University. He was President of the A.I.M.E. in 1946.

WE have come a long way since the order of the day was the chance discovery of mineral deposits; breaking rock with fire and water; melting metals in open fires in holes in the ground or in primitive furnaces; digging pits to collect oil seepages; burning eroded coal outcrops to develop heat, and so on. During the past 5500 years, gradual improvements in methods and equipment have come about; explosives have been developed and used; steel has been used in increasing quantities and effectiveness as its physical and chemical characteristics and composition have been altered and made to serve specific ends; hand equipment has given way to almost completely mechanized operation. Thus, by the aid of mechanical equipment, one person is now able to move several thousand times as much material as one person was able to move a relatively few years ago.

When this Institute was formed 75 years ago, the Suez Canal had been open to traffic but three years. It had taken ten years to complete and was built under the direction of French engineers by workers of whom many were girls. During the first four years of construction, these workers dug up the sand with their fingers, threw it into rush baskets, carried the load a hundred feet or so and dumped it.[2] (With the termination of forced labor, dredgers completed the digging of the channel.) At the present time there is in use in the United

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[2] References are on page 790.

States a power shovel that moves with each scoop some 40 cubic yards of material, or approximately one hundred thousand times as much as the two hands of the Egyptian digger held at the Suez Canal. The 20 to 30-pound loads carried in the Egyptian rush baskets are now to be compared to the loads carried in trains of 100-ton cars!

Inasmuch as steel represents about 90 per cent of all metal used in the United States, it is a fair yardstick by which to gauge the growth of mechanization, largely the result of its use. In 1872, or 75 years ago, less than 200,000 tons of steel was produced in the United States. (Rolled iron production 1,850,000 tons, approximately half of which went into rails.[3]) Recently, the production has reached 90 million tons.

Power represents another yardstick by which to measure mechanization. Since the turn of the century, while the population has increased some 64 million, or somewhat less than doubled, the power developed per inhabitant has nearly quadrupled. Specifically, it has increased from a per capita figure of 40.6 thousand horsepower-hours per annum to 101.23 thousand, or from 4.63 horsepower per person per hour to 11.5 horsepower.* In other words, the power developed in the United States is equivalent to around the clock service of 11.5 horsepower per person.

PART I—METALS

Man is thought to have lived without using metal until about 4000 to 3500 years before Christ when, it is believed, metal was first smelted out of ore. As mankind is generally assumed to have first inhabited the earth some 500,000 years ago, it would appear that man has used metal only about one per cent of the time he has been on earth.[1]

Finding

Geological data still represent the chief criteria in prospecting for and exploring mineral deposits. These data are interpreted by miners and trained mining geologists in the light of their knowledge of known ore bodies. Outcrops, float, geological associations, dumps, vegetation and ancient workings all supply some evidence from which deductions can be made. Aids in prospecting for certain ores are the ultraviolet light, the electroscope, the Geiger-Müller counter, and various geophysical methods of which a combination of the electric and magnetic probably afford the most comprehensive data from which to draw conclusions. The airborne magnetometer, especially when operated from a helicopter, appears to represent the most revolutionary development in geophysical prospecting for mineral deposits. Its many advantages over ground surveys are too nu-

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* From 7.85 quadrillion B.t.u. to 36.07 quadrillion B.t.u. per annum.

merous to mention in this brief summary but attention should be called to the statement that results from a two-hour helicopter survey are said to be equivalent to 108 days of a conventional ground survey.[4] This combination of devices is expected to contribute real aid in finding and exploring mineral deposits in the future.

Exploiting

When gold was panned in California about a century ago, ground containing an ounce of gold to the cubic yard was considered pay dirt. Then the cradle made 1/4-ounce dirt profitable and the sluice box made 1/20-ounce dirt profitable. Hydraulic mining and dredging have made dirt profitable that contains as little as 5 cents to the cubic yard. Dredges are now constructed which will dig 125 feet below the waterline and treat 15,000 cubic yards per twenty-four hours.

HOWLAND BANCROFT
Mining Consultant of broad experience, Mr. Bancroft served for many years in South America, holding important posts for a number of large petroleum-producing companies. Returning to the United States about ten years ago, he has been active in consulting work. He was an Adviser to the Metals Reserve Company during World War II and is an author of numerous articles and reports published by the Government and by technical journals.

In open cuts, pits, and other surface workings, as well as in underground operations, mechanization has improved mining procedure to the extent that increased production per man employed has permitted the mining of many mineralized areas that a few years ago were not considered ore. Improvements in mechanical devices used have still further extended minable areas of marginal material that previously were below the "cutoff," and it is to be expected that in the future improvements in equipment will still further extend the limits of minable material.

Improved mining methods involving the use of diamond drills for drill-hole blasting have added to the efficiency and safety of underground work. Briefly, the conditions favorable for the use of diamond drills and long-hole blasting are in ore bodies of good width with strong regular walls. The advantages of long holes over conventional methods include safety of men, lower costs of development, explosives and labor, more uniform rate of production, improvement in ventilation and fewer dust hazards, fewer skilled men necessary, less oxidation of ore, and so forth. In some properties, long-hole blasting can be used in selected areas only, conventional drilling being necessary in the remaining sections. Recent improvements in drill bits—hard metal cutting edges on smaller bits, and the apparent increase in the range of drill footage, together with the decrease in the size of the rock drills used—make it interesting to speculate upon the application of tungsten carbide bits in percussion drills to the long-hole blasting methods developed by diamond drilling. It appears that under some conditions more footage per drill shift may be drilled with hard metal bits in light jackhammer-type machines mounted on a jumbo than with diamond drills. Factory tests to date on tungsten carbide bits indicate that there is a definite promise of developing percussive drills equipped with such bits to drill holes with a gauge loss of approximately ⅛ inch, or less per 100 feet of hole. Insofar as gauge is concerned, this gives a range of drilling approximating the diamond drill. The life of a well-designed tungsten carbide bit under proper operating conditions is said to approach 80 feet in very hard rock, 250 feet in average rock and 350 feet in soft rock with a loss of ¼ inch in gauge from a 1½-inch bit, the life of which usually exceeds the life of the thread and coupling used to join the bit to the rod.

Many possibilities of mechanization of the drilling and breaking of rock may be forecast by the drilling performance of the new tool. The ability to drill a number of holes with one bit to the full depth of an average heading round suggests the possibility of mounting a number of light drills on a jumbo device and gang-drilling successive quadrants of the heading. The elimination of frequent drill changes, "bit knocking" and other duties of the drill operators indicate a reduction of labor attendance and the replacement of the usual large heading gang by a few skilled operators. The economies of air consumption and drilling speed, and the labor attendance on steel and machines, forecast a reduction in mining cost for this operation. The cost of the bits per foot of hole will equal or be slightly less than the cost of conventional steel.[5]

Mention should be made of fusion-piercing for blast holes. This process is now in a development stage and tests to date indicate that it may be successfully applied in fusing vertical holes through extraordinarily hard rock, and may be useful in surface operations on parts of the iron range or in other localities where the rock to be drilled and blasted is exceedingly hard.[6]

Improved output per man resulting from the utilization of heavier equipment, in many instances especially designed, is illustrated in all of the surface as well as the underground operations of progressive mining companies. For example: At one property, in the last 40 years 4-yard and 6-yard cars have been replaced by 40-yard cars; 3-yard and 4-yard steam shovels have been replaced by 4½ and 5-yard electric shovels, and the capacity in average tons of ore per shovel shift has been increased from 2800 to 6600 tons; spreaders, track shifters, and electric transmission have taken the place of manual labor and steam power. In the same interval the grade of ore mined in this property has decreased by 50 per cent and the quantity treated per day has been multiplied more than 15 times.

At another property during the same interval, the rated production capacity has increased nearly 8 times while the tons per man-shift of ore has increased approximately 45 per cent; 2½ and 4-cubic yard steam shovels have been replaced by 4, 5 and 7-cubic yard electric shovels, and the average tonnage per shovel shift has nearly trebled. The haulage cars on this property were 7 cubic yards capacity and are now 30 cubic yards.

At one of the most modernly equipped properties in the United States, the average tons per operating man-shift has been raised to 119 through the use of improved mining procedures and properly selected heavy mechanical devices. To attain increased tonnage per man-shift or per piece of mechanical equipment, all operations must be synchronized and efficiently conducted, so that there is a minimum of idle time on the part of either men or equipment. For example: At one of the most efficiently run properties the average tons of ore per shovel-shift was increased from 3650 to 4665 with identical shovel and bulldozer equipment, but with electric locomotives instead of steam locomotives and a number of additional 100-ton ore cars, which apparently eliminated loss of shovel time. Effective equipment efficiently used increases output and reduces costs. The same equipment inefficiently used does neither.

In underground operation, scrapers and mobile loaders and wagons, conveyor belts, electric locomotives and various other pieces of specially designed equipment have replaced a great deal of hand labor and permitted the continuous operation of mineralized areas that long since would have been abandoned had the operations remained largely dependent on hand labor. Proposed transportation of ore by air, or by water in pipe lines, may still further simplify and cheapen the movement of ore and mineral products from one place to another.

Beneficiation

Improvements in metallurgical practices and equipment are responsible for an equal share in keeping many mineralized areas in production. A realization of the extent to which smelting procedures have been benefited by improved practices, larger furnaces and mechanization may be gained by recalling that in 1901 more than 200 furnaces and several thousand men were required to produce about 9½ million pounds of copper per month in the largest copper-smelting works then in existence. Batch smelting gradually became antiquated and now reverberatories treat up to 2000 tons per furnace day as compared with 15 or 20 tons in the early '80s. While no attempt will be made to evaluate the real merits of the respective metallurgical improvements, there is no question about the major role that flotation has played in the life of many properties, and the variety of metals and minerals floated continues to increase.

The decade between 1916 and 1926 marked the transition from gravity concentration to flotation, and in the treatment of certain sulphide ores gravity concentration is no longer used in many plants. It is worthy of note that this transition was accompanied by a 50 per cent increase in recovery on sulphide ores treated from two of the largest known copper deposits. Later, the application of selective flotation made possible the making of a high-grade concentrate from almost any sulphide copper ore. This led to the adoption of "wet smelting" and the elimination of blast furnaces and roasters from the copper-smelting industry in the United States. At present, flotation tests are conventional procedure for almost every ore-dressing problem that arises. The frequency with which flotation presents the solution to the problem is worthy of special comment.

Flotation machines have been or can be built to serve in practically any set of operating conditions and the diversity and special applicability of flotation reagents has kept pace with the improvements in the mechanical design of cells. Improvements in design, construction and operation of cells and advances in the use of flotation reagents have been accompanied by an ever-broadening knowledge of the possible utilizations of flotation, and the "know how," so important to the success of any operation, is gradually extending throughout the field of mineral dressing. The natural result of all these factors is a continuous expansion of the applicability of flotation. Large ball mills (10 by 10 feet), capable of grinding 1500 to 2000 tons of ore per day to flotation feed, have helped to increase throughput and reduce costs.

"Sink-float" or "heavy-media" separation of unsized, relatively coarse materials of different gravity has increased the recovery of a number of products over the savings accomplished by conventional methods. Such widely different materials as iron, fluorite and coal have been treated successfully. Doubtless this process will find many further applications in the future.

In the field of gravity concentration perhaps the most revolutionary development since the invention of the shaking table and the application of sink-float is the Humphreys spiral. A great deal has been written about these spirals, and those interested in a detailed description of their construction and function are referred to the references for source material.[7] These spirals have successfully concentrated chromite, rutile, and ilmenite from sands. They are being used to make a preliminary concentrate from a large lead-zinc tailing dump that has existed in an active mining district for years. A relatively small, unenclosed space (80 by 112 feet) is required for an installation capable of treating 5000 tons of material per day; operating labor is reduced to a minimum, three men per shift, and the overall costs are proportionately low. By and large it would appear that the Humphreys spiral may eventually largely replace tables in gravity concentration. Tests indicate also that it has found a place in coal washing, in concentrating iron ores, in recovery of pyrite from flotation tailings and, in fact, in recovering and upgrading any material that can be benefited by low-cost gravity separation.

Future Mineral Exploitation

In a general way we are all acutely aware of the prime part the so-called strategic metals and minerals play in our national defense program. Having this in mind, it seems worth while to outline briefly our national position in regard to a number of these, as their occurrence in the United States may have a real influence on our future security even though the exploitation of some of these deposits may never be undertaken on a peacetime commercial basis.

Aluminum, magnesium, mercury, molybdenum, sulphur, tungsten, and vanadium are available in quantity from known sources, which are or have been in commercial peacetime operation. In addition, there is an almost unlimited quantity of vanadium contained in the phosphate beds of Idaho and Wyoming, and this could be made available at a price. The low-grade chromium deposits in Montana and the Oregon beach sands are capable of producing several hundred thousand tons of chemical-grade chrome per year, and this can be upgraded for metallurgical uses at a price. Manganese, in the form of nodules containing 14 to 20 per cent manganese, can be obtained from an enormous area of manganiferous-bearing shale in South Dakota, but this source probably will not be utilized unless all outside supplies are entirely cut off. As everyone knows, we are entirely without a domestic source of tin and nickel; our production of antimony is very limited and our production of platinum is negligible.

Although steel has held the center of the stage for the past 75 years insofar as industrialized mechanization is concerned, and doubtless will continue to play the leading role for many years to come, as we are engaged in an endeavor to prognosticate some future trends it behooves us to recognize, and attempt to evaluate in some measure, the part the lighter metals may play in the continued growth of our mechanized era. Aluminum and magnesium and their alloys are becoming of vast importance in our industrial development and for many purposes bid fair to become competitive with steel, and to a lesser extent with copper and other metals. As there appears to be an inexhaustible supply of both in and on the earth, and as people are slowly but surely appreciating the fact that much of the equipment and many of the tools they use might be just as effective and considerably more efficient if manufactured of metals lighter than steel, the remainder of this summary on Metals will be devoted to aluminum and magnesium and their alloys.

ALUMINUM*

Aluminum is the most abundant metallic element in the earth's crust. Although it occurs as a constituent of all clays and of most rocks and soils, the only commercial source of the metal is an ore called bauxite, which, geographically, is of fairly wide distribution. Compared with enormous tonnages in foreign countries, our domestic reserves are limited and the bulk of our ores are low-grade. Increased interest in bauxite promoted discovery of large deposits in all continents of the world and with the increasing demand the world production continued to grow until in 1943 it reached an all-time high of over 14 million tons, of which over 6 million tons came from the United States.

Geologically, most of the world's bauxite is of comparatively recent age and, except in many of the European mines, the ore mined is under very little overburden and development has generally been carried forward by open-pit mining methods. Developments in earth-moving equipment and in the art generally of moving large volumes of dirt have greatly increased the stripping limit that formerly was considered the economical maximum. This trend undoubtedly will continue, and deeper and deeper ore bodies will be mined by open-pit methods. At the same time, since a large part of our domestic reserve lies too deep for economical stripping by any method known today, underground mining, thus far of minor importance in Arkansas, probably will have to be resorted to for an ever-growing proportion of our domestic output.

Prior to the war, approximately two thirds of the domestic consumption of bauxite was imported. The bulk of these imports came from Surinam; smaller quantities from British Guiana and Europe. The imported bauxite invariably has been of a higher quality than can now be produced in the United States. Continued imports, probably exceeding the prewar figures in percentage of total consumption, are of utmost importance in the conservation of our fast-dwindling domestic reserves. Figures covering the total domestic reserves of bauxite are not available at this time. During the period of World War II, however, the United States Bureau of Mines carried on an extensive exploration program in Arkansas. As a result, the reserves, as of Jan. 1, 1946, for that state have been estimated by that agency to be nearly 40 million long dry tons, containing 32 per cent or more available alumina. It should be borne in mind that only a relatively small percentage of this total is high-grade bauxite

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* Contributed by Aluminum Company of America and its subsidiaries on request.

and much of the tonnage estimated would be of lower grade than can be employed for many of the various uses. However, it is illuminating to compare the foregoing with the maximum tonnage of bauxite produced in the United States during the war years, which, as previously mentioned, was over 6 million tons in 1943.

Beneficiation of Aluminum

Prior to the war, the tendency on the part of producers throughout the world was to produce the highest grades and the most cheaply mined ore first. However, attempts to improve the quality of run-of-mine ore by beneficiation have been made in this country for many years. As they occur in situ, most bauxites are associated with more or less clay and also are contaminated to a varying degree by iron oxide. The removal of the clay by log washers, wet screening, and rake classifiers has been practiced for many years in the United States, and also in British Guiana and in Surinam for certain deposits whose physical characteristics lent themselves to successful beneficiation by those means. Magnetic and electrostatic methods to remove iron oxide have also been used with some success on certain types of bauxite. Experiments with flotation technique began about 25 years ago and this type of beneficiation has recently received active attention by the United States Bureau of Mines, which published in August 1946 a report of its recent work along this line. Thus the general subject of beneficiation to produce ore of commercial grade from noncommercial material, or further to improve ores already of commercial grade as mined, has already received a great deal of attention. To date, the chief obstacle to greater progress along this line has been the wide variation in physical characteristics and in chemical composition of the bauxite, not only as between different fields or deposits but often within the same deposit, so that a process that works successfully today on a given ore may not work tomorrow nearly so well, or at all perhaps on ore from the same mine. We are still a long way from the development of a beneficiation technique that can be applied successfully to all bauxites.

The problem of how best to make use of our low-grade ores is of utmost importance to the United States, since the great bulk of our reserves, limited as they are, consist of material that would have been considered noncommercial prior to the war. In addition to the attempt at beneficiating the bauxite itself, the aluminum industry has attacked the problem from another angle; namely, the development of processes that can economically and competitively extract alumina from the lower grades of other aluminum-bearing materials such as clay. Parenthetically, it might be mentioned that ways of extracting alumina from clay and some other aluminum-bearing materials have been known for many years, but all of these processes, some of them perhaps scientifically sound, have as yet proved to be commercially impractical. Some of these processes were actually tried on a pilot-plant scale during the war, since military emergency always outweighs commercial considerations. However, it was found that even the most promising of them had the disadvantage of being wasteful of materials such as special steel for equipment and certain chemicals and reagents that also were in critical supply, so that, even as a wartime measure, these processes had their disadvantages.

The most encouraging development in this problem in recent years has been in the appearance of the Alcoa Combination Process which operates in conjunction with the standard Bayer Process. Already an actuality on a laboratory scale at the beginning of the war, this combination was rapidly perfected and two large new plants based upon it were built by the Government, one in Arkansas and the other at Baton Rouge, Louisiana. The process owes its success to its economical recovery of alumina and soda from the waste material (called red mud) produced in the standard Bayer process. The latter, used the world over for producing alumina from high-grade bauxite prior to the war, has been costly and wasteful when used with bauxite containing excessive amounts of silica in the combined form, since this silica unites with soda and alumina, forming a product that was wasted. The new process, by controlled sinter technique, recovers most of the alumina and soda from the Bayer waste. Full development of the combination process proved that it was possible to extract as much alumina from a ton of high-silica bauxite as had previously been extracted by the Bayer process from a ton of standard bauxite, and the resultant product was of quality equal to the standard set by the Bayer process, both chemically and physically. Although the combination process has never been the sole source of alumina for the industry, it has operated commercially and produced alumina of standard quality. The alumina plants at Hurricane Creek, Baton Rouge, Mobile and East St. Louis have a combined capacity of 4,895,000,000 pounds of alumina per year, whereas the economical reduction capacity of the nation can convert but approximately 2½ billion pounds of this alumina into aluminum. As less than 5 per cent of the alumina capacity is devoted to uses of alumina other than making aluminum, this leaves a great deal of room for expansion in reduction-pot lines before they will catch up to the present potential of the bauxite refineries.

Aluminum has many distinct advantages in addition to its light weight, and one of its most important is its strength in alloys. Commercially pure aluminum has a tensile strength of only 13,000 pounds per square inch, but by various methods of cold-working, alloying, and heat-treatment the tensile strength of wrought material may be increased to more than 80,000 pounds per square inch, or well above the strength range of structural steel.

'MAGNESIUM*

In any broad consideration of the future of mineral exploitation, the lightest of all common structural metals, magnesium, is important because of its unusual properties as an engineering metal and because of its abundance and availability. While this second point today means little more than that the metal thereby has commercial status, it assumes increased significance the moment we shift our thinking to the future.

With high-grade iron ores rapidly diminishing, it is of more than passing interest that magnesium is the third most abundant engineering metal in the earth's crust. These sources are widely distributed over the face of the globe, so that nearly every nation has access to one or another of the common forms in which it appears. Its carbonate, oxide and chloride compounds appear most frequently, as dolomite, magnesite, brucite and carnallite. Still more interesting, however, is the fact that, added to these abundant magnesium ores, we have an unlimited supply of the metal in the waters of the oceans and smaller supplies in some concentrated deep-well brines. Every cubic mile of sea water contains recoverable quantities of magnesium in the nature of five million tons. Hence it becomes apparent that whatever may come to pass the world should never be in want for a metal. Magnesium's unusual properties today indicate it for rather special types of uses, yet its metallurgy is advancing to a point that indicates magnesium could fill the requirements for other metals should that need ever arise.

Commercial Production of Magnesium

Commercial production of the metal in this country dates from the first world war, when it was critically needed for flares and other military pyrotechnics and the price was in the neighborhood of $5.00 per pound. While several companies undertook production at that time, only two important processes were employed, the oxide process of American Magnesium Corporation and the chloride process developed by the Dow Chemical Co. The Dow process was economically superior to the extent that in 1927 the American Magnesium Corporation discontinued its production in favor of buying its ingot requirements from Dow. Both companies continued in metallurgical and fabrication research and development and these two alone kept the industry in this country alive between the two world wars.

The Dow sea-water process is an adaptation of the one developed and employed by the company at Midland, Michigan. The chief problem, of course, in utilizing the ocean source was in the extraction of anhydrous magnesium chloride from so dilute a solution as sea water. Magnesium is found in sea water to the extent of approximately 1280 parts per million.

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* Contributed by the Dow Chemical Co. on request.

However, since Dow had already been successful in commercially extracting a mere 67 parts per million of bromine from the same source, it seemed logical that there should be an economic means of obtaining the much more abundant magnesium.

The Dow sea-water plant in Texas was built in 1940, and on Jan. 1, 1941, the first ingot of metal ever taken from sea water on a commercial basis was poured. This plant is today the only commercial magnesium plant operating in the United States.

Other techniques for the production of magnesium have been the object of experiment from time to time, including the electrolytic process utilized by Basic Magnesium Inc. in Nevada. Here again anhydrous magnesium chloride served as the cell feed, but was obtained by mixing calcined magnesite with powdered coal and heating the mixture in an atmosphere of chlorine. The plant, which was the largest in the country from a standpoint of potential capacity, having produced metallic magnesium at the rate of 10 million pounds per month, was closed down before the end of the war and thus far has shown little indication of resuming operations.

Tremendous quantities of power are required in the Dow process and in this direction seems to lie the greatest possibility for a substantial reduction in the cost of ingot magnesium. Natural gas is now used in Texas and is quite economical, but possible future developments, such as low-cost atomic power, would be of great significance in this operation.

The Future of Magnesium

It is difficult to project the future of magnesium as an engineering metal other than by indicating the extent to which it is now growing in importance. Taking 1938 as the last real prewar year, only about 6 million pounds was produced, of which a substantial portion was exported. The remainder consumed in this country went largely into aircraft and industrial uses. In 1946, the first real postwar year, approximately 15 million pounds went into structural uses, of which nearly half was in the field of consumer products. With the war years placed aside, magnesium as an engineering material has had something like a fivefold growth in a single year.

Both industrially and in the field of consumer merchandise a trend toward reduction of weight is increasingly evident. All lines of transportation are now interested in reducing weight of equipment to enable operating economies or increase payloads, and people are just beginning to realize that the common tools and appliances they use daily need not be so heavy.

Magnesium sells at 20½ cents per pound. It is one third lighter than aluminum and one fourth the weight of iron. On a volume basis it is cheaper than any other metal except pig iron. While this volume concept does not entirely work out in direct ratios, it does indicate that ingot magnesium is highly competitive with other raw metals. The difference, then, lies in the spread between the cost of ingot and the cost of sheet, extrusions, castings and other alloy forms.

Mechanically the magnesium industry has been, for the most part, using equipment designed for other metals. Standard lathes, for example, are used in machining even though the properties of the metal permit much higher cutting speeds than the maximum possible on such equipment. Only cold-chamber die-casting equipment is in commercial use, yet the properties of the metal permit hot-chamber techniques.

When such problems as these have been solved, and they are readily capable of solution, the way will be open for a scale of production that might seem fantastic in the light of present figures. The properties of the metal permit notable handling advantages, which are of great significance. The use of the reverberatory furnace for alloying is of such a nature; likewise the fact that molten magnesium can be pumped like water in iron and steel equipment. The use of direct-chill continuous billet-casting equipment is still another. These three relatively recent developments, as coupled together in Dow's alloy plant at Midland, Michigan, effect truly efficient metal production.

Meanwhile the difficulties of fire and corrosion are being overcome. The fire hazard, while still something to be reckoned with, existed much more in public fancy than in reality and is rapidly being dispelled; and the corrosion test work which has been carried on for years on the Atlantic coast in North Carolina is finally beginning to show results. It is proving that the metal is actually more resistant to damaging corrosion than some of our commonly accepted metals. Metallurgical improvements and the development of new and superior finishing techniques are also abating this once-serious problem.

With such difficulties removed, the future of magnesium as an engineering metal appears exceptionally bright. The designer of the future need be concerned only with what the metal can do for him rather than with the difficulties he may encounter in its use. Its unusual properties make it a metal of infinite engineering importance. Its universal availability makes it a metal of infinite economic and social significance.

PART II—COAL*

In considering the exploitation and utilization of coal in relation to the future, an individual would indeed be courageous to attempt to prophesy

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* Submitted by H. F. Hebley, Director of Research, Pittsburgh Coal Co., as a summary of the contributions of the coal staff of the M. A. Hanna Co. to this paper.

the adventures that may befall this unpredictable industry. An endeavor will be made, however, to draw attention to certain facts that may influence the trends of the future.

Among coal's greatest assets are its low cost, its ability to meet many needs, its abundance, and its wide distribution throughout the world. It has been the traditional fuel in centers of population for centuries, but came into general use in the 19th Century with such titans of the industrial age as Watt, Stevenson, and Murdock. The growth of cities dominated by industry was influenced by the availability of convenient thermal energy to fashion the metals and minerals into the shapes and articles useful to man. Nature has been bounteous in her gifts of the coal measures but they have been used with a prodigality that is appalling. Throughout the world, many thoughtful individuals are seriously concerned with the profligate rate at which this heritage is being expended. Man now is living in the machine age and is quite dependent on metals. As pointed out by Dr. P. O. Rosin,[8] "Recent American Statistics show that 90 per cent of all metal—ferrous and non-ferrous—fabricated and used is steel. . . . "

In the broadest sense, the production of steel rests on coal. The extraction of the metal from the ore, the electrical energy required for the processes, the transport of both the raw material and the finished product are all largely dependent on coal. Yet, in spite of all the advances gained in the thermal economy for the various processes, the efficiency of utilization of the total energy contained in the deposits is extremely poor. Eavenson[9] has focused attention on the wasteful extraction of coal in indicating "that from a broad economic viewpoint not more than 50 to 60 per cent of the fuel value is actually being recovered." Lyle[10] has indicated that if the various efficiencies of the different existing applications of thermal energy are placed on a weighted average basis dependent on the size of the various industries, the grand overall efficiency from seam to use is only 15 per cent. Such a poor efficiency must not be construed as a reflection on industry; rather, it is a fact that should arrest the attention of the coal industry and challenge it to develop methods that will appreciably improve the performance.

In addition to the imperative need for devising more efficient methods for the winning and utilization of coal, greater care must be exercised in the application of coals to uses for which they are most suitably fitted. Dr. A. C. Fieldner[11] has indicated the percentages of the total national coal reserves (Table 1). The small percentage of reserves available in the highly desirable low-volatile, low-sulphur bituminous coal is alarming and its most effective utilization should receive more serious consideration.

Although certain encouraging developments in new methods of producing iron have been discovered, it is safe to sav that the blast furnace will still be the dominating factor in iron production for many years, and steel is the backbone of America's security. Because of its highly desirable characteristics in the formation of metallurgical coke, low-volatile coal should be viewed as a special-purpose fuel, and that factor should be kept steadily in mind. It is interesting to note that consideration is being given in the Union of South Africa and in China to the exclusive assignment of metallurgical coal for use in the blast furnace.

TABLE 1—*Coal Reserves of United States*[11]

Class of Coal	Total Reserve in Equivalent Tons of 13,000-B.t.u. Coal, Billions	Year's Supply at Present Rate of Consumption	Percentage of Total Reserves in Equivalent Tons of 13,000-B.t.u. Coal
Anthracite	15	165	0.5
Low-volatile bituminous	56	317	2.5
High-volatile bituminous	1,403	2,024	55.0
Sub-bituminous	598		23.0
Lignite	484		19.0
Total	2,556	2,500	100.0

Exploitation of Coal

Ever since World War I there has been a steady trend toward the use of mechanized and power-operated equipment underground, in an effort to attain a greater production per man employed. Notwithstanding the mechanization that has taken place, the real labor cost per ton has increased because of the dominating item of wages (approximately 65 per cent) in the cost of mining coal. The continual increase in unit labor cost has been a major reason for the steady rise in the price of coal. The present method of mechanized coal production is essentially cyclic, the nonproductive periods in the cycle amounting to approximately 67 per cent. An additional factor that influences the price of coal at destination is the nature of the transportation costs. As pointed out by Dr. D. R. Cowan,[12] "When coal volume expands, there is no decline in coal-transportation charges per ton. Whether 50 tons or 5 million tons are shipped from a given origin to destination, the freight cost per ton is the same." Thus, the influence of labor and freight tend to neutralize coal's inherent advantage as a relatively cheap fuel.

In contrast to this, the two great competitors of solid fuel—oil and natural gas—have steadily reduced the labor item per unit of fuel produced until it is approximately 17 per cent of the total value of the products. Similarly, there have been great advances in the methods of transportation of these two fluid fuels by utilizing long-distance pipe lines. The transportation factor of a pipe line is a function of the velocity and area, and the cross-sectional area varies as the diameter squared, while the amount of steel in the line varies only as the diameter. In addition, the amount of labor required to operate a 30-inch line is not proportionally greater than that required for a 24-inch line. A recent address by Eugene Holman[13] indicated that "the oil industry has made steady progress toward better use of its raw material. These advances have extended supplies and reduced costs. Furthermore, we have learned how to extract more of the oil we find. A few decades ago it was not unusual to recover only about 20 per cent of the oil in a new field. Today we recover as high as 80 per cent."

It is inherently easier to handle a fluid (either liquid or gaseous) than it is a solid. It can be pumped, elevated, dropped, delivered continuously, stored economically, and drawn on as desired. If coal could be so prepared that it could be handled economically in a similar manner, some of the inherent difficulties of a solid would be overcome.

UNDERGROUND GASIFICATION

The gasification and liquefaction of coal has been carried on for a number of years, more notably in Germany and Great Britain than in America. However, American scientists are quite familiar with the Bergius and Fischer Tropsch methods and large-scale plans are rapidly being completed for intensive work on these methods. Also interesting is the new experimental development by the U. S. Bureau of Mines and the Alabama Power Co., whereby coal may be gasified underground. This idea is old, but it was not until the 1930's that experiments were carried out, by the U.S.S.R. More recently, plans have been commenced to carry out other underground gasification experiments in Belgium, for the Belgian Government.

The U. S. Bureau of Mines and the Alabama Power Co. recently commenced an experiment at underground coal gasification at Gorgas, Alabama, in a narrow seam of coal in which openings had been drilled to permit the ignition of the coal, the introduction of air and steam and the withdrawal of gas. The results of this experiment should point the way to further investigations involving the utilization of coal in place.

Another phase of this investigation is the use of steam for the production of water gas. Naturally, the raw gas would be subjected to further treatment aboveground before being placed in storage for use. If successful, the possibilities of applying such a method to the vast deposits of lignite contained in

North America will be vigorously followed. A great deal of encouraging work has already been completed on this phase of the problem. In addition, such a system would permit the exploitation of thin seams—the mining of which under present-day methods is not economically feasible.

A modification of the deliberate manufacture of gas underground is a scheme for the withdrawal of occluded gas from the seam prior to mining. Those engaged in the extraction of coal have long been aware of the wastage of valuable gaseous fuel through the loss of methane given off from the seam during the exploitation of a coal mine. In addition, the emission of such inflammable gases has added immeasurably to the hazards and cost of mining. That the gases might be bled off prior to the actual extraction of the coal has been an intriguing thought for many years. Recently, however, with the development of methods of horizontal drilling, permitting the drill hole to be maintained in the seam for long distances, a renewed effort has been made to revive experimental investigation in the process. The many advantages that would accrue to all concerned, if successful, can hardly be calculated in money. The question of the economics of coal extraction by such a system must be carefully weighed, however, especially when applied to deposits in the U. S. A., where most of the seams being exploited lie at shallow depths. The yield of gas and the construction of pipe lines, when compared with the availability of natural gas from other fields, may discourage the adoption of the system for the present.

COAL-MINING METHODS

There has been developed in Germany, and is being introduced experimentally in Great Britain, what has been called a "coal plough." It has its application to the "longwall method" of coal mining and as such would have little application to present American coal-mining practice, where practically all of the underground operations are laid out on the room-and-pillar system.

The coal plough is an interesting device, however. Briefly, it consists of a cutting head that is hauled along the longwall face in either direction, shearing off a slice of coal 8 to 12 inches thick, according to conditions. The coal so sheared is delivered immediately to a heavy-duty scraper chain conveyor, laid parallel to and close to the face. This conveyor delivers the coal to one end of the face. Special arrangements have been devised for driving the plough and for moving it over toward the face after each slice of coal has been removed. There is a possibility that such a system may be suitable for the working of a soft, well-bedded coal seam associated with reasonably hard floors and roofs.

If orthodox methods of coal extraction are to be retained, economy and safety could be greatly improved if research in roof control were actively pursued and the results applied in practice. It is well known that the fundamental pattern for good mining is set at the working face, where a large percentage of equipment, materials and labor is engaged. Dominating that pattern is the control of the roof. Up to the present, much of the knowledge of roof control has been on the "trial and error" basis. In many cases, faulty methods of control are inherited from the older miners and perpetuated in the industry. In general, however, sound practices have evolved by a process of elimination, but, as may be expected, the solutions vary widely under different conditions and at best are applicable only to a local area of a particular seam. If basic facts in regard to roof control could be established, practical experience and theory could be reconciled to yield more successful methods of extraction. The work of Bucky[14] and Holland,[15] together with the investigations of George S. Rice, of the U. S. Bureau of Mines, all had this fundamental study as a goal. In Great Britain, Phillips,[16] Winstanley,[17] and Hudspeth[16] have carried on excellent work in this regard. Where the roof and floor conditions are uniform, and the effects of other factors are at a minimum, the application of the knowledge derived from these studies have shown distinct promise. With roof conditions that are not uniform, however, such as those encountered in the Pittsburgh seam, influences are encountered that add complications to the work, and may so overshadow the observations made during the research that much of its usefulness is neutralized. Nevertheless, when sufficient investigation has been completed to permit the anticipation of the influence of the tectonic stresses in roof strata, the mining layout and methods may be planned so that greater safety and economy will result.

In the meantime, however, there are indications that some proposed modifications of the usual room-and-pillar system as practiced in the U.S.A. will yield far better results. Briefly, if mobile mechanical equipment can be employed to the utmost, and that equipment can be kept in useful operation a major portion of the shift, the period of time required for the complete extraction of a panel will be kept to a minimum. Thus, the difficulties due to the weighting of the roof on long-standing pillars will be greatly mitigated. In order to achieve these results, a retreating system is employed in which the method of development on retreat is to create pillar blocks directly ahead of pillar extraction. Shuttle cars are used simultaneously, both in the development and the pillar extraction. These operations are kept in sequence at all times, so that both sides of the panel finish together. Panel-belt haulage is developed parallel to the retreating pillar line, thereby keeping all developed blocks equidistant from the "break line," although within the shortest possible range of it. When the pillars are drawn back to this panel haulage, the conveyor is moved to the next haulage panel and the mining procedure is repeated. The rapidity with which this "get in and get out" method is accomplished requires that the haulage conveyor be moved every two weeks. Under such circumstances, good extraction is obtained and difficulties due to roof and "weighting" are reduced.

In localities where conditions favor the extraction of coal by surface mining methods, advantage may be taken of the remarkable developments in equipment for moving and handling earth that have taken place in recent years. A decade ago, a practical ratio of coal-seam thickness to overburden was one inch of coal to twelve inches of earth. Present practice and equipment, with their huge capacities for earth removal, have increased this ratio to one inch of seam to twenty-one inches of earth. Overburden 87 feet thick has been handled. At the present time a mammoth stripping shovel taking 40 cubic yards at each dip has moved about 9,500,000 cubic yards of material in one year. Even now, designs are being studied for the construction of shovels of 50 cubic yards capacity, thus further extending the application of this method of mining to other areas that may become economically suitable.

When handling material on such a stupendous scale, it becomes imperative that a coal-cleaning and preparation plant be installed to fit the coal for the market. Present practice follows the orthodox methods of transporting the raw coal by large-capacity trailer trucks to the cleaning plant and the removal and disposal of the refuse by similar means. Recently, however, consideration has been given to the development of a mobile wet-cleaning unit that would accompany the loading shovel and would clean the coal on the site, allowing only clean coal to be taken from the pit. The refuse will be discharged directly to the spoil bank. Although this system is being developed only on a small scale, it may well contain a solution somewhat akin to the large gold dredges of California, by which the raw material is mined and washed to recover the valuable product, and the tailings are discarded to the bank as the equipment travels along the site.

COAL CLEANING

Great strides have been made in the development of coal-cleaning equipment, using heavy-density media for the separation of refuse from the raw coal feed in order to prepare it for the market. Of course, the system of using finely ground media mixed with water to yield a liquid of high density has been used for a number of years. The Chance cone is an excellent example of this principle. More recently, however, the Loess and the Barvoys systems have found favor, especially in Europe. Here in America, heavy-density pilot plants have been erected, and tests have been made using a new heavy-density application of ground magnetite or ferrosilicon as a medium. One of the ingenious features of this system is contained in the method utilized in the cleansing of the finely ground solids composing the medium from the contaminants with which it has become associated during the coal-cleaning process. As the magnetite is magnetic, the process passes the polluted medium over a magnetic separator, which effectively selects the particles of magnetite from its accompanying impurities composed of clay and shale. In so doing, however, each particle of the medium becomes highly magnetized, which effectively prevents the maintenance of a uniformly dense fluid for use as a separating fluid in the coal-cleaning vessel. This drawback is cleverly overcome by pumping the cleaned but magnetized material through a pipe encircled by a demagnetizsng coil, similar in action to the "degaussing belts" placed around ships during the war. The medium is then ready for further use.

Transport and Handling

It is little realized outside the coal industry how stupendous is the task of transporting coal to the market. In tonnage, it exceeds any other single commodity, and the gigantic handling facilities at transfer points from train to ship to dock must be seen to be appreciated. As an illustration, a few salient facts regarding the Pennsylvania Railroad's car unloader at Sandusky Docks on Lake Erie may be of interest. The problem is to unload railroad cars loaded with coal with utmost dispatch and with a minimum of breakage. The car unloader is designed to unload cars to the ships' holds at the rate of one car per minute. The maximum size of car that can be handled has a capacity of 120 tons, although at the present time the average load per car is approximately 66 tons. In order to keep this giant in operation at its rapid rate, 6 miles of railroad storage tracks are available on a specially constructed dock. These tracks are sufficient to handle 350 loaded cars and 200 empties, or a total of 550. As a further safety factor, there are other concentration yards in the vicinity yielding a total capacity of 7800 cars.

The whole loading cycle is carried out electrically, and the adoption of the Ward Leonard system of control ensures extreme flexibility, which is so vital to the efficient operation of the equipment.

Utilization and Research

However, it is to research that the future of coal must be anchored. As in the oil industry, the greater the number of products that can be obtained from coal, the greater will be the diversity of demand, with its tendency to dampen the fluctuations in production. Nevertheless, for many years to come, the primary use will be as a source of thermal energy. There are many who are willing to spell the doom of Old King Coal; but it is encouraging to note the comprehensive research programs for the more efficient use of coal as a source of heat. Changed methods of utilization of solid fuel may have a great influence on the method of extraction. Taking the steam locomotive as an example, according to Lyle[10] the efficiency of the usual road engine is less than 5 per cent when considered from seam to the drawbar. The present locomotive boiler of the fire-tube type, with its inherent difficulties of design and restricted grate area, has reached the approximate limit of operating conditions with 300 pounds per square inch and 750°F. total steam temperature. In order to create the necessary draft for the rapid coal-burning rates required, the exhaust pressure from the cylinders is about 15 pounds per square inch at full load. Developing a boiler of the water-tube type will permit the operating conditions to be raised to 600 to 800 pounds per square inch, and a total steam temperature of 900° to 925°F. Such conditions are extremely favorable for a noncondensing turbine with approximately 5 pounds per square inch back pressure, although it may be necessary to adopt independent forced draft to attain the necessary burning rates.

According to C. Kerr, Jr.,[18] the Class S-2 Pennsylvania steam-turbine locomotive, with gearing operating the drivers, was delivered late in 1944, and has completed more than 50,000 miles of revenue service. Its entire propulsion equipment, which develops 6900 shaft-horsepower, weighs less than 6 pounds per horsepower, which is about the lowest weight-to-power ratio ever attained in propulsion equipment for traction purposes. In addition, the Chesapeake and Ohio Railroad is introducing a steam-turbo electric locomotive using the principles that have proved so satisfactory in marine propulsion. With the higher efficiencies attained, there is every chance that coal will continue as the source of energy.

Now that the designers can avail themselves of the metallurgical research developments born of war demands, the possibility of a gas turbolocomotive using pulverized coal is not at all fantastic. As a matter of fact, the Swiss Government Railways have been testing an oil-fired design for many months. Research work on this project is being pressed with the utmost dispatch at a number of institutions at the present time. It is hoped that the efficiencies attained will approach those of the diesel electric locomotive and that the dollar economy will exceed it.

Conclusion

So it can be seen that coal, in spite of the many economic and labor ills of the past, and the probable experience of further vicissitudes in the future, can be confidently expected to continue to supply the bulk of America's thermal energy. With the help of the extensive research programs in progress coal will be the source on which our industrial economy and our national preparedness will be secured.

PART III—PETROLEUM*

Discovery

Petroleum has been known since prehistoric time, but the petroleum industry was conceived in the chemist's laboratory where it was demonstrated that mineral oil could be split into fractions and could be used for illumination and lubrication instead of whale oil, coal oil and vegetable oil. The industry was born when Drake, in 1859, demonstrated that petroleum in quantity could be secured from wells drilled into the earth.

The pioneers depended on surface manifestations of petroleum or associated substances, such as oil and gas seepages, escapes of saline or sulphurous waters, or tar sands to guide their explorations. The geological control of oil accumulations had been recognized by T. Sterry Hunt in Canada only two years after Drake's discovery, but about fifty years elapsed before it was generally recognized by the oil operators that geologists could improve their chances of finding oil pools.

At first the geologists concentrated on the task of mapping the exposed rocks to find anticlinal structure. Soon this was supplemented by study of the subsurface conditions revealed by wells. Their work was excellent but their tools were inadequate. In particular they lacked dependable information concerning the concealed strata. They soon realized that the rocks penetrated by the drill must be identified with precision. Paleontologists became important members of geologic staffs and micropaleontology developed rapidly.

The microfossils—so small that many can occur in a tiny rock fragment, so abundant that they may be found in many strata where larger forms are not identifiable, and so diagnostic that they indicate with reasonable certainty the age of the rock—were ideally suited to the needs of the petroleum geologist. Microscopic identification of heavy minerals and of insoluble residues in carbonate rocks was also used to correlate and determine the origins of strata.

The introduction of the automobile increased the area that could be covered by the geologist and the quantity and size of equipment he could carry. With it came road development. Man-made exposures in roadside cuts were responsible for the discovery of important oil fields. The development of machinery for making those cuts provided another important

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* **Submitted by K. C. Heald, Vice President, Gulf Oil Corporation, as a summary of the contributions of the staff of the Gulf to this paper.**

geologic tool—the bulldozer. The core drill was used to supplement surface observations. Today self-propelled drills develop information from depths of 2000 feet or more. Correlation by use of electric logs reduces actual coring to a minimum. The airplane now lifts the geologists to elevations of thousands of feet to recognize structural and stratigraphic conditions that otherwise could be determined only by extended effort. On airplane photographs he recognizes land forms and interprets them in terms of stratigraphy and structure.

ROLE OF GEOPHYSICS

Remarkable improvement in geologic work followed the development of geophysical well-logging methods. The first and most important of these was the electric log, which is now supplemented by the gamma ray and neutron logs. With these devices lithologic units may be identified and traced from well to well with extraordinary accuracy. Under favorable conditions they also indicate strata most likely to contain oil. Finally, there are the geophysical surveys, now indispensable, although it was only in 1924 that they became a part of the oil industry's exploration activity. In that year the Nash dome, in the Gulf Coast of Texas, was discovered by means of the torsion balance, and the Orchard dome, also in the Texas Gulf Coast, by means of the refraction seismograph. These were the first discoveries made by geophysical methods. The speed and economy with which they were made were spectacular and geophysical departments and geophysical contractors soon appeared in numbers and enjoyed a robust growth.

Since we are celebrating its anniversary, it is appropriate to recall that the A.I.M.E. provided the first forum for the geophysicists. Its 1929 volume, "Geophysical Prospecting," was the first of its kind. Although subsequently other professional organizations entered this field, notably the Society of Exploration Geophysicists, the A.I.M.E. has continued its activity and is today recognized as providing the outstanding forum in the field of mining geophysics.

It is not a mere coincidence that during the 15-year period following the first application of geophysics to oil prospecting the backbone of our present U. S. reserves was discovered. During this period discoveries exceeded production by more than 11½ billion barrels, more than half of our present reserves. During these 15 years the oil industry in the United States produced nearly twice as much oil as in all of its preceding history and accumulated the larger part of its present reserves. In 1925, the reserves were about ten times the annual production; today, the factor is about twelve.

This might seem to indicate that the oil industry has its raw-material problem well in hand, but there is another side of the question. During the past five years the industry in the United States has doubled its expenditure rate for geophysical exploration, with results barely equaling the average for the past 20 years. In view of the rising trend of demand and production, this is not a comfortable position. To a country that provides about 66 per cent of world production while containing within its borders only about 40 per cent of known world oil reserves, this poses a serious question.

The United States undoubtedly has been prospecting for oil more intensively than any other comparable area in the world. Where geophysical techniques have been used extensively, the oil fields most easily and most cheaply found are, for the most part, now in production. The areas that remain unexplored have been regarded as unprospective, too difficult to work, or as possessing other economic handicaps. There is little doubt that substantial quantities of new oil remain to be found in the United States, but it is more certain that the average finding cost will be high compared with past standards.

The earliest geophysical discoveries were made by means of the gravity and the seismic methods. Although there have been changes in their techniques and in their instruments, these, together with the magnetic method, remain the basic tools of the petroleum geophysicist. There appears to be no present prospect that this basic trio will be displaced or rivaled by new methods. A great deal of effort is being devoted to the improvement of the basic methods, but the changes to be anticipated are more likely to be evolutionary than revolutionary.

An account of even the principal developments that have transformed the geophysical art of 20 years ago into that of today would fill many pages. Only a few will be mentioned here. The torsion balance, which was the mainstay of these who used a gravity method in the early days, has almost become obsolete. The gravity pendulum, which found transitory use, is in the same category. Both have been succeeded by the gravimeter, or gravity meter, which is available in numerous, substantially equivalent, forms. The best gravimeters in use today can do adequately about everything that is known to be useful in prospecting for oil by gravity methods.

Probably the outstanding development in geophysical prospecting in recent years is the airborne magnetometer. It provides a continuous record of the total magnetic intensity along the path flown by the plane. The quality of the magnetic record is as good as or better than that of the corresponding data obtained on the ground. One hundred and fifty miles or more of magnetic profile can be secured in one hour's flying time. Profiles may be flown, if desired, at several different heights, so the geophysicist now has a third dimension at his disposal.

DRILLING, TESTING AND COMPLETING TECHNIQUES

The changes in drilling, testing and completing techniques share with geology and geophysics the credit for the discoveries that have met our needs during past years. The most important of these improvements was the development of the rotary drill. Without it this nation would, long since, have starved for oil. With it, wells can test geologic conditions and depths that would defeat percussion tools. Core barrels developed for use with the rotary drill provide information indispensable to modern petroleum engineering. As an aid to discovery, the core barrel has been supplemented by devices for securing samples from the walls of holes. It now is possible to drill a well, run an electric log to locate the most promising strata, and take side-wall samples to learn whether or not oil is present. If desirable, the productive capacity of selected strata can then be determined with a drill-stem tester before the hole is cased. A very important development is the gun-perforator, which will shoot bullets through steel casing, through cement between casing and rock, and into the rock itself. The operator may now drill to any desired and attainable depth, determine the positions of prospective oil-yielding horizons, set pipe to the bottom of the hole, cementing it from bottom to a point above the shallowest stratum he desires to test, and then perforate the casing opposite horizons he wishes to bring into production.

In the beginning, adequate supplies of petroleum were discovered by drilling comparatively shallow wells at random. The parts of the United States in which oil may reasonably be expected to occur at a depth of 3000 feet or less, have, for the most part, been so intensively explored by drilling that new pools of important magnitude at shallow depths are not anticipated. Drilling to great depths on locations selected at random is not to be considered. The cost of finding petroleum by such a program would exceed that of supplying the nation's need through the manufacture of synthetic oil from coal and shale.

FUTURE SUPPLIES

Within the general environments of the oil-yielding parts of the nation there are few local situations of obvious geological merit that have not been drilled on all of these to the deepest possible producing horizon, but it seems safe to predict that further prospecting on well-defined traps that have been revealed by past geological or geophysical work will discover far too little oil to compensate for the declining production of existing fields, to say nothing of meeting increased demands that may be in prospect.

We must place our dependence on the hope that some of the areas that thus far have yielded little oil or no oil will prove to be richly productive;

on the ability of our geologists and geophysicists to discover fields that have thus far escaped detection in the regions that have already been proved to be oil-bearing; and on our technologists to develop methods for drilling and completing wells at depths greater than have thus far been generally practicable, either because of the capacity of the available equipment or because of high cost.

There are extensive unproductive or slightly productive areas in the United States where the formations are at least superficially similar to those in productive areas. It must be conceded that important new fields may be discovered in all such regions. Some exploratory drilling has been done in practically all these areas, and many of the exploratory wells have tested conditions that, from the geological standpoint, were perfectly suited to cause oil to accumulate if oil was present. The failure of such tests indicate that oil either is absent or that geological relationships that are not now known must be recognized before good locations for exploratory drilling can consistently be selected. Indeed, one of the reasons why most of these extensive areas are not now either productive or condemned is that important discoveries were not made by such wells as have been drilled, and geological study of exposed formations did not reveal situations that obviously were more promising than the places that had been tested without success. On the hopeful side, it is true that many of these little-explored areas have not been worked by geophysical methods, and such work may reveal favorable conditions that were not indicated, or at least were not detected, by geological study of exposed formations.

The manpower and the money required to find new fields has steadily increased. This trend probably will continue. However, there are important and underdeveloped facets of geology which should add to the resources of the geologist; also, it is inconceivable that a youthful science, such as applied geophysics, has reached the peak of its development. Even if science should not expand, improved organization of exploration activities and coordination of geological and geophysical evidence should convert many interesting possibilities into promising probabilities. The greatest deterrent to deep exploration, to the testing of prospects of uncertain promise and to drilling holes primarily to secure geological information, is cost. This means that the greatest possible aid to discovery would be the development of a drill that would bore deeper, faster and more cheaply than will existing tools. A substantial reduction in drilling costs would be reflected in increased discovery.* [In this connection it is interesting to speculate on the possible effects improvements in "turbine rotary drills" or other types of drills receiving the driving power at the bottom of the drill stem might bring about. If any of

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* Gulf Oil Corporation not responsible for remarks between brackets.

these types are perfected, a substantial decrease in drilling costs should follow if the formations penetrated do not tend to cave.]

Exploiting

With the discovery of an oil pool the finding phase is concluded and the exploiting phase begins. Exploiting covers that group of operations by which petroleum is extracted from the earth and delivered to the refinery.

The early drillers used cable tools, and in 1945 about 33 per cent of the wells were drilled by this method. However, in regions where formations are soft, water sands numerous, or where great depths must be reached, the rotary drilling method is used. Periodically, these tools set new depth records —the deepest hole in this country was bottomed below 16,600 feet—and strength and design of equipment has steadily improved to permit these results.

To penetrate hard formations, rotaries are equipped with rock bits of special design. Alloys impart strength, hardness and resistance, not only to these rock bits but to many items of oil-field equipment. The addition of silicon to steel has increased the strength of derricks and beams by 38 per cent. Sucker rods made of nickel-molybdenum and nickel-chromium steels have great strength, ductility and corrosion resistance. The strength of pipe of the same wall thickness has been doubled by the use of manganese. Hard-surfacing materials, particularly tungsten carbide and cobalt-chromium-tungsten alloy, have increased the service of bits, sprockets and tool joints.

The drilling fluid originally was any mud that was easily available, but it is now controlled by "mud engineers," who add materials in the proper proportions to secure desired properties of weight, viscosity, gel strength, salinity and low water loss. Equipment and personnel to maintain continuous mud control are parts of every well-conducted drilling operation.

The holes are cased with pipe about twice as strong as pipe of the same dimensions in use 25 years ago. Seamless and electrically welded pipe of improved steels have easily resisted the pressures encountered at great depths. To reinforce and protect the well casing from corrosive agents and to prevent the migration of fluids behind it, cement is placed between it and the walls of the hole. Special equipment for cementing and special cements have been developed and companies with trained personnel have been established to perform this service.

About 20 years ago it was discovered that many wells drilled with the rotary deviated from vertical. Instruments were developed for surveying these holes and surveys are now made at regular intervals as the wells are drilled. The deviation was due to excessive weight on the bit, and weight indicators now permit the driller to control this weight. Finally, tools were designed that permit purposeful deviation of the hole in any desired direction to penetrate a predetermined "target."

Drilling operations are conducted over water as well as over land. In water 18 feet deep or less, they may be drilled from barges that support derrick and machinery. The barges are partially submerged to rest solidly on bottom. When the well is finished they are raised and floated to a new location where drilling can begin with a minimum of delay. In deeper water wells are drilled from platforms resting on piling. By drilling deviated holes, four or five wells may be completed from a single foundation.

[In water more than 60 feet deep hollow concrete caissons, sometimes 185 feet long, have been used successfully to support drilling platforms. An excellent description of prefabricated caisson foundations for submarine oil wells appeared in *Engineering News-Record*, Dec. 26, 1946, pp. 859 to 867. A portable "seadrome type" offshore drilling rig, described by E. A. Armstrong in the *Oil Weekly* of Jan. 27, 1947, designed to drill in water from "20 to 200 feet," is one of several methods proposed to solve deep-water offshore drilling. J. E. Kastrop, in the Feb. 3, 1947 issue of the same publication, in an article entitled Drilling Rigs Are Going to Sea, briefly discusses other deep-water drilling methods designated as The Kirby Marine Tower, the Robert's Method, the Shrewsbury Drilling Column, and the Fairlead Method of underwater drilling.]*

MODERN METHODS

Completion methods now permit a well to be equipped with two strings of tubing and completed in three separate strata, each yielding its oil independently through tubing or annular space, so that one well has the productive capacity of three wells, each completed in a separate zone.

Production may be stimulated by shattering the reservoir rock with blasting gelatin, or, if the rock is a limestone, it may be treated with acid to increase permeability close to the well bore. Such treatments may convert small wells into excellent producers.* [It will be interesting to learn the results of commercial-scale tests on the use of bacteria to release oil from oil-bearing sediments, a procedure demonstrated as feasible by laboratory experiments.] For many years the trend has been toward wider spacing of oil and gas wells. Spacing now is recognized as an economic problem. In some states regulations aimed at preventing too close rather than too wide spacing have been passed.

About 14 years ago, production technology began to include existing knowledge concerning the state, relationships and movements of gas and fluid in the underground reservoirs. The knowledge, and with it the ability to recover oil and gas from the reservoir, has steadily increased. Conservation

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* **Gulf Oil Corporation not responsible for remarks between brackets.**

and use of reservoir energy have extended the period during which wells will flow with resulting maintenance of yield and lowering of cost. Today about 11 per cent of the wells in this country flow, and they yield about 50 per cent of the production. Many fields that could no longer be operated profitably by conventional methods have been rejuvenated by secondary recovery. This is defined as any method employed to produce oil or gas through the joint use of two or more well bores by the injection of liquid or gases into the reservoir for the purpose of augmenting reservoir energy. These procedures are also applied to young fields to prolong the flowing lives of the wells or to permit maximum recovery from reservoirs in which much or all of the oil is in vapor phase. In vapor-phase fields, reservoir pressure must be maintained if the oil is not to condense and adhere to the porous rocks of the reservoir. The maximum efficient rate at which the wells in any field should be allowed to yield oil can be determined. If this rate is exceeded, the ultimate recovery from the field will be reduced or ultimate cost of recovery will be increased. At present most of the fields of this country are believed to be producing at approximately their maximum efficient rates, which means that the margin between the demand and the capacity to produce is narrow. Improved technology may improve the situation somewhat but the only real insurance is more fields.

PRODUCTION

The daily average production of crude oil in the United States in 1945 was 4,690,000 barrels. At the end of the year, 423,948 wells were producing and the daily average production per well was 11.1 barrels. It is estimated that one half of the total daily production comes from the 88 per cent of the wells, which are produced by artificial lift. In the United States 26,879 wells were drilled in 1945, the largest number since 1941. Excluding the service wells, 60 per cent were oil wells, 11.7 per cent gas wells, and 30.3 per cent dry holes.

Prior to 1946, the highest daily average production for one month, 4,890,000 barrels, occurred in July 1945, just before the termination of the Japanese war, when wartime requirements reached their peak. The daily average production for July 1946 was 4,922,000 barrels, and it is estimated that the daily average for 1946 will exceed that for 1945 by at least 60,000 barrels. The daily average production in the United States increased from 3,697,000 barrels in 1940 to 4,690,000 in 1945, and one authority estimates that in 1948 the daily average will be 5,550,000 barrels. This production trend assumes a special significance when viewed in relation to world production, consumption and reserves. Since 1860 the United States has consistently produced more than 60 per cent of world production and for years has consumed nearly all it produced; so its consumption has been over 60 per cent of the world consumption. In 1926 the reserves of the United States were estimated to be 70 per cent of the *known* world reserves; but since the large reserves have been discovered in South America and the Middle East, the United States' part of the known world reserves has been reduced to 39 per cent.

According to the Petroleum Administration for War, in early 1941 the maximum efficient rate (MER) exceeded production by 1,000,000 barrels per day, but in July 1945 production exceeded MER by 300,000 barrels per day. The margin between demand and total capacity was small. The demand has increased and no large discovery has been made; therefore, the margin is still small, in spite of the fact that the industry has drilled more than 260,000 wells in the past 10 years, or 9½ times as many as have been drilled in the East Texas field.

STEADY IMPROVEMENT

Transportation of petroleum has kept pace with improved methods of discovery and recovery. The first pipe line was 2 inches in diameter, the largest today is 24 inches. Stronger pipe of less weight, cathodic protection against corrosion, and machine methods for trenching, stringing, laying, welding and wrapping the pipe have all contributed to improvement. Tank cars for rail shipments have increased in size and number. Barges for movement in rivers and coastal waters moved about 1,500,000 barrels per day in 1945. Tank ships have grown from midgets, which carried 9000 barrels at a speed of 10½ knots, to giants that plow along at 18 knots with a cargo of 200,000 barrels.

The story of exploitation has been one of steady improvement of materials and equipment by the industries that supply the oil fields, spurred and stimulated by the operators and engineers who recognized weaknesses and needs for improvement. It is a story of adaptation of engineering to meet special conditions, and of the use of basic principles of physics and chemistry to permit understanding of those conditions. There is no doubt that there will be further improvement of tools, methods and understanding. The limits to which engineering may be applied to exploitation with resulting improvement in recovery and lowering of cost, have not been approached.

Trends for the Future

Following the explosion of the first atomic bomb, there was a wild wave of speculation as to the effect this new-won source of energy would have on existing sources of energy, petroleum products included. However, the facts now available do not justify the assumption that atomic power will be a competitor of gasoline or diesel oils for propulsion of automotive equipment in the foreseeable future. Nor does it seem to offer a serious threat to fuel oil, which is largely used by railroads, steamships, and a host of small users. That it could decrease the use of lubricants is inconceivable. The talk of utilizing atomic power generally veers to discussion of large power stations where necessary safety provisions can be installed without rendering the use of atomic energy impracticable. Of course, knowledge of the utilization of atomic power is still in its infancy and many new discoveries will be made, but it is so difficult to imagine atomic power competing with petroleum products within the next 20 to 30 years that the possibility certainly should not influence our planning for better production and utilization of petroleum products.

The aviation industry has been experimenting on a large scale with jet engines, and for most of these has been utilizing a special natural naphtha for fuel. The quantity of this type of naphtha the refiners can at present produce is limited, a fact that jet-engine designers should bear in mind if they look ahead to the eventual replacement of the present type of engines by jets. However, as jet engines come into greater use, the refiners doubtless will find a way to supply them with a satisfactory fuel, though some compromises with the jet-engine designers may be necessary.

The use of diesel engines for automotive power will increase in the future, as their economies, for certain types of service, are attractive. At present, diesel fuels of high cetane number are produced by straight distillation from selected crudes. Supplies from this source are ample for the present demand at the existing cetane-number levels. In the future, the demand will be increased and cetane-number levels are expected to rise, so the refiner may be faced with the necessity of installing equipment, or possibly finding additives, to solve this problem.

In its earliest days, the refining business was a crude art. Today, with the vast amount of research going on, and the application of scientific principles to the refining of the crude, it can be considered a science. Advances in instrumentation have eliminated many of the trial and error methods of operation, and availability of many special alloys has allowed the refiner to use the most favorable conditions in his operations. The metallurgists have provided alloys to overcome difficulties that once seemed insurmountable. Physics and physical chemistry have provided knowledge concerning molecular structure and the behavior of molecules that has permitted the development of new processes and new products.

Summing up, the refining industry can look forward to the installation of large units, more catalytic and solvent refining equipment and entry in a large way into many branches of the chemical business. The basic sciences are far from completely developed, and until such complete development is achieved, the applied sciences, such as petroleum refining, may be expected to advance. Startling changes are possible. Consistent improvement of existing processes and procedures is certain.

Acknowledgments

Thanks are gratefully expressed to those in the mineral industry who have given generously and freely of their time and knowledge and without whose cooperative assistance it would have been difficult, if not impossible, to gather and assemble the varied data that appear in this paper. It is a tribute to them that the spontaneity and high quality of their several endeavors have made the compilation of this paper a pleasure sincerely appreciated by the authors. Unfortunately, limitations of space preclude the incorporation of several excellent contributions submitted at our request by authorities in their respective industries.

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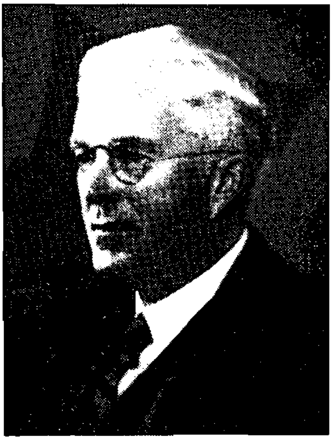
Seventy-five Years of Progress

Seventy-five Years of Progress in Mining Geology

BY L. C. GRATON

Civilization did not begin until metals became the material of tools, implements and machines.—RICKARD, *Man and Metals.*



L. C. GRATON

Professor of Mining Geology at Harvard University since 1912, Dr. Graton is a recognized authority on the principles of ore deposition and the development of geologic art as it relates to metalliferous ores. Various important corporations have engaged his services as consulting geologist; and he is the author of reports on the geology of mining districts in many parts of the world and of articles dealing with geologic subjects of national and international significance.

HISTORY is no more an end in itself than is a backsight the sum total of a survey. This Institute may view with satisfaction the remarkable development of the mineral industry since its founding three score and fifteen years ago, its own enlarging service to that industry, and the contribution thus made toward the enhanced welfare, opportunity and mutual understanding now in greater or less degree reaching and benefiting all peoples of the globe. But neither this professional society nor the dynamic mining industry as a whole wishes on this anniversary to direct its gaze chiefly toward the past. The foremost purpose of historical review should be to throw into clear perspective the strong points and the defects in the forward march thus far, primarily as the basis for conceiving and designing a still sounder progress henceonward.

At various times since the Institute's founding, the *theories* of ore deposition have been considered from the historical viewpoint.[1–7] For the present occasion it seems fitting to lay prime emphasis on the *practice and utilization* of geology in its varied relations to the problems of the mining industry.

It is hoped that the reader will understand and accept the degree to which the whole is sampled by parts familiar to the present writer, and the disproportionate attention to thought and achievement within the United

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[1] References are on page 38.

States. Draughts have freely been made on the unwritten experience and conclusions of generous fellow workers, not only through direct appeal for the present purpose but acquired also in the course of numberless informal discussions during past years in diverse lands. Because of the many from whom the present article has thus gained, it is hoped that this collective acknowledgment will be accepted as assurance of the writer's grateful appreciation.

Geology the Offspring of Mining

Mining evolved from that blend of curiosity and self-interest that drove early man to seek and win selected components of the solid earth. Even in its primitive stages, the immediate problems of operation came to be attended by more subtle but no less important queries regarding these concentrations of useful metalliferous substances: *where? how?*—questions that lie at the very core of geologic genesis. About the middle of the sixteenth century the true complexity of the mining art became so manifest that its various subdivisions began to acquire entity. This was especially true in the already long-famous mining districts of Saxony, then the chief metal-producing center of the world. In the initial paragraph of his best known work, Agricola, a resident of that region, recites the wide range of qualifications of "the miner"; and first among the requirements are listed: knowledge of where prospecting is profitable and where futile, understanding of the veins, stringers and seams, and thorough familiarity with the rocks and minerals, the mineral-bearing solutions and their deposits. Thus in very truth was Geology sired by Mining.

More than one chronicler has implied that for a long period after publication of Agricola's seven large works interest languished in the geological aspects of ore occurrence, and even in geology generally. The truth is that Agricola was far ahead of his time. His explicit observations and rational conclusions, when once on record, undoubtedly discouraged much of the prior kind of superficial and speculative writings. But in the mines as well as in the broader aspects of the science, Agricola's views exerted a dominating and constructive influence on geological thought and method for two centuries.

With the eighteenth century began the establishment of the famous mining schools among the mining districts of Central Europe. The earliest, 1702, in the Saxon Erzgebirge, was reorganized in 1765 to become the renowned Freiberg Mining Academy. This close interrelation of mines and schools powerfully affected the development of all the major branches of the art. As will later appear, the course of geology, and particularly of mining geology, in the United States was profoundly influenced by the teachings and experience brought back from these European sources during the third quarter of the last century.

Geology still finds the mines to afford a most fruitful soil for its further growth—and more and more is the dependence becoming reciprocal, as progressive exhaustion of the world's ores requires specialized new talents and techniques for the finding of further supplies.

General Background Preceding 1871

Save for lingering imperfections here and there, the face of the earth could be regarded as known at 1871. The successive waves of exploration since the fourteenth century B.C. and the ensuing colonization and development that had yielded this geographical knowledge were actuated by a common aim—riches; and among these the metals were predominant.

METAL DISCOVERY AND PRODUCTION

Of the countless districts that had yielded metals to man during the five or six millennia of his use of them, surely a great number had left no memory behind. Others, like Ophir, had retained little more than a name. Only a very few continued known and productive on a scale proportionate to mid-nineteenth century needs. Most of the exploitable occurrences of metal to the end of the Medieval Era had been found wholly by chance; and the regions of the Old World that had long been inhabited by civilized races were not, at that time, replacing their exhausting mines by discovery of others. Even for the grander cycle of metal production that had opened with rapid exploration of the New World, it must not be forgotten that very important fractions came from long-accumulated stores in treasuries, temples and tombs of the natives whom the *conquistadores* subjugated and plundered. And most of the "discoveries" of actual mining places rested on the information freely proffered or forcefully wrung from the indigenous peoples whose forefathers had found and first worked these occurrences.

In the seventeenth and eighteenth centuries, discoveries of prime importance occurred in many lands. More and more, these were virgin finds, as prospecting extended and improved. In the meantime, sudden realization of the value in what had been the least prized products of the mines—namely, iron and coal—was chiefly responsible for the Industrial Revolution. Significantly, the steam engine, symbol of that new era, was first put to use in mine pumping. Expanding utilization of mechanical power enormously stimulated production of coal and the industrial metals. With manufacture, commerce and general trade mounting dizzily, new monetary requirements arose which fortunately were met by the spectacular gold discoveries in California and Australia; and these, in turn, brought forth a new and unprecedented cycle of search for ores of all kinds, which was in full vigor when the Institute was founded in 1871.

GEOLOGICAL THOUGHT AND PRACTICE

By 1871 geology had been recognized for three quarters of a century as an independent science. It possessed a substantial and expanding literature; it had become segregated into a number of accepted subdivisions, of which Economic Geology was one; and it embraced an integrated and growing group of professional workers. Besides the older schools of Freiberg, Clausthal, Paris and Cambourne, younger institutions in both Europe and America were offering instruction in geology as applied to mining.

Many of the grand principles of geological science were then in view, and more or less firmly established. But numerous questions second in importance only to these were in highly controversial state; examples relating to ore occurrence may be typified by the following:

The broad concept of igneous intrusion was widely accepted in Europe, and the striking relation of many ore occurrences to the margins of intrusive bodies had already been emphasized; yet numerous geologists, notably in North America, urged that granite and other varieties had been produced by metamorphism of sediments.

The common contrast in character between the parts of an ore body near the surface and those at greater depth, the bands of altered country rock marginal to veins, and the phenomenon of pseudomorphism were matters of common observation; nevertheless, the principle of replacement had not yet been enunciated with convincing clarity.

That the great majority of ores had been transported and deposited by a water-rich solution had gained overwhelming acceptance; yet for great classes of deposits there was strong divergence of view as to whether the transport was from above or below, and whether the water was derived from rain or magma.

Erratic shape and highly restricted localization of workable ores was the overwhelming experience of mining; yet ore minerals present in *part* of the areal extent of a sedimentary bed were urged by many as coeval—syngenitic—with the commingled unquestionably sedimentary sand, mud or calcium carbonate.

Stream placers, the type of ore concentration longest known and worked, were accepted as a special product of sedimentary deposition; but active controversy persisted as to their subsequent "enrichment" and the "growth" of nuggets.

Observers of equal competence held divergent views as to the downward persistence of various types of deposits; but there was common agreement that the "true fissure vein" bottomed below any possible reach by man.

The mobile and controversial state of the science, together with the speculative excitement attending new ore discoveries, afforded fertile ground for the charlatan and the unscrupulous promoter. On the other hand, the reliable geologists were fortunately supported by the mining engineers, mine superintendents and even metallurgists, who wisely reflected their close contacts with ores and ore deposits in contributions of authority and value.

The actual employment of geologists in connection with the mining industry at 1871 was virtually limited to teachers, members of the national and state geological surveys under either civil or military authority, and those

temporarily engaged for some given problem or project, not uncommonly involved with mine promotion. Perhaps the earliest important instance of engagement of a consulting geologist in the present-day sense was the retention of Baron Ferdinand von Richthofen by a group of the Comstock mines, beginning in 1864, to give counsel on the threatening decline of the ores with depth and upon the Sutro Tunnel project. His intelligent and realistic treatment of these problems did much to establish the dignity and value of the profession in the United States at a most opportune time in its mineral development, and without doubt influenced support for the establishment, in 1879, of the United States Geological Survey.

To the inroads that mining had already made upon the world's mineral resources, some of the wisest minds of the time were not oblivious. But the succession of great discoveries, the rapid industrial developments and all the resultant effects caused the industry to be mainly permeated by the same unbounded optimism that had fired the ancient searchers for the Golden Fleece. True perspective of the period is now to be had in the following approximate ratios of output of major products at the beginning and at the end of the seven decades preceding the founding of the Institute (compare with Table 2):

TABLE 1—*Relative World Production,* 1801–1871

Product	1801	1871	Product	1801	1871
Gold	1	10.6	Iron	1	17.4
Silver	1	1.9	Lead	1	15.0
Copper	1	7.1	Zinc	1	384
Tin	1	3.9	Coal	1	21.5

These ratios give more than a measure of the increase in discovery, extraction and consequent exhaustion. They imply also the increased difficulty of finding new supplies, a matter then given little serious concern but that nevertheless led to gradually increasing dependence on those adequately trained and experienced in the special domain of mineral deposits.

The Seventy-five Years 1871–1946

ROLE OF THE INSTITUTE

From its inception, the American Institute of Mining Engineers gave wholehearted haven to mining geology. Of the three signers of the proposal to establish such an organization, two are found among the contributors to the literature of geology. One fourth of the 68 charter members and 8 of the 18 original officers are in the same category. The first scientific paper

presented at the founding meeting in Wilkes-Barre and assigned to open Volume I of the Institute's TRANSACTIONS treats of the geographic and geologic distribution of the mining districts of the United States, by that grand patriarch of the Institute, Dr. Rossiter W. Raymond; and 14 of the other papers in that initial volume deal with geological subjects. During its existence thus far, the presidency of the Institute has been accorded to eight geologists, and thirteen renowned geologists over the world have been elected as Honorary Members.

Through the years, the sympathetic environment and live discussion drew to the Institute's meetings oral presentation of the summarized fruits of investigation by leading mining geologists of this continent. The TRANSACTIONS, of high technical excellence, afforded worldwide distribution of these and other contributions, and are among the most valued archives of the subject. Among its outstanding offerings may be cited the following, each of which, within its particular scope, has exerted a profound influence on the understanding of ore deposits:

	Volume
The Genesis of Certain Ore Deposits, by S. F. Emmons	XV
Structural Relations of Ore Deposits, by S. F. Emmons	XVI
The Genesis of Ore Deposits, by F. Posepny	XXIII
The Secondary Enrichment of Ore Deposits, by S. F. Emmons	XXX
Metasomatic Processes in Fissure Veins, by W. Lindgren	XXX
Some Principles Controlling the Deposition of Ores, by C. R. Van Hise	XXX
The Ground Waters, by J. F. Kemp	XXXVI
Ore Deposits at Butte, Montana, by R. H. Sales	XLVI
Relations of Metalliferous Lode Systems to Igneous Intrusives, by W. H. Emmons	LXXIV
Magmas, Dikes and Veins, by W. Lindgren, with extended reply by J. E. Spurr and discussion by many others	LXXIV

The Committee on Mining Geology, since its establishment in 1913, has effectively continued the early tradition of this subdivision of the Institute's activity by organizing broad and timely programs, which have drawn excellent attendance at sessions of the annual meetings. During recent years many of these sessions have been arranged jointly with the Society of Economic Geologists.

Special reference must also be made to the three special volumes devoted to mining geology, each issued in honor of an outstanding leader: the the Posepny Volume, in 1902; the Emmons Volume, in 1913; and the Lindgren Volume, in 1933. The first two assembled noteworthy papers previously published; the third embraced a carefully organized group of new contributions. All three had the common purpose of throwing added light on the genesis of ores. It is safe to say that no other three volumes yet printed

hold contributions on such fundamental aspects of this subject by so many authoritative specialists. The period they cover, 1886–1933, is peculiarly significant in the history of the subject—and perhaps never again will so brief a period yield so much for the future to build upon. Truly may the Institute take pride in this geological series, unapproached as it yet is in any other of its fields of interests.

ROLE OF GOVERNMENTAL AGENCIES

At 1871, the operating locus of most professional geologists was in either the educational establishments or some governmental organization. Several of the nations had already founded geological surveys; and a number of the states of this and other countries had established corresponding organizations. These had contributed much to the scientific foundation of general geology, with notable additions here and there to an understanding of ore deposits. But up to about 1870 metalliferous geology by governmental agencies had not attained great prominence.

With the discovery of gold in California and the rapid succession of important mineral disclosures in other western states and territories, mainly on lands of national ownership, the United States Government had increased the geological explorations in that great unfolding domain.

During the latter part of the '60s and through the '70s four official surveys were simultaneously engaged on western geology. One of these, the Geological Survey of the Fortieth Parallel, 1867–77, was the first important organization under any government to apply intensive geological investigation to ore deposits. Directed by Clarence King, and with J. D. Hague, Arnold Hague, and S. F. Emmons, alumni of Freiberg, as assistants, this unusually capable organization may fairly be said to have set a new standard in both general and economic geological work. Prompt recognition of this achievement led to the all-important next step.

Work of the U. S. Geological Survey

In 1879, all geological activities of the Federal Government were consolidated into the United States Geological Survey, with Clarence King as Director. In one of his first official acts, King established a Division of Mining Geology, under the joint supervision of S. F. Emmons and G. F. Becker. Their instructions were broad and challenging:

> You will make accurate, detailed and exhaustive studies . . . so that . . . the varied types of deposits in all important mining-districts will have been studied; and the many phenomena bearing upon the genesis of ore-deposits thus accurately determined should be sufficient for a new theory of ore-deposits, based on facts actually determined in the light of modern geology.

Merely to mention all those who in the succeeding years have worthily shared in execution of that central program would unbalance this review; it must suffice to typify all these by three leaders of the Survey's early middle years, Lindgren, Spurr and Ransome. Even more is it impossible to summarize the principal contributions to an understanding of ore occurrence made by Survey geologists, but the major objectives and methods of this greatest geological organization in the world merit consideration.

The production of an accurate topographic-geologic map of such area and scale as to reveal broad setting and close detail has almost invariably been the foundation of the Survey's studies in mining districts. Carried out under a scheme of supervision that, at least potentially, brings to bear on each special area the Survey's cumulative knowledge of stratigraphy, structure, and igneous history of the greater province in which the district lies; enriched and safeguarded by the ministrations at Washington headquarters of corps of specialists in paleontology, petrography, mineralogy, chemistry, etc; and reproduced with beauty and rare precision, these special maps of the mine fields stand in the eyes of the mining industry as symbol and acme of the Survey's work and contribution. This has remained true from the beginning; and every itinerant geologist knows that, whether in prospector's shack or the geological quarters of a large mine, the Survey's map of the local region is carefully preserved for constant reference long after the "main report" to which it was attached may have been lost or shelved.

In the earlier days, the detailed studies of such scholarly and penetrating specialists as those already mentioned were of great value to the local operators. Disclosure of district-wide relationships, details of underground geology, ore structure, and genesis, and broad inferences as to downward continuity and tenor—these represented rich contributions which the local companies were in no position to provide for themselves. Coupled with a fine record of dealing with confidential material, achievements of this kind in district after district brought enthusiastic support for the Survey while also further expanding its own scientific grasp and power. (Pending issuance of the elaborate official report, the concentrated essence of such studies has in many instances been presented before the Institute—see outstanding examples already cited—or in the pages of *Economic Geology*. They constitute veritable gems of the science.)

In more recent years, the background against which the Survey's work in mining geology is performed has materially changed, and in two somewhat contrasting directions.

In the first place, most mining companies of substantial size in this country now carry on their own geological work. Even in this the Survey has had important, if indirect, part: it set a general pattern of investigation which the

companies recognized as desirable to adopt; numerous able Survey geologists, entering corporate practice, have aided in adoption of the pattern; still other Survey men, joining university staffs, have expounded the pattern to those whom the mines are to employ. Elaboration and fitting modification of the Survey technique plus quite independent extensions in new directions have been achieved by the mine staffs themselves. As a result, many mines are now qualified in most respects to conduct their own geological investigations on a high plane of scientific reliability and practical utility.

Such advantages as inhere in total richness of staff and broad scientific background of the Survey have to be balanced against the constant and continuing attack of the mine staff on the ever-changing facets of the local problems, and the close integration of the geological with the other company departments and with the complex variations of the local economic picture. Moreover, in recent years the Survey has been obliged to secure its future leaders in a three-cornered competition with university faculties and mining companies for the best among the oncoming supply of young geologists; the while mounting administrative loads attending marked increase in Survey personnel have gravitated to its contemporary leaders, thus restricting their own productive contact with the realities of outcrop and stope and their opportunity in the presence of these realities to guide and inspire their younger colleagues.

As consequence, the flow of geological benefits is no longer in a single direction. In detailed mapping, on surface and underground, Survey practice in recent years has tended not so much to lead as to follow what has become conventional in the mines. Likewise, there has been effort to incorporate in the Survey's work in mining areas something of the basic quantitative approach the mines have been forced to develop. These and similar trends became highly accentuated and conspicuous during the recent war, when duties unprecedented in magnitude and kind were imposed on the Survey, as well as on the sister organization, the Bureau of Mines, and the several special war agencies for mineral development and acquisition at home and abroad (see the revealing summary by Bateman[8]). Now that the turbulent pressures and breathless haste are past and the Survey's fine contribution to the war effort is of record, realization that the effective future role for the Survey does not lie in duplication of or competition with the functions of company geology is plainly shared by the present Survey administration.

It would seem to follow, then, that the initial program of the Survey, which brought it so much of acclaim and support—namely, the intensive study of great mining districts—should no longer hold primacy in its future plans of activity in mining geology. This will be progression, not withdrawal. It will represent wise and satisfying recognition that the Survey's early

function of pioneering leadership in one great objective has now been so well discharged that it may safely leave further extension in that area to the private endeavors it has aided, taught and inspired; and that the Survey is thus freed to turn more fully to the subjugation of other problems where governmental attack is now as appropriate and necessary as was the study of Comstock and Leadville, Butte and Cripple Creek scores of years ago. Moreover, if leadership is to continue the Survey will expect again and again in the future to devise, perfect and eventually turn over to industry one fruitful program in order to attack a new one, in quite the same way that the research department of a great corporation feeds its findings to the production department.

The second great change brought by the years points to exploitation by the Survey of new concepts and methods as the effective means of present-day adherence to the initial lofty objective of scientific advancement and practical usefulness which time has so fully confirmed. For decades, the implication in the instructions handed to Emmons and Becker was sufficiently valid; namely, that the best keys to broad understanding of ore deposition are to be found in the individual mining districts. One by one, the districts have yielded up specific, fundamental secrets: Leadville (1882), replacement and certain aspects of structural control; Marquette (1893), structural barriers for descending solutions; Butte (1896), secondary sulphide enrichment; Seven Devils (1899), contact-metamorphic ores; Rico (1901), structural barriers for ascending solutions; Coeur d'Alene (1908), pre-ore faulting of vein structures; Goldfield (1909), alunitic alteration—to name but a few examples. But to perpetuate indefinitely this district program in the manner available to the Survey would, from the all-important standpoint of genetic understanding, almost surely lead toward diminishing returns. Concurrently, the tasks of ensuring (1) that the known major districts will in due time be scoured centrally, peripherally and vertically until they retain little ore that is worth getting, and (2) that districts now ascribed lower levels of promise will receive eventual thorough testing, are now properly becoming responsibilities of the mining companies. An example of the seriousness and effectiveness with which this corporate responsibility is being discharged is seen in a paper just published on the Michigan copper region.[9]

The outstanding unfilled need lying ahead is the discovery of *new* mineralized districts. Enough scattered effort has already been directed toward this objective to confirm that it is much more difficult and even more speculative than has been mine finding up to now. It is hardly debatable that this is precisely the type of endeavor in which government can and must take leadership. And there is widespread conviction both within and outside the Survey that here lies its own chief future role insofar as concerns metalliferous re-

sources. The present Director, W. E. Wrather, long in intimate touch with the Survey tradition and of extended experience in commercial geological practice, is fully abreast of these objectives, with definite plans for realizing them. Fortunately the chief requirements fit exactly with the Survey's greatest strengths of the past: precise mapping and fundamental research. Extension of aereal mapping and related study to regions not now productive but possessed of the lithologic and structural potentialities of ore concentration seems fully justified, and holds great promise of bringing to light numerous places for more localized and intensive exploration by mining companies. In recent addresses before groups of the mining industry, Dr. Wrather has advanced a most proper and reassuring policy for this branch of the Federal Government. The following paragraph is quoted from his address before the American Mining Congress at Denver in 1946:

> I believe the efforts of the Survey should be designed to supplement those of industry, that the Survey's work in exploration should leave off where industry begins. . . . Therefore, the activities of the Survey in the field of mineral exploration should presumably represent the public interest in undertaking work which (*a*) private groups either cannot undertake, (*b*) will not undertake, or (*c*) cannot do as well as a Federal agency.

On another occasion he outlined the Survey's contemplated program of fundamental research as embracing: (1) discovery and elaboration of basic geological principles, (2) interpretation of these principles as applied to specific regions and problems, (3) development of appropriate instrumentation and techniques for geological, geophysical and geochemical investigations.

Among the directions that would seem particularly fruitful is a continuation of systematic studies of the ore occurrence of large regions, such as those already made by Lindgren in New Mexico, by Butler, Loughlin, and Burbank in Utah and Colorado, and now in progress under Ferguson in Nevada. Also deserving of active attack are topical studies, like that on interpretation and appraisal of aureoles of hydrothermal alteration as clues to ore, currently being followed in given districts by T. S. Lovering and G. M. Schwartz. It is gratifying to see work of that nature placing such strong emphasis on investigation in the field as contrasted with the library. For special inquiries of this kind, a topic entrusted to an individual or small team could profitably be pursued in district after district to the exclusion of all other district features that do not bear significantly on the theme in hand.

Work of Other Nations

Problems of past and present similar to those discussed in the foregoing pages have faced and still face the corresponding Surveys of other nations. It is natural that the outstanding contributions to mining geology have come

from those countries most blessed with mineral resources; and on the whole it seems to be true that in these the governmental geological agency is more alert and productive than when geology for geology's sake mainly prevails. High place on the roster of attainment in studies of ores must be accorded to Canada and its Provinces, Mexico, Sweden, Norway, the Australian states and the Union of South Africa. The Canadian bureaus are particularly noteworthy in their active aid to mineral development by early field investigation and prompt publication.

EDUCATION IN MINING GEOLOGY

In the training of men for the worldwide mining profession, the mining schools of Europe were at peak influence in 1871. The Freiberg Academy in particular at that time drew many students from outside Germany, and sent even larger numbers as graduates far and wide. Among the considerable number of Americans trained in those schools, a noteworthy proportion chose a career in mining geology, and proved to play a most influential part in shaping the ideals and the course of that science as it developed in this country. Although these undoubtedly were men of marked inherent ability, it is indubitable that their eminence derived at least equally from the training and viewpoint they had absorbed abroad.

It was fortunate, as we now can see, that the ablest of these men, instead of taking up teaching, should have been drawn to a career of systematic field work in the West at a time when new discoveries gave need and opportunity for their best. Their studies and writings extended, vitalized and dignified the broad principles and revealing relationships that were to enrich future instruction in mining geology.

It is significant that the new wealth of truths regarding ore occurrence being brought to light especially by the U. S. Geological Survey was utilized by teachers of deep faith and extended experience in field study—such men as Kemp, Van Hise, Lawson and Smyth. In due time the universities called to their geological faculties a number of those, typified by Ransome and J. D. Irving, who had acquired experience in mining districts under those seniors, Emmons, Lindgren and others earlier mentioned. Lindgren, youngest of the mining geologists coming from European training, climaxed 30 years of active field studies with 25 more of teaching and writing of the most stimulating kind.

The basic writings and textbooks dealing with ore deposits at the beginning of the period under review were chiefly of European origin. Conspicuous among these were the papers of de Beaumont and the treatise by von Cotta; but a translation of the latter by Prime, one of the charter members of the Institute, and Whitney's Metallic Wealth were available in

English. Most of the texts appearing up to the '90s followed a common pattern. Imperfect efforts toward generalization and a groping for genetic understanding constituted a comparatively brief preliminary part; relatively uninspired descriptions of great numbers of individual mining districts occupied the major part of the book. By 1893, De Launay and, in particular, Posepny had presented substantial treatises in which the principles and general relationships were given dominance, with local descriptions introduced chiefly to illustrate the genetic features discussed. Posepny's work, presented through the medium of the Institute, made a profound impression on American thought. Scholarly and sane increments to a consistent philosophy of ore genesis are found in Stelzner's manuscript (edited and published by Bergeat, 1904), De Launay's three-volume work (1913), and Lindgren's successive editions (1913–1933). In all these cases, the high quality and insight seem to be intimately connected with the author's long-sustained contacts with ores in the field.

The emphasis given to mining geology in the colleges and universities in this country varies markedly, but has increased with time. At one extreme stands a single course, designated economic geology, which covers metallic and nonmetallic occurrences, water supply, soils, etc., given by a professor carrying other subjects also. Certain of the larger institutions emphasize one or more special branches, such as petroleum geology, engineering geology, or geophysical prospecting. At a few places two or more faculty members deal exclusively with various aspects of the geology of ores.

Certain generalizations are rather plainly deducible from this experience of three quarters of a century. The increasing dependence of the mines on geology, already so evident in the quantitative sense, must extend also in the sense of better quality if the accelerating exhaustion of known ores is to be offset. This improvement of quality and power must be attained both in the course of practical application and in the preceding educational preparation. Because the fundamental principles and relationships in geology itself and in the sciences on which it rests are increasing in number and complexity, it is already clear that both better teaching and longer study are required.

The mounting need to utilize more of physics, chemistry and mathematics in geological interpretation must be disclosed by the teacher rather than left for discovery by the student. The individual teacher will progressively lose power if he relies solely on a background of field experience acquired early in his career; continuing touch with the reality in its own habitat is indispensable. Worthy and valuable investigations are possible in laboratory and library; but exclusive restriction to these is unwise, since *ore* is a treacherous image when divorced from the dollar sign.

Steadily it is becoming more evident that successful ore finding is to be

achieved only by research in the highest sense, ***conducted right on the ground.*** As in other sciences, no one in geology is qualified for research until he has mastered its body of fundamental principles and relationships. For the student of mining geology who justifiably aspires to full stature in the profession, the conventional four-year undergraduate course no longer suffices. Decision as to whether to pursue graduate study at once or after acquisition of some practical experience depends on circumstances. But in any event, before his scholastic preparation can effectively function in use it must be integrated with the training and background to be had only in the mines. This can be achieved in part during the summer holidays by a sympathetic policy of cooperation and very modest remuneration extended rather generally by the mining companies. Better still are the carefully organized training programs already instituted by a few companies. In any case, it is clear that the mines that recognize and meet the necessity for the postcollegiate professional training of geologists will secure the pick of the young graduates. Fortunately, the number of mines in this category is growing. Results in these deserve watching.

GEOLOGY IN THE MINES

In the professional study of the geology of ores, the mining companies, strangely enough, were preceded by governmental officials and teachers primarily concerned with discovery and illumination of basic scientific principles. And before American companies came to adopt geology for the central purposes of finding ore or facilitating its extraction, less constructive intermittent use had been made of geological talent and prestige in mine promotion and mine litigation. By the '60s and '70s, however, mining engineers whose training had included courses in geology were dealing, either as regular employees or as retained consultants, with the geological problems arising in normal operation and in exploration.

Anaconda's Leadership

The first geological department of any importance established by a mining company—and perhaps the earliest on any scale—was that of the Anaconda company at Butte. The later record of this department is so noteworthy that the conditions of its initiation merit summary record here. Systematic study of the Butte deposits by the U. S. Geological Survey had begun in 1896 under the direction of S. F. Emmons and continued for several years. Controversy having arisen in 1898 over extralateral rights, D. W. Brunton (later a president of the Institute), as consulting engineer for Anaconda, advocated geological study of the ground in dispute, and engaged for

that purpose H. V. Winchell (himself later a president of the Institute), who organized a staff and began systematic underground mapping. Following the larger consolidation into the Amalgamated company, Winchell's staff was expanded; and in 1901, R. H. Sales, who had earlier worked in other of the mines and had been assigned to cooperate on part time with the Federal geologists, joined the company's geological department. In 1906 Sales became chief geologist, and has since directed Anaconda's geological activities at Butte and elsewhere.

In its early years, Anaconda's geological work remained closely concerned with the tensely contested problems of boundary rights. The underground study was therefore carried out with unprecedented care and detail to make the maps, sections and models express most effectively the exact conditions underground. Inasmuch as Butte is characterized by numerous strong, through-going veins of various attitudes, and by several sets of strong fault displacements, and since extralateral litigation involves primarily geometrical considerations, the geological work of those early years was concerned chiefly with interpretation and solution of the structural problems.

After consolidation of ownership of most of the Butte mines had practically ended the period of litigation, and the department had come to deal with the geological features on a collective, district-wide basis, two important developments arose. First, the accumulation of geological understanding was turned to the directly constructive service of normal mine operation and production. In particular, great proficiency was acquired in projecting the known pattern of intersecting veins and faults into contiguous unopened ground. It became standard practice to give the operating staff precise directions for appropriate procedure even before the fault had been cut—a rare achievement in those days.

Second, the nature as well as the geometry of the mineralization received consistent attention. Systematic variations in mineral character and texture and in kind and intensity of wall-rock alteration were gradually shaped into the now well-known zonal pattern. Sale's Institute paper of 1913, already mentioned (p. 6), made Butte one of the classic examples of mineral zoning, besides treating most revealingly of faulting, vein structure and other important features of one of the world's foremost mining districts. It stands as one of the great geological contributions made directly by a mining company.

For many years the largest and strongest of its kind, the Anaconda geological department trained a large number of workers in the procedures and techniques that had been developed at Butte; in particular, a standardized and effective method of geological mapping underground. In the course of time, many of these geologists took up work elsewhere over the world, so that underground observation and mapping according to the "Anaconda school"

is now in very wide use, being especially appropriate where persistent tabular loci are important factors in ore distribution.

Current Practice

Emulation of Anaconda's success came rather slowly, but where sympathetic officials, carefully chosen geologists and tough geological problems coincided, the value of company geology began to receive general recognition. The allocation of geological tasks to trained geologists was, indeed, but one exemplification of the rapid spread of specialization throughout the mining industry as size of operating unit and complexity of problems increased. At the present time, most mining companies of importance employ geology, some of the larger departments comprising up to 20 or more geologists. Even numerous small companies contrive to utilize geology on a scale commensurate with their resources. For it has become clear that among the reasons why properties of small and intermediate size so commonly gravitate into the control of larger companies is not merely the greater resources of the latter in funds and facilities but also the superior geological judgment of possibilities for ore.

The function of the geological department has considerably expanded in recent years.* Formerly, the geologists' maps and other records, together with appropriate explanation, were submitted to the operating department for such use as might be made by the latter in laying out exploratory and development work. More and more the direction of exploration in and about the mine, whether by open work or by drilling, has been delegated directly to the geological department. Also, geological counsel now enters automatically with respect to rock character and structure as affecting location of main workings and plant, prediction of heavy or bursting ground, methods of extraction and support, water hazards, and related questions.

With steadily declining grades of ore and narrowing margins of profit, the necessity for reliable underground sampling naturally increased. In contrast with ores of great monotony in composition and structure, there are many others in which conscientious mechanical precision is not enough to assure a true sample. In a growing number of mines the sampling crews now work under supervision of the geological staff.

Likewise, periodic census of ore reserves is gravitating increasingly to the geologists. Many feel that this introduces more specialized skill and more objectivity into the proper determination of cutoffs and average grades, the

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* The organization of the Anaconda department as it was nearly 20 years ago is described by Sales.[10] Other illuminating discussions of geological procedure in representative mines, by McLaughlin, Sales, Linforth, Perry, Bjorge, Shoemaker and Billingsley, constitute chapter 12 of the Institute's Lindgren Volume, 1933. See also: J. D. Forrester.[11]

controls over dilution vs. clean mining, and the balance between extraction only vs. combined extraction and marginal exploration from the stopes, than where the responsibility for sampling and estimation as well as breaking of the ore is left to the operating staff. But whatever the division of responsibility, effective pooling of operating and geological information is essential.

Various incidental uses of geological experience are proving valuable to the mining companies. Microscopical study of the ore minerals and of the successive milling and metallurgical products has often aided in improved recoveries and lowered costs. Mine depletion and mine life as affecting rate of depreciation are important considerations in these days of heavy taxation. Several companies that operate custom smelters now afford geological service to the client mines as a cooperative assurance of maintained output of material in proportions for best smelting practice.

There are, of course, a few large companies and numerous smaller ones in which systematic geology is not yet employed. Obviously, in these ore still "comes easy." Presumably, for most of them a different outlook will eventually arise. The prosperous companies that work without geologists are less likely to understand the origin and controls of their deposits and are least likely, when their mine shall be exhausted, to meet the moral obligation of leaving for the future science and industry an enlightening record of the treasure they have destroyed.

EXPLORATION

Examination and appraisal of mines and prospects owned by others had long been entrusted to mining engineers. In the first two decades of this century, some of the most powerful mining organizations set up exploration subsidiaries for the more continuous and aggressive quest for new properties. In some of these, competent geological talent was engaged to join in the investigation and appraisal of the known ore and the possibilities of developing more. General Development Co. and Guggenheim Exploration Co. were in the latter category. Anaconda achieved the same end simply by assignments from its regular geological staff, which was increased accordingly. This latter practice has now spread, so that most geological departments carry the major responsibility for outside exploration.

The progressively increasing use of geology is interestingly revealed in the exploration that has yielded the largest number of great new mines in the last quarter century; namely, Northern Rhodesia. The rich copper deposits of the Katanga region to the north had been "discovered" by the standard method of gaining information from the natives combined with prospecting of the conventional kind. In the Rhodesian area, numerous copper-stained outcrops had for years teased prospectors and companies' representatives,

and at Bwana M'Kubwa an operation had been started—extravagantly extolled but soon fading. During the eight or ten years beginning with 1923, three important field groups, with strong London backing, explored this cupriferous region. The general philosophy, method and results of each may be briefly recalled.

The first group, under Raymond Brooks, mining engineer with extended experience in Katanga, "started out to find mines, wherever and however they occurred, having no preconceived ideas as to where they would be found or in what kinds of formations."[12] All facilities in the region were then most primitive. The scouting was organized in teams containing a prospector skilled in the African bush and the local dialects, and a young man with enough engineering training to keep track of locations and data. The native inhabitants were depended upon as the chief source of information. Locations were established by compass and wheel-odometer traverses. Promising exposures were probed by conventional shallow work, with a little drilling, done under difficulties. An important discovery was made at N'Changa, the Mufulira outcrop was located, Chambishi and N'Kana, which had already attracted attention, had been partly tested out, and several smaller deposits had been found before control changed hands; Roan Antelope was not in the ownership under the direction of Brooks. In what proved to be a rich region, this intelligent use of time-tried methods in an essentially virgin area accomplished much in the short period of its operation.

The second group, under J. A. Bancroft, geologist, took over in 1923 part of the area in which Brooks had started and added still further areas in its explorations. The program was designed to be essentially geological; and a very large corps of young geologists were central in it. Under this regime, each party consisted of a geologist, a native to push the odometer, and incidental helpers. Systematic, closely spaced traverses were run, with natives ranging the bush for fixed distances on either side to locate the sparsely scattered rock outcrops. As soon as an outcrop was found, it would be inspected by the geologist. On the basis of such outcrop data, boundaries of rock formations were deduced and thus geological maps were constructed; and from the interpretation of these, in turn, were deduced whatever ideas could be gained as to localities potentially promising for ore. The general geological relations of a large area were fairly well ascertained and ultimately published,[13] together with outline descriptions of such mines, previously located, as lay within the concessions studied. It may never be known whether the methods of this group, so lavish in geological manpower, would have been as successful in ore finding as those of their predecessor had the identical areas and the same priority of opportunity been involved.

In the meantime, a third group took over study of that restricted tract known as N'Kana Concession, on which some work under Brooks had already been done. Under R. J. Parker and Anton Gray,[14,15] this was primarily a geological enterprise. It had the advantages of the roads and other physical improvements just previously made, of more concentrated attack because of much smaller area covered, and of the clues to major ore control (within a single sedimentary formation) deducible from the environments of deposits already in evidence: Kansanshi, Bwana M'Kubwa, Roan Antelope, N'Kana, Chambishi, N'Changa and Mufulira. This control was strikingly confirmed and explained by the mapping (involving study of both outcrops and the residual soils), and the favored stratigraphic horizon in which great tabular dissemination of ore had been introduced was correlated with the "Série des Mines" of Katanga. Selection of the most promising smaller tracts and drilling of these led at the end of two years to the following major results: "three large mines were developed and an extension to a fourth property was found. These were: Mufulira, Chambishi, Baluba and Roan Antelope Extension." (N'Changa, Roan Antelope main mine and N'Kana were being concurrently developed under other auspices.)

The following general inferences seem deducible with respect to this sudden blossoming of one of the greatest known mining regions:

1. Intelligent prospecting of the conventional kind remains a powerful tool in virgin regions where distinguishing surface exposures are combined with an indigenous population that has mined them on a primitive scale; a corollary is that early arrival on the scene gives enormous advantage.

2. No intrinsic magic attaches to effort merely because designated geological; results will vary with the vision behind the geological procedures and the quality and leadership of the geological staff.

3. Geology is as yet probably best justified and most productive when conditions of time-competition and property control permit its application in a fairly intensive manner; this ordinarily implies tracts of moderate, not enormous size.

4. Since neither conventional prospecting nor scientific geology can succeed where no ore exists, final judgment of the relative merits of the two procedures can hardly be made while the district is so young; but the several "blind" occurrences thus far located by geological study, such as Baluba, West Extension and Chingola, suggest that more may follow. Conceivably geophysical methods will find more occurrences in the future.*

5. It is to be remembered that exploratory effort brought in such imposing tonnages so rapidly because of two important groups of conditions: (*a*) the region, of friendly climate, is a tableland of very gentle relief, open woods

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* Cf. the successful geophysical results of Lunsemfwa, page 85 of ref. 12.

and residual soil; all the major discoveries were made within 30 miles of an existing railway, which tapped abundant coal 500 miles to the south; (*b*) the copper deposits are tabular bodies conformable with the bedding at a fixed horizon, and maintain unusually consistent grade over long distances along strike and dip. These are highly favorable conditions, especially for the geological type of exploration. It may well be a long time before a new district of anything like such magnitude is opened so easily and quickly.

A method recently adopted by the Swedish Geological Survey for reconnoitering large undeveloped areas with sparse outcrops is noteworthy for its economy of funds and geological manpower. Experienced young woodsmen, after brief specialized training, are sent out individually to comb a given area, note the position and size of outcrops and collect specimens from them. When such a scout returns to base, his collections are given competent inspection and any deserving specimens are at once subjected to further investigation. Those deemed worthy of examination in situ are tabulated, and in due time the scout takes a geologist to the site of each tabulated specimen. The plan is regarded enthusiastically by Swedish geologists.

Courageous and highly effective application of geological principles and the indices of geological favorability to the search for mines is illustrated by Ventures Limited and other activities in which Thayer Lindsley is a moving spirit. It is to be hoped that he may be persuaded to put on record the essentials of his method of calibrating the geological yardsticks, his criteria of selecting areas for investigation and his procedure in appraising the merits of ground chosen for consideration.

TECHNIQUES, THEORIES AND TRENDS

The governmental geologist is assigned to study a district with the direct expectation that the product will be a report. This is fundamentally true whether the district be notable for ore occurrence or for other reasons. The geologist of a mining company, by contrast, is set to work in a district to find ore or promising places for exploration, or else to decide that ore hunting does not appear economically attractive. In either group, the conscientious geologist is fully aware that the one or the other of these objectives is his obligation as an employee,* and he acts accordingly. Invidious conclusions, of whichever complexion, that some incline to draw from these undeniable differences of purpose and condition are not likely to be constructive. But recognition that the differences exist and in large degree are inescapable is essential to clear understanding of the function and methods of the company

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* Field work of his own choosing by the college teacher ordinarily fits the pattern of the governmental worker, whereas the independent consultant in mining geology naturally approximates the company viewpoint.

geologist. Because the governmental geologist does ordinarily publish his findings in full, his general approach and technique are well known.

During the half century that company geology has been practiced, the trend has been toward reduction of the contrasts in methods and objectives of the two groups of workers; this has been especially manifest in recent years, as already noted in the section on governmental geology. Beyond the fact that man is inherently imitative, each group possessed something lacked by the other. So far as the United States is concerned, search for minerals during the war pressed governmental geology probably too far in the "practical" direction, an unbalance now apparently being righted. But the growth of interest and understanding by the company geologist continues and must continue as to both breadth of scientific base and mastery within his special field.

Compared with the scope appropriate for any other specialist in the geological domain, whether structural geologist, petrologist, physiographer or other, the mining geologist, even in a single district, is likely to be confronted with conventional problems in most of these subjects, and compelled to solve them as the essential foundation for effectively following known ore and finding new. And for him, this means to *solve*, not merely to find a temporarily plausible explanation; otherwise, crosscut or drill hole will be wasted or ore will be missed or the shaft will be located ineffectively or in treacherous ground. A good mine geologist is thus likely to find himself a rather busy person, both physically and intellectually.

It was wholly natural that company geological work should, at its outset, put prime emphasis on mapping of the underground geology. Not only the kind, boundaries and attitudes of the rocks and of the major structures, such as a general geologist would record on surface, but also the position, shape, nature, and structural characteristics of the ore. The underground map came not only to typify but largely to comprehend the mine geologist's work. To "keep the mapping up to date" was his prime job. Mines not previously using geology decided to hire or assign an engineer to "do the geology"; that is, the mapping. In skillful and ingenious hands, precision of location and observation and depiction of details improved notably. As more details, such as changing mineralogy of the ore, alteration margins, and minor structure were brought into the mapping record, first on the levels and then also in the stopes, map scales were increased appropriately. At present, many companies have elaborate files of geological maps and sections of very high perfection; and now, of course, most mine geologists have been technically trained especially for that work.

The tangible value derived from the geological mapping at first varied greatly from mine to mine, both because of the difference in intrinsic applica-

bility of the mapped record to the important problems of the given property, and also because of the varied effectiveness with which the full significance of the map was apprehended. In any case, here was something tangible, that could be checked against the evident facts and grasped by superior officers. In very many instances it has paid handsome dividends in ore found, in clean mining, and in reduction of useless work.

It is to be realized, however, that the typical mine map, even at the present time, is predominantly a *representation of structure;* and for probably the majority of mines its chief function is to emphasize *channelways*, actual or potential. Emphasis on structure in general and channelways in particular has likewise dominated most of the geological thinking of the mine geologist. This has tended to confirm the value of mapping and crystallize contentment with that aspect of geological effort.

Evolution of Theory

No one confronted with the problem of ore finding could remain oblivious, however, to the existence and the growth of theories of ore genesis and localization, as expounded especially by governmental and university geologists. Review of a few major changes and additions in theory during the present century will afford opportunity to gauge the mine geologist's role in utilizing and contributing to this core of principle and concept (compare ref. 16).

At the opening of the century the long controversy between the magmatists and the meteorists was in its final and most violent stage. The paradox that sometimes happens occurred in this case: i.e., that a theory is doomed by its most brilliant and explicit presentation—that is to say, when all that can be marshaled in its support has been brought clearly into view, its crucial shortcomings become manifest as never before. For the great family of ores now regarded as hydrothermal, the theory of rock leaching by meteoric water could not hold against contemporary factual and philosophical presentations favoring magmatic affiliation and ascension. Stampede to the magmatic viewpoint soon led to extremes. The concept of immediately local derivation of the ore from the intrusive body, spearheaded by acceptance of pneumatolitic origin for contact metamorphic ores while the adjoining igneous mass was still more or less molten, was carried to the extent of viewing each dike or sill as a potential source from which ore might have come.

We are now witnessing a recoil, as a result of wider experience and clearer reasoning. It is becoming manifest that the magmatic episode is long and complex; that even the ore-bearing magmas were not everywhere and from the instant of intrusion surcharged with ore stuff, which they belched

into whatever they touched; but that instead a considerable outer shell of the body had crystallized before the escaping volatile-rich fluid had acquired a sufficient proportion of metals and associated elements to effect at favored places that degree of concentrated deposition which constitutes a commercial ore body. We are left with the somewhat disconcerting presumption that we have never seen the specific source of any hydrothermal ore body—that particular nest where the ore fluid came into being and then started on its journey in quest of places for deposition. Widely differing views are consequently held as to the place, the dating, and the nature of such sources. Opinion is again in a state of flux.

So a new swing of the pendulum pushes the ore hearths down to great depths. Holmes[17] would draw the ores of lead, and presumptively other metals, from greater depth than that at which granitic and basaltic magmas originate and thus would make them nonmagmatic in the accepted sense. This stimulating conclusion, deduced by extreme extrapolation from a tiny "baseline" of isotopic differences, has since been materially weakened by corrected data. Still more recently, Hulin[18] proposes that the date of liberation of the ore fluid is so long after the emplacement of magma, and hence the place of liberation is so deep in the magma chamber, that "no idea of a direct genetic relationship between the ore deposits and the near-by intrusive body can be longer entertained." Instead, the characteristic association of ore deposits and intrusive masses "is recognized as resulting from structural control of the mineralized district." This thought-provoking paper, which builds on to views presented 40 years ago by Spurr, fits also as a further step in the author's well-known concepts of intramineralization fracturing and of ore derivation from basic magmas. It will doubtless receive the careful study it so clearly deserves. Interest will attach to the resulting discussion, which must eventually pass judgment on the relative soundness of this thesis and accumulated counterindications now widely accepted.

Rejuvenation and elaboration, in the '20s, of the venerable concept graphically called the "ore magma" and its product, the "vein dike," found many active supporters and not less numerous and emphatic opponents. The issue gradually subsided, presumably because of majority conviction that the evidences against it are too strong. But it still finds occasional advocacy; and something of the sort seems to be in the minds of those European writers who still allude to "injected" sulphides or ore "displacing" the country rock for examples which most American geologists would ascribe to the process of rock replacement effected by a dilute and tenuous solution.

The influence of physicochemical conditions on ore deposition, as propounded by Lindgren in 1906, the theory of ore formation as related to magmatic differentiation advanced by Spurr a year later, and the discussion

of primary downward changes by W. H. Emmons in 1924, contributed to the broad concept of vertical zoning to which allusion is now frequently made by scientific and practical workers. The realization developed that these successive zones, when visualized on a district scale, could be regarded as adjoining, not as a series of cylinders piled one above another, but rather as a succession of interfitting conical sheaths, the flaring bottom of each sheath thinning to zero at some distance above the corresponding bottom of the sheath representing greater intensity lying next below. It also became evident that the horizontal-concentric manifestation of zoning, such as displayed at Butte, could be regarded as merely a horizontal slice across the vertical stack of conical zones.

In accordance with this idealized image or model, the vertical line through the apices of the sheaths would mark the axis of major permeability and of the "hot center." If sound, the theory should afford, through the indicated intensity of the conditions attending ore deposition, an idea of the relative initial depth of formation of the observed ore. But independent check on depth of formation is commonly handicapped by uncertain reliability of estimates of post-ore erosion. In a few districts, however, such as Butte, Ouray and Casapalca, deep mine workings seem to confirm the order of change in mineral character with depth which the theory postulates; opposite order appears to have been nowhere encountered.

Obviously, judgment and restraint are needed to avoid overworking so alluring a picture; judgment and openmindedness are equally needed to avoid rejecting it hastily. It is certainly not yet justifiable to assume that every hypogene district must exemplify zonal distribution, nor that all zonal patterns must approximate the one outlined above. Unrest is wholesome to whatever extent it stimulates quest for a better theory. In the meantime, scattered evidences of a somewhat cynical distrust of the philosophy underlying the zonal theory seem more likely to represent sterile retrogression than the initial stirrings of something new and constructive.

Depth of Ore Persistence

On the economically important depth below present surface to which ores persist, views have oscillated markedly during the past 75 years. The early decades disclosed strongly contrasting ideas; those who knew of mines that failed at shallow depths inclined toward general pessimism, while promoters stressed the argument that the heavier the metal, the deeper, obviously, it would persist. Gradually, round the turn of the century, conscientious and capable men, in the face of speculative fervor, inclined toward very conservative views. Able geologists, like Gilbert and Van Hise, concluded that the inevitable constriction of openings with depth places a definite

bottom to the formation of ores (if formed, as they largely assumed, by waters of meteoric origin). Engineers of extended experience with many mines, like Rickard and Hoover, cited statistical implications that profit could be expected only rarely from depths greater than about 2000 feet.

Fortunate it is that these well-meant counsels were not heeded. The swing to belief in a magmatic origin for many ores lessened or nullified the theoretical denial of deep deposition; and realization that numerous mines of considerable depth and not yet "bottomed" were dealing with ores belonging in the middle depth range according to the zonal concept strengthened this reversal of the earlier theory. Fact also came to the support of the newer view; for mines continued to deepen and still make profits. Not all mines, of course. In the main, the hypogene deposits that have faded at modest depths below the present erosion surface have the characteristics ascribed by the zonal theory to "shallow-seated" formation, whereas those on which mining has persisted to 5000 or 8000-foot depths fall in "deeper seated" categories of the theory, which thus receives a further measure of pragmatic support.

At present it is regarded as probable that for many instances the downward limit of mining will be reached not because of actual decline in grade and/or quantity of mineralization but because rock pressures, temperature-humidity conditions and the increased distance of hoisting, pumping, ventilation, etc., will eventually raise costs to a figure where profits vanish. Because it has become clear that the world is going to need ore from the greatest depths that can feasibly be reached, postponement or lessening of the adverse effects of depth needs more attention than at present. Prophylaxis is possible even if not cure—for deep mines grow from shallow mines; and many of the difficulties encountered in the deep ones are aggravated because of neglect of precautions that should have been taken while the mines were shallow if the prospect of becoming deep had been adequately foreseen. Sound geology should be helpful in deciding, for mines of intermediate depth, to what extent the combination of zonal type and local structure may justify present steps that would improve conditions if the mine becomes deep.

Secondary sulphide enrichment had been sensed as to essence by many mine operators and engineers,[19] and when presented by geologists in the form of a clearcut hypothesis about 1900 was given widespread and confident acceptance. Yet quickly this fine, sound concept was carried too far. The hasty application to silver ores has proved in many instances not to fit; enrichment in nickel sulphide ores is relatively insignificant, and in gold ores probably little more so. Even for copper, for which its enormous importance is universally recognized, there exists a long-standing disparity of interpretation of chalcocite from deep levels. At Butte, where this question is notably

important, the Anaconda geologists feel convinced that the deep chalcocite is primary—hypogene; presentation of the results of their detailed studies is awaited with interest.

Extension of Geological Research

The foregoing examples of theoretical nodes in the broad problem of ore deposition only inadequately sample the total. The character of the ore-bearing fluids; the validity of direct magmatic segregation; the theoretical and practical status of contact-metamorphic ores; the role of colloids; the mechanisms of weathering as affecting both the occurrence of lateritic ores and the connection between weathered outcrops and what lies beneath—these are among additional subjects, partly theoretical, partly factual, as to which views have fluctuated markedly with time. All this clearly means that *majority opinion at any given time does not necessarily reflect the truth.*

Geologists may fervently wish for greater fixity and finality of geological theory; and managements may be puzzled or even rendered suspicious by the change and controversy evident. Yet neither must be disheartened; for only thus does a science grow. Because of the inherent inaccessibility in time and place of so many important geological processes, and particularly because of the limitation on *experimentation* in duplication of natural conditions, speculation has largely lacked the control so wholesome and productive in physics, chemistry and engineering. It has therefore been a natural reaction to utilize and value a type of geological procedure that is least speculative in nature.

This brings us back to the great wave of emphasis now placed on the subject of structural control. Structural study unquestionably has found more ore to date than all other phases of geological work combined. Undoubtedly, such study will continue to be highly productive, since so much ore is dependent for its importation and localization on some manifestation of permeability. But just as the arteries, veins and capillaries are no more important to the human system than is the character of the blood that flows through them, or than the subtle reactions of so many kinds that contribute to the total physiological process, so the attention to channelways, reopening and preparatory "ground-conditioning," to channelway details as by contouring attitudes or widths, to relative fracturability of different rocks, represents a most one-sided and partial approach to the problem as a whole. It is an unsound approach only in that it tends to neglect, if not indeed to discourage, other important and necessary adjuncts. Chemical, mineralogic, petrographic and mineralographic studies have as yet been pursued far more for the writing of articles than for the hunting of ore. To realize that the burden of justification for this lies strongly on the ore hunter, one need only

recall what chemistry, microscopy, X-rays and spectroscopy have done for modern metallurgy.

It is highly encouraging, therefore, to realize that company geological departments, like metallurgical departments before them, are becoming alert to the need and advantage of *research* in the modern sense. International Nickel, Anaconda, and Cerro de Pasco are among the companies that in recent years have established laboratories for geological research, equipped with modern instruments appropriate to a wide kind of investigation and staffed with men soundly trained not only to conduct the investigations but also to interpret their significance to the geological problems in hand. These laboratories are adding so notably to understanding of ore occurrence and ore controls that adoption of the same program by many other companies in the near future seems inevitable. The research right on the spot will achieve its optimum in effectiveness and satisfaction to the extent that the work and the men in the laboratory be most intimately integrated with the geological work and workers in the mines. The problems of ore occurrence are already too large to be handled masterfully by any single individual. By deliberately bringing into teamwork men of different backgrounds of training and experience, the larger geological departments can begin to realize something of the collective power and success that the great medical clinics have so notably acquired.

Prospecting of the Future

Even if this broadening and scientific enriching of geology in the mines soon becomes common practice with the stronger companies, it will come none too early to serve as foundation for the new body of knowledge required for the successful location of entirely new mineralized areas, whether in covered regions or with bedrock exposed. Present intellectual armament for attack on that great problem is decidedly inadequate, as even the best reflections thus far offered on the subject make plainly manifest. No consistent record of success in this challenging program can be expected from following any given hunch. Only a comprehensive and reasonably sound philosophy of ore deposition can hope to make more than chance, sporadic hits.

In this eventual grand campaign of ore hunting in the blind, geophysical and geochemical methods will certainly be employed. The conspicuous success in recent years of geophysical exploration for petroleum[20] gives some idea of what may be hoped for when methods, instruments and techniques become sharpened to suit the smaller bull's-eyes that ore bodies constitute.

Magnetometric methods, since they deal with a specific and wholly unambiguous response of certain substances, will doubtless continue to stand

at the top in reliability, and may be expected to be still further refined in sensitivity and expressiveness. The recent development of airborne magnetometry holds high promise of rapid and cheap reconnaissance of great areas, not only for locating magnetic "highs" but also, probably, for much areal mapping, since slight differences in magnetic quality from one rock type to another can now be detected from surface or from air, even under cover of vegetation, drift or water. The acme in magnetic usefulness will come if and when depth of the magnetic source can be positively determined. That end seems especially likely of attainment through airborne determinations at different elevations above the same area.

Spontaneous potential methods probably will continue to be more reliable than induced fields for ore occurrences in which a definite chemical process like oxidation is going on; and will become still more valuable if it becomes possible to recognize and eliminate responses from reactions probably not related to ore bodies. Because many ore bodies have notably higher density than ordinary rock, gravimetric methods may possibly be perfected to pick up responses from heavy masses of ore-body size. Seismic methods seem better suited, as to scale, for disclosing broad structural features favorable as loci for ore occurrence than for finding the ore itself.

Minute traces of telltale elements in rock outcrops, soils, ground waters and the ash of vegetation have received considerable attention in this and other countries[21] as clues to ore finding. If further trials demonstrate the economic utility of such geochemical inquiry, the hillsides may see, instead of prospector's burro, shovel and pan, a jeep with spectrograph and other modern instrumentation.

Present-day perfection of aerial photography is already an enormous aid in mapping for reconnaissance or detail. Frequent disclosure of rock structure unsuspected from the ground can undoubtedly be put to excellent productive use; in reconnaissance of virgin territory it may record prime successes. The helicopter is already far toward proving itself the answer to the geologist's dream. If reliability of performance, first cost and maintenance expense can all be brought to proper level, the craft's unequaled versatility will make it ideal for all kinds of country.

In the quest for blind ore, deep drilling obviously will play an even greater role than now. Relative lightness and flexibility, besides the advantage of pointing in any direction and of yielding core, indicate diamond drilling as most appropriate. Every improvement in cost, speed, core recovery and control of wedging or diversion will be welcomed.[22] If the "wire-line core barrel," which can be removed from the hole without pulling rods, and/or the method of "counter-flush continuous coring" become practical for hole diameters appropriate to diamond drilling, much time and expense can be

saved. Doubtless there will be wider employment of rapid, cheap drilling by diamond bits of the "blast-hole" type until the critical objective is neared, then changing to a coring bit—perhaps with an independently removable core barrel, or with continuous coring. With the rapid advances in interpretation of powered material under the microscope, it is entertainable that for certain purposes core drilling could be completely displaced by solid-bit drilling combined with careful collection and microscopical study and assay of the sludge; or perhaps followed by deflected short runs of core drilling starting just above where interesting material has been cut. The possibility of a synthetic product—a carbide?—of adequate hardness and toughness and materially cheaper than diamond may not be a wild vision in this era of metallurgical wonders.

This section may well be concluded by allusion to the difference in conceived function of mine geology by two men of wide experience and conspicuous success, much of whose work has lain in the same province, the Cordillera of North America. In "Mining Geology Today,"[23] Joralemon is at the disadvantage of writing first; in "Mining Geology Today and Tomorrow,"[24] Sales replies. Adequate summary of the papers is out of the question here; but a reader will be well repaid by this cross fire of philosophy on some of the basic problems of mining geology.

Reserves and Conservation

Seventy-five years ago, mining was proceeding, as of old, largely on faith from initial outcrop outward and downward. The long-accumulated experience that depth was most feasibly dealt with not by uninterrupted downward extraction but by a succession of spaced levels tended to increase evident ore supply by conspicuous periodic increments, even though anything approaching dependable measurement of the increments was uncommon. Since that time great changes have come about.

The gradual evolution of mining from a romantic adventure and gamble to a business involving recognized hazards, the expanding size of mining units, the rapid increase in outlay for equipment and plant with resulting requirement of knowing amortization period and rate, the need to raise large sums from the public through the appeal of frank information, the widespread growth of income taxation with recognition of mine depletion, and the mounting awareness by mine management of continuing responsibilities both to their shareholders and employees and to the dependent communities—these have brought to each mining unit throughout the industry a pronounced consciousness of ore reserves and mine life. As these topics involve predictions of what the rocks contain, they have naturally come into the domain of the mining geologist.

Next, the significance of quantity and duration of mineral reserves spread from the scale of the individual mine to the scope of the nation and of the world, through realization that wasteful methods are neither good company business nor good social policy, that individual mines and mining districts were dying, and that the rate of exhaustion of these nonreproducible resources was steadily accelerating. For the United States, conservation of natural resources was brought to the fore by President Theodore Roosevelt, who, in connection with a National Convention which he convoked in 1908 to consider the subject, called on the U. S. Geological Survey to estimate the country's reserves of economic minerals. The resulting data, though recognized as most imperfect, served nevertheless to affirm the importance of the subject. Even then it was predicted that lead would be the first of the country's important metal products to reach exhaustion.

The great demands of mechanized warfare in 1914–1918, and particularly in 1939–1945, focused still more conspicuous attention on national and world resources. These remain a vital topic in the considerations of peace. The simplest logic of arithmetic, that less remains than at the beginning, is confirmed by the increasing difficulty and decreasing rate of finding new supplies. But there simplicity ends. In the abundant present-day publication on ore reserves there is much contradiction and confusion. The turmoil serves to prevent complacence; but if quantitative estimates continue to be made, probably we shall continue for unknown decades ahead, as for decades in the past, to see estimates successively revised.

Hitherto, passage of time has required revisions upward. For example, in 1915 a recognized authority estimated the *total* expectable reserves of petroleum in the United States; 30 years later, the estimate solely for *proved* reserves was four times the 1915 figure, notwithstanding the enormous intervening production. Similarly, a competent expert in 1907 estimated the period during which the coal reserves of the United States would last; 40 years later, the estimated period is 20 times as long. Admittedly, more pertinent information for all mineral products is available now, both in this country and over the world, than was at hand 30 and 40 years ago. However, when one considers how difficult it is for those best informed to estimate the remaining reserves in a single, compact district of long history, the probable error in predicting eventual worldwide reserves known and as yet unknown should slow down the guessers' impetuosity.

The actual inroads on world reserves during the 75 years of the Institute's existence are approximately as indicated by the total production in column 4 of Table 2. In column 3 are shown the growth ratios; that is, the relative production at beginning and end of that period.

For the products that were mined on an important scale during the first

TABLE 2—*World Metal Production,*[a] 1870–1945

NEW METAL ONLY

IN TONS OF 2000 POUNDS EXCEPT AS OTHERWISE NOTED

Mineral	1 1870	2 Maximum Year	3 Ratio Col. 1:Col. 2	4 Total 1871–1945
Gold[b]	5.95	41 (1940)	1:7	1,260
Silver[b]	49.5	276 (1937)	1:5.5	12,800
Copper	130	2,800 (1942)	1:21	74,000
Tin	31	282 (1941)	1:9	8,100
Iron	14,200	122,000 (1943)	1:8.6	4,140,000
Lead	315	1,870 (1940)	1:6	79,000
Zinc	148	1,820 (1943)	1:12	62,500
Mercury[c]	100*	275 (1941)	1:3	8,600
Nickel	0.45	156 (1943)	1:350	3,400
Manganese[d]	70	6,680 (1937?)	1:95	119,000
Antimony	1.5*	52 (1943)	1:35	1,600*
Cadmium (1882)	0.005*	5.3 (1943)	[1:1,000]**	70
Aluminum (1890)	0.2*	1,920 (1943)	[1:9,600]**	15,100
Chromium[d] (1895)	44*	2,170 (1942)	[1:49]	27,000
Magnesium (1896)	0.05*	284 (1943)	[1:5,600]**	1,200
Bismuth (1900)	0.009*	1.9 (1942)	[1:200]**	20*
Molybdenum (1901)	0.024*	34 (1943)	[1:1,400]**	240
Tungsten[e] (1905)	4*	44 (1939?)	[1:11]	740
Vanadium (1907)	0.003*	5 (1943)	[1:1,700]**	50*
Coal	258,000	1,915,000 (1942)	1:7.4	99,000,000
Petroleum[f]	5,800	2,625,000 (1945)	1:453	49,140,000

[a] Statistics derived from U. S. Geological Survey, U. S. Bureau of Mines, American Bureau of Metal Statistics, *Mineral Industry*, American Petroleum Institute, *Iron Age* and other sources.

Dates following name of metal indicate approximate beginning of significant production. Dates in col. 2 represent the year in which the indicated maximum production was obtained.

Productions marked by asterisk are approximations.

Ratios in brackets are for periods less than the full 75 years; those marked by ** are to be regarded as only rough indications because of smallness and uncertainty of the production in col. 1.

[b] Millions of fine ounces.

[c] Thousands of flasks of 76 pounds.

[d] Thousands of tons of ore.

[e] Thousands of tons of ore of 60 per cent WO_3 equivalent.

[f] Thousands of barrels of 42 U. S. gallons.

seven decades of the nineteenth century, shown in Table 1, comparison may be instituted with the growth ratios in column 3 of Table 2. The reasons for the variations in these ratios from product to product and from early period to late period are well known. It is interesting to note, however, that gold, lead, zinc, iron and coal, among the old standbys, have not held the same rate of growth in the last 75 years as in the preceding 70 years, whereas copper and tin have bettered their position, as also has silver because of its by-product status. But the really striking feature (resembling the behavior of zinc in the earlier period) is, of course, the growth of the metals with the newer uses: the alloy metals and the light metals.

As many have pointed out, the present century has witnessed greater inroads upon the world's supplies of metalliferous minerals and carbonaceous fuels than took place throughout all prior history. What fraction of the initial total still remains cannot even be guessed, since that depends probably as much on man's future ingenuity and on the prices civilization may find it possible to pay for the metals as upon the actual quantities contained in the rocks to depths that man can reach.

Factors that Affect Reserves

Reserves obviously are raised and conservation achieved by all improvements that lower production costs and increase recoveries of the major valuable component or components; and, also, to whatever degree recovery is extended to "rebellious" or rare components in an ore. Vast strides have been made regarding costs by mechanization and increased size of units. As physical metallurgy has developed uses for rare components (at least 40 of the metallic elements are now "commercial"), ore dressing and process metallurgy have kept abreast in recovering them from their source materials. Relatively little now escapes being caught in the by-product net, and for most elements further efforts are likely to show progressively diminishing returns. Increasing attention to the collection and reworking of scrap metals —already a most important industry—will probably repay the effort. In all these respects the mining, metallurgical, chemical and manufacturing industries have labored most earnestly and effectively.

Ore reserves, however, are much more sensitive and mobile quantities than most statisticians seem to assume. They vary on the scale of the individual property with the owner's direct activity, rising or falling as his ore finding exceeds or falls behind extraction, as his costs decline or mount and as his recovery efficiencies improve or regress.

Reserves also vary through industry-wide causes beyond influence of the individual mine: supply vs. demand, new uses vs. substitutes, and the in-

dustry-wide balance between exhaustion and replenishment of ores. This second group of influences is felt, for all save gold, through the factor of metal prices. Under natural and normal conditions, these broad influences, like the laws of physics and chemistry, work toward self-correction and equilibrium by automatically augmenting or shrinking the reserves in each and every occurrence, whether these reserves be in known mines or as yet wholly undiscovered, and also by encouraging or restraining ore hunting.

Both the mine-scale and the industry-scale influences have existed since mining could be regarded as an industry. Recently, however, through expanding governmentalism, wholly new factors have arisen, which profoundly affect ore reserves: crushing taxation, arbitrary and punitive restraints and controls, and governmental support—whether overt or covert—of demands for wages out of line with the economics of the industry or the times. Under reasonable governmental regulation, the mining industry had long demonstrated that it could produce metals from steadily declining grades of ores, and from ores drawn from greater depths and more remote localities, with increasing wage scales yet without substantial change from long-prevailing levels of metal prices. Legislators, political propagandists and labor leaders may well ponder whether more than this can be expected; in the long run, policies that cancel low-grade reserves are fully as dangerous and damaging to nations as to mine owners.

In recent years, hope for new supplies of ore have lain in two directions: (1) small bodies of moderate grade possibly commercial under modern techniques; and (2) great bodies of very low grade. As between these two groups, the latter is strongly favored under the conditions that have been brought into being during recent years. The small properties, with high requirement of labor per unit of output, are severely handicapped. And among the low-grade units only the very largest can hope to amortize the excessive capital requirements. Yet this tendency toward ever larger units is the direct opposite of the objective held by the dreamy ideology that has brought the causative conditions into force.

Let it not be forgotten that the recent war was won, above all else, by *production.* The totalitarian powers were astounded and the democracies jubilantly surprised by the productivity of the latter. Yet even the bounties of nature are to be effectively won only in a climate economically, socially and politically favorable. The fundamental conditions, objectives and policies that during the last century and a half have prevailed in Great Britain and the United States have not been mere accidental coincidence paralleling the attainment of greatness and prosperity by those nations; but instead, have been the sound and indispensable basis of these qualities which all nations of the world desire. Radical departure from those same objectives and poli-

cies can bring only disillusionment, retrogression and distress, however or by whomever the trial be made.

Because, at a few places where all conditions are especially favorable, ore in place averaging 0.5 per cent copper or 0.0002 per cent gold has been mined profitably, reference is often made to the vast low-grade deposits available to prolong metal supplies for a period beyond present anxiety. The thought has even been seriously proposed that for each reduction of one decimal place in grade accepted as ore, say from 3 to 0.3 per cent, from 0.3 to 0.03 per cent, etc., a new tonnage more than one decimal place greater is thereby made available. Those familiar with ore occurrence know that this simply is not true. For most metals, the abnormal local concentration that constitutes an ore deposit has real geometrical limits, beyond which the tenor more or less abruptly drops off to values far below anything entertainable as economic.

Of course, it is true that for ores like those of iron and aluminum, which, by current standards, average in the tens of per cent metal content, there is realistic prospect of gaining adequate supplies for a very long time into the future by utilizing materials of progressively lower grades; chromium and manganese are in a closely analogous category. Magnesium, in rocks and oceans, stands at the extreme of abundance. But for metals like copper, tin, nickel, for which present world-average grades of ore range from 2 per cent downward, there remains a much smaller leeway for ingenuity; gold and silver, except when recovered as by-products, are in a corresponding category. Zinc and possibly lead occupy a position somewhere between the iron-aluminum and the scarcer group.

Possibilities for the Future

Although the facts of the past have clearly shown the dangers in prophecy, it is necessary, nevertheless, to cast our sights ahead.

The period between 1871 and 1946 has disclosed no new land areas of first rank except in the south polar region. However, for great areas whose existence and major features were already known, there has been enormous increase in knowledge of detail of the kind pertinent to classification regarding suitability or unsuitability for ore occurrence. Much of this advance has come, of course, through specific and deliberate search for mineral wealth. Concurrently, the criteria for suitability have become much better understood. The general nature and distribution of rocks and their ages and structures are now known for most of the land surface. Islands of ignorance still remain; one such, Labrador, is just now in process of promising investigation. The frigid and tropical belts contain most of these blank areas.

Within the next quarter century or so, these scantily known regions

doubtless will have been brought pretty well within the fold of understanding, especially by aid of aerial reconnaissance, and above all if this includes the helicopter or equivalent means of grounding safely and at will in virgin terrain. During that period it is reasonable to expect new ore discoveries.

Thereafter, increments from deposits having visible surficial indications may be expected to fall to a new low; and thenceonward most new ore must come from exploring known districts more thoroughly laterally and mining them to greater depth, from wiser geological prediction of favorable but buried loci, and from the aid of geophysical and geochemical techniques. If anything like the past rate of advance in scientific understanding and technologic efficiency may be projected into the future, the common and most of the rarer metals may be counted on for a long time to come. On the other hand, if the sociopolitical climate is not conducive to metal hunting, neither will it be to metal using; then the standard of living will recede, and a new Dark Ages will reign until man regains his common sense and honesty. There is no guarantee that what happened to Egypt and Babylon, to Greece and Rome, will not happen in today's world, save the steadfast determination that it must not be.

Role of Atomic Energy

No consideration of conservation and no look into the future can ignore the amazing new reality, atomic energy. It is clear that research on this subject is proceeding feverishly on both sides of the Atlantic, and enough has been made public on this side to leave no doubt of great advances in scientific understanding. But in addition to what other nations may be doing, a vast pool of secrecy remaining in this country incites much superficial and emotional writing.

Most of the world fervently hopes that this supreme triumph of the human intellect may be turned from warlike to peaceful use. Many seem to take for granted that this outcome is most likely to be achieved by prompt application to industrial uses under rigid international control. Existing proposals before the United Nations imply such programs. And there is much near-official activity toward bringing them into being as rapidly as possible. Neglecting the wholly fantastic notions of columnists and others among the less informed, plans are being seriously discussed that envisage for the near future a consumption in the United States alone of 10,000 tons of metallic uranium annually; and of competing soon with the most efficient coal-burning power plants. An earlier, more official (Smyth) report phrases the situation thus:

> Early rough estimates, which are probably optimistic, were that nuclear energy available in known deposits of uranium were adequate to supply the total power needs of this country for 200 years (assuming utilization of U-238 as well as U-235).

Two considerations, however, warn of the need for caution in the contemplation of such plans. First, a growing number of thoughtful scientists have come to believe that, in the present turbulent state of the world, the enormous complexities and difficulties of international control of nuclear energy, if produced on a great industrial scale, combined with the tremendous temptation to circumvent this control, would constitute such extreme hazard to peace as not to be justified by the sum total of gains presently visualized from industrial use. The proposed alternative is international restriction to scientific research, a scale of use far easier of rigid control and enormously less tempting to evade. Second, there are unquestionably uranium and thorium deposits capable of yielding enough bombs to wreak unconscionable havoc over great areas of concentrated population, not only by immediate destruction but also by slower but wider-reaching radioactivity. *But there is yet no demonstrated certainty that there exist sufficient natural concentrations of these metals to support a long-continuing atomic-power industry.*

These two challenging considerations, moreover, have a possibly sinister interrelationship. If there surely were enough of these two metals to permit sustained extension of the benign effects of cheap nuclear energy to great masses of people hitherto energy-starved, this very factor might be hoped to ease present world tensions, and, combined with other earnest efforts toward peace, to reduce steadily with time the temptation of treacherous evasion of control and of resort to malign use. The longer peaceful production would continue, the less the probable chance of perversion. But if industrial plants established in many countries—as would naturally be demanded by these countries as condition of their acceptance of control—should after a period demonstrate that the supply of physically obtainable uranium and/or thorium metal would not last much longer, doubly compounded temptation might incite vicious leaders of an aggressive nation to make their evil strike before too late.

Conceivably, therefore, even if agreement on international control can be reached, much more may hinge on the available reserves of uranium and thorium than such mere practical questions as the possibility of economic competition with coal.

The easy detectability of uranium and thorium minerals by such device as the Geiger-Müller counter, when held *close* to a rock on surface, in mines or drill holes, promises unusually prompt discovery of new occurrences wherever such detailed studies are made; but similar detection at the distance appropriate to aerial reconnaissance seems beyond hope. As far as yet disclosed, no spectacular additions to reserves of a grade hitherto minable resulted from the feverish and extended searches by the Allied governments during the war years. Lower grade materials are known in several localities, but much

comment, even by insiders, about supplies for a great nuclear energy industry either rests on secret information or else is superlatively optimistic and naïve.

The requirements are worth brief inspection. Material containing 0.2 per cent uranium,* with an assumed overall recovery of 75 per cent, would have to be mined at the rate of over 6,000,000 tons per year to yield the mentioned 10,000 tons annually of uranium metal. If, as seems probable, such rate of exhaustion would make rapid inroads on world reserves of that tenor available to this country, resort would soon have to be taken to progressively lower grades. Considerable tonnages of shales are known containing roughly 0.02 to 0.002 per cent combined uranium and thorium. At these figures, again with 75 per cent recovery, to secure the expected annual 10,000 tons of metal, the higher grade would have to be mined at 60 million tons a year, or 200,000 tons a day, or the lower grade at 600 millions tons yearly; that is, equal to all the coal mines of the United States. Complacent reference to the occurrence of uranium and thorium to the extent of a few parts per million in ordinary rocks—i.e., about another decimal place lower still—misinterprets the manner of deriving as well as the significance of such figures, and also reveals an unrealistic appreciation of the limitations of metallurgical recovery.

However, even if enough of these rare metals could be found and produced to supply a peacetime energy industry for a term of economically justifiable duration, their exhaustion merely for ordinary competition with coal or petroleum would seem most inadvisable. A few superlatively urgent uses for energy in remote regions might be justifiable. On the other hand, schemes like pumping from wells to make the Sahara bloom seem likely to belong on the same shelf with Baron Munchausen's tales. Until it may be proved impossible, production of controlled supertemperatures for tomorrow's metallurgy and chemistry might be the most valuable use of these rare fissionable elements. If so, their exhaustion otherwise would be lamentable.

Assuming, however, that fissionable material from uranium and/or thorium is to be used on a considerable scale for either military or industrial purposes, certain consequences pertinent to the mining industry obviously will result. Besides stimulation of search for and production of these metals, doubtless under most rigid governmental or international control, there would be forced increase in production of metals naturally associated: vanadium, cobalt, selenium, radium, silver, molybdenum, nickel, chromium, tantalum, columbium, and rare-earth elements. There would also be increased need for certain elements used in the processing reactions: beryllium, boron, cad-

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* This is approximately the same as the average grade, 0.21 per cent, for the carnotite ores of the long-known deposits of Colorado and Utah, as given in the official report of extensive exploration during the war; the roscoelite ores of the same area are of much lower grade. Tonnages are not stated.[26]

mium, indium, rhodium, and gallium are potentially indicated. And as synthetic products of the fission reaction there would be substantial quantities of various elements lying in the middle range of atomic weights; some of these are rare, and of these certain ones in the form of stable isotopes are valuable. For the list of needed elements, the prices would tend to rise. For the elements naturally occurring with them, and thus made available as forced by-products, the previous prices would tend to be depressed, likewise the price for the rare products of fission. Beyond these very general influences, the economic consequences are now too vague to deserve further speculation.

Now that the binding energy of atomic nuclei has been brought within reach, derivation from commoner elements beckons alluringly—above all, if of such nature as not to be "chain reacting" and explosive. But all this is as yet too speculative for more than mention here.

If the present worldwide wave of greed for political power leads to perverted employment of this majestic new-found knowledge, may the Infinite Judge enter the charge against those grasping despots who lead their peoples by falsehoods, rather than against the earnest scientists who, almost without exception, hope and strive against such prostitution of all that science stands for.

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