Top ten lists for metallurgical and mineral processing engineers

by John O. Marsden

This article is an attempt to capture a presentation given at the 2016 SME Mineral & Metallurgical Processing Division (MPD) Luncheon held on Feb. 24, 2016, in Phoenix, AZ. It was presented as a tongue-in-cheek, light-hearted view of several of the issues facing our industry, while identifying some of the challenges and opportunities available to new engineers entering the industry today.

Attendees enjoying the top ten lists at the MPD Luncheon, held at the SME Annual Conference & Expo, Feb. 24, 2016.

Disclaimer

- What you are about to read includes personal preferences, biases and occasionally arbitrary opinions.
- Some readers may have dissimilar opinions on the contents and/or the rank order of the lists.

There are eight top ten lists offered in this article: (1) Industry realities (2) Things a metallurgical or mineral process engineering graduate should do (3) Books every metallurgist should have on their shelf (4) Things I wish I had known (5) Legends of metallurgy (posthumous, with highlights) (6) Things we've forgotten (7) Mineral processing innovations of the past 20 years and, finally, (8) The future? For some items, additional context or clarification is provided after the item, while for other items no further explanation is warranted and none is offered.

John O. Marsden, 2014 President of SME, is president of Metallurgium.

Top 10 industry realities

1. Metal price cycles.
2. Bigger is better (except when it isn't).
3. Ore grades declining across the board of metals/commodities.
4. Ores becoming more complex.
5. Three-fold increase in capital costs between 2004 and 2015.
6. Three-fold increase in operating costs between 2004 and 2015.
7. Less capital availability/challenging financial markets.
8. Environmental constraints increasing.
9. Socio-political constraints increasing.
10. The mine manager is always impossible to work with.

As Table 1 shows, there was more than a three-fold increase in gold operating costs between 2004 and 2014. The increases for copper, iron ore and other commodities were similar.

Top 10 things a metallurgical or mineral processing graduate should do

1. Know how to (really) design an ore transfer chute.

How wide does this chute need to be? Do I need a dead box? What liners do I use? Do I put in a flared discharge or parallel? How far off the belt should the chute be placed? What is my largest particle size? How wet and sticky is the ore? What about ease of access for cleaning?

2. Accurately trace a pipe through a plant.

You'll learn a lot about pipe routing doing this, and you'll discover why certain things in the plant behave the way they do.

3. Work night shift as an operator (for more than one full shift cycle).

You'll learn more from the operators on night shift than you will at any other time on the plant. There is more time to shoot the breeze with them. They use "tricks of the trade" more frequently on the night shift than on the day shift, when there are less supervisory and management staff around. Also, you'll have more time to get curious and explore the plant.

4. Run a flotation test (properly).

Do I really know how to run a standardized float test? How full do I fill the cell? Have I allowed for air hold up? How fast do I pull froth and how deep do I go? How well do I get into the corners (does that matter)? How am I timing? What happens when I get distracted? . . . You get the idea.

5. Watch a float cell working for eight hours in the plant.

This item is borrowed from Jim Arnold's Richards Award lecture in 2006. How does the froth move? How does the froth color and texture change? Where does it overflow and how? Is the WEMCO wave working, and is it helping or hindering? Is there enough air or too much? How is the grind size affecting the froth? Should we be adding more frother, less frother, a different frother? Why are we using two collectors, perhaps one would be better or maybe three? Where are we adding them and why? Is there enough conditioning time? What happens if we increase shear in the conditioning tank? Why is there no agitator in the conditioning tank?

6. Use a Marcy cup (correctly).

Where and how do I take my sample? How full do I fill it? Is the overflow hole big enough? Is the overflow hole blocked? How long should I let it stand? Does any of this really matter?

7. Measure and adjust the gap on a cone crusher.

You'll gain an understanding for how the crusher wears and an appreciation for hydraulic jacks for gap adjustment. If you're really lucky, you might have to adjust one with a come-along.

8. Work on a mill relining job inside the mill.

You'll learn how maintenance really works, and time management, job task preparation and logistics in a high-stress, time-critical environment.

9. Hose out a sanded thickener (completely).

You'll learn a lot about how a thickener works: why the rakes broke or didn't break, as the case may be. You'll find out how coarse the sanded material really is and how it behaves, and, most importantly, you will get to be the first person to read the name on the hard hat you find stuck in the apex cone.

10. Work in every area of the assay lab.

Top 10 books every metallurgist should have on their shelf

1. *Handbook of Mineral Dressing*, by Taggart, A.F., 1945 (John Wiley & Sons).
2. *Ore Dressing*, by Richards, R.H., 1908-1909, 4 volumes (McGraw-Hill).
3. *Flotation*, by Gaudin, A.M., 1932, (McGraw-Hill).[1]
4. *Mineral Processing Plant Design*, by Mular, A.L., Halbe, D.N., and Barratt, D.J., 2002, 2 volumes (Society for Mining, Metallurgy & Exploration Inc.).
5. *SME Mineral Processing Handbook*, by Weiss, N.L., 1985, 2 volumes (Society of Mining Engineers/AIME).
6. *Rate Processes in Extractive Metallurgy*, by Sohn, H.Y., and Wadsworth, M.E., 1979 (Plenum Press).
7. *The Circulating Load*, by Shoemaker, R.S., 2002 (Society for Mining, Metallurgy & Exploration Inc.).
8. *Solution Mining*, by Bartlett, R.W., 1992 (Gordon & Breach Science Publishers).
9. *Cameron Hydraulic Data*, by Heald, C. C., 1988 (Ingersoll-Rand).
10. *Ore Deposit Geology,* by Edwards, R., and Atkinson, K., 1986 (Chapman & Hall).

[1] Consider also *Froth Flotation*, edited by Fuerstenau, D. W., 1962 (AIME), *Flotation*, edited by Fuerstenau, M.C., 1976, 2 volumes (AIME), and *Froth Flotation - A Century of Innovation*, edited by Fuerstenau, M.C., et al. (Society for Mining, Metallurgy & Exploration Inc.) as similarly important companion texts to Gaudin's first.

And a few bonus books you might find interesting:

- *Sustainable Energy Without The Hot Air*, by MacKay, D.J.C., 2009 (UIT Cambridge) – a straight-talking book about the numbers.
- *The Moral Case for Fossil Fuels*, by Epstein, A.J., 2014 (Portfolio/Penguin).
- *Into Thin Air*, by Krakauer, J., 1997

Table 1

Gold operating costs in 1994 and between 2004 and 2014.

2014	$749	$983	$1,314	$1,266
2013	$767	$989	$1,620	$1,411
2012	$766	$970	$1,276	$1,669
2011	$643	$809	$1,044	$1,571
2010	$557	$723	$857	$1,225
2009	$478	$619	$717	$972
2008	$464	$601	$690	$872
2007	$395	$496	NA	$695
2006	$317	$397	NA	$604
2005	$269	$337	NA	$444
2004	$253	$313	NA	$409
1994	$241	$293	NA	$384

Source: GFMS Thomson Reuters.

Top 10 legends of metallurgy

(posthumous, with highlights)

1 Georgius Agricola

1494-1555, birth name: Georg Bauer.

Physician – treated mine workers and mine-related illnesses.

"Bermannus, sive de re metallica dialogus" (the first attempt to reduce metallurgy to scientific order in writing during a time of alchemy and witchcraft).

De Re Metallica, published 1556 (The preparation of woodcuts delayed publication until after his death.)

Famously translated by Herbert Hoover and Lou Henry Hoover in 1912 (*Mining Magazine*, 1,476 original printing, reprinted by Dover as a paperback in 1950).

2 Robert H. Richards

1844-1945, MIT-educated

The father of ore dressing in the United States.

Sizing and concentrating classifiers – hydraulic classification.

Developed the Richards pulsator jig.

Department head, MIT Metallurgy, 1873-1914.

1893: Began research for book, traveled to 100 mills in 11 western states.

1903-1909: Four-volume book, *Ore Dressing*, the first to codify and disseminate operating information effectively.

1946: Tribute from Dan Jackling: "He (Richards) had a more important part in this (Utah Copper Company) innovation in the practice of copper producing technology than any other consultant from whom I sought advice . . . ."

3 Arthur F. Taggart

1884-1959, Stanford-educated.

Worked in Bolivia and throughout the Americas.

Chair, Columbia School of Mines, NY, 1919.

1927: *Handbook of Ore Dressing*.

1945: *Handbook of Mineral Dressing*, 1953 (5th), 1954, 1956 (6th), 1966 (9th), 1976.

1951: *Elements of Ore Dressing* (text book), second printing 1958.

4 Fred C. Bond

1899-1976, Colorado School of Mines – Metallurgy (B.S. and M.S.).

Worked in Honduras, U.S. Mint in Denver, and Tennessee Copper Co.

Casualty of the Great Depression, 1930.

Worked in Peru and Bolivia – gold.

Start-up of radium mine during WWII.

Allis-Chalmers.

Developed the rod and ball grindability tests (completed 1937).

5 Antoine M. Gaudin

1900-1974, educated in Paris, Aix-en-Provence and University of Utah.

Professor at Montana School of Mines, 1929-1939.

Professor at MIT, 1939-1966.

Uranium extraction from low-grade ore in WWII.

1939: *Principles of Mineral Dressing*.

Founding member of National Academy of Engineering.

6 John Stewart MacArthur

1857-1920.

1885: Physicians office in Glasgow, partnership with J. and W. Forrest brothers, invented cyanide process.

Cassel Gold Extracting Co., Scottish Min Proc Company (electrolytic process).

Proof of concept of cyanide process on 15-t sample of ore from Crown Mines, New Zealand.

Traveled to New Zealand and South Africa to implement and apply.

The Great Cyanide Case, Pretoria High Court, February 1896, "no novelty," patents annulled.

During WWI, produced radium for medicinal purposes and luminous paint.

7 John V.N. Dorr

1872-1962, Rutgers (B.S. Chemistry).

Worked for Thomas Edison.

1904: Developed sand-slime split using rake classifier, founded Dorr Co.

1907: Oliver Co., founded by Dr. Edwin Oliver, developed continuous thickener.

1914-1916: Dorr clarifier and DorrCo suction pumps introduced.

1931: Dorr and Oliver merged.

1935: Dorr torque thickener invented, Oliver precoat filter introduced.

8 Peter R. von Rittinger

1811-1872, Vienna, Austria.

1840: Stamp mill inspector in the civil service.

1845: Spitzkasten (classification of fine particles).

1849: Introduced continuous shaking table for gravity separation.

Mathematical descriptions of unit operations – the first to reduce the art to science.

The work done in crushing is proportional to the new area of surface produced.

Rittingers Law.

1867: Textbook of the Processing Art (*Lehrbuch der Aufbereitungskunde*).

1900-1940: Rittinger-Kick controversy.

9 Robert S. Shoemaker

1925-2016, B.S. and M.S. Inorganic Chemistry, Oregon State; M.S. in Met. Eng., Wisconsin.

Union Carbide – Norway, Australia, United States.

1962: Bechtel – chief metallurgical engineer.

1968: Consulting metallurgist – leading metallurgical design role in many of the great gold, silver and copper operations of the time.

San Francisco Mining Associates.

Gold and Silver Cyanide Plant Practice, Vol. 1 (1972) and Vol. 2 (1975).

10 Klaus Schonert

1927-2011, Built on the work of Hans Rumpf.

Single particle breakage: One-third to one-half the energy of a ball mill for 3-mm to 100-µm particles.

University of Karlsruhe.

University in Clausthal.

HPGR patent in 1982.

Applied HPGR to cement, iron ore, diamonds, copper and gold. ■

(Villard Books) – to demonstrate how otherwise intelligent and sensible people make really stupid decisions at high altitude.

Top 10 things I wish I had known

1. HDPE-lined concrete is not the best combination for acidic environments.

No matter how well the liner is placed in the concrete structure, at some point acid will come in contact with the concrete. That isn't to say that no one should ever install HDPE, or another liner type, in a concrete structure, because it can provide adequate protection and may be cost-effective. In fact, HDPE is a remarkable liner material that performs well in many applications, meeting or exceeding permitting requirements and providing effective environmental protection. However, you need to know what you are getting into and plan accordingly.

2. Any sump, no matter how big, will overflow at some point.

Everyone knows this. That's why we design our mills and plants with sloping floors and hose outlets.

3. A test screen that is stated to be 200 mesh never is.

Woven wire screens change over time and with use. Depending on the procedure applied and the operator using the screen, the screen aperture may change significantly within a few weeks of use. Even brand new screens as-supplied vary in specification. You can purchase certified reference screens from the suppliers that are made to tighter specifications. You can use these to calibrate the screens you are using in the plant.

4. Bond Ball Mill Work Index (BWI) tests are hard to duplicate.

Several projects have run into issues with lack of reproducibility of BWI results. If something doesn't make sense, it may be worthwhile running some checks at another laboratory.

5. Don't waste time debunking crackpots.

Sometimes you just need to decide that the idea being presented to you just doesn't make sense and let it go.

6. If it isn't documented, it didn't happen (attrib. Bill Brack).
7. The "twiddly bits" in the flowsheet always cause the most problems (attrib. Phil Thompson).

An extension of this is that the unit operations we have to add on to the end of a flowsheet to actually make it work are generally the most problematic. Clue: If the add-on piece(s) of a flowsheet is taking more time and effort to develop than the main flowsheet, then you have a problem.

8. Politics sometimes trump logic and common sense (pardon the pun).

As we have learned from the recent political debates.

9. The boss is always right, especially when he/she's wrong.

You can only argue for so long and then you need to move on.

10. Don't allow geologists to assign ore types for metallurgy (at least not without supervision).

Metallurgical ore types need to capture the key geometallurgical attributes that affect processing, not the genesis of the deposit. We need to be able to understand and model those components within and across a meaningful set of ore types to be able to do our job most effectively.

Top 10 things we've forgotten

1. There are no new mistakes (attrib. Bob Shoemaker).
2. Online particle size monitors really do work (and most plants need them).
3. Design the plant for the optimum 80 percent passing size.

Many grinding circuits produce a product coarser than the economic optimum grind size. There is nothing wrong with pushing throughput to maximize cash flow. But it is the job of the plant manager and chief metallurgist to (i) communicate what that means economically for resource utilization and (ii) take the steps required to get the grinding product back (or closer) to the optimum size.

4. Automatic slurry samplers are a requirement, not an option.

For every new project being developed, this should be non-negotiable. No, it doesn't matter who is driving the cost efficiency review for the capital appropriation document, or "AFE." You can't and shouldn't run a modern-day mineral processing plant without automatic feed and tailings samplers.

5. Cut the whole slurry stream, stupid.
6. Keep the flowsheet simple.

When you are developing a flowsheet, it is always tempting to add bits to try to make it more efficient. Resist the urge.

7. Large-diameter core is (almost) always better than a "bulk" sample.

Sometimes, you need to get a very large bulk sample for metallurgical testing, and it is hard to do this with drill core alone. But for many deposits and projects, drilling eight to 10 large-diameter (15-cm or 6-in.) cores will give you a better representation of the entire deposit (or the first five years of ore production, if you prefer) than a bulk sample. Yes, it is expensive, and it takes time and planning to execute.

8. Three 90° elbows in a slurry line are about equivalent to a blind flange (attrib. to Alan Taylor in *The Circulating Load*).
9. Expert process control?
10. The lowest-grade ton of ore to the mill must make money.

You might be surprised at how many tons go through a mill or process that lose money.

Top 10 mineral processing innovations in the last 20 years

1. HPGR – Cerro Verde & Boddington.

For competent (uniformly hard) orebodies with little or no clay content, HPGR is a great alternative to SAG milling. Freeport-McMoRan's Cerro Verde operation (Peru) recently expanded to 360 kt/d (397,000 stpd) processing capacity using HPGR and ball milling technology. There are significant energy and wear savings compared with conventional SAG milling. This has enormous implications for our industry.

2. SAG mill performance predictor tests and methodologies.

The development of SAG and AG performance indicators has provided a number of effective tools for the design and optimization of comminution circuits. Importantly, these tests are relatively low in cost, use modest amounts of sample, can be run on drill core, and provide rapid results. In some cases, there is no substitute for pilot-plant testing in 1.8-m (6-ft)-diameter mills.

3. Sea water for flotation and leaching.

The use of sea water in major copper flotation and leaching facilities in Chile and Peru is having a big impact on how fresh water is managed and used. It is also helping to reshape the socio-political conversation around mining in these countries.

4. High-efficiency centrifugal gravity concentrators (and intensive leaching).

The Knelson and Falcon concentrators introduced widely in the 1990s and 2000s have revolutionized gravity concentration for gold and silver recovery. When coupled with intensive cyanide leaching of the concentrates, this is an effective one-two punch for gold metallurgists. We have Byron Knelson and Andre Laplante to thank for this, among others.

5. Ultra-fine grinding (Glencore IsaMill, Metso Stirred Media Detritor, Metprotech, etc.)

The ability to efficiently grind down to 7-10 µm has opened the door to new hydrometallurgical approaches to treat refractory and semi-refractory gold/silver ores, and for emerging base metal sulfide concentrate treatment options.

6. Pressure leaching of copper/molybdenum concentrates.

Pressure leaching of copper concentrates continues to gain momentum.

7. Rapid, automated SEM (MLA/QemSCAN/TESCAN).

We have witnessed a major revolution in process mineralogy with the advent of rapid, automated SEM technology that can provide quantitative mineralogy on representative samples of material in a timely manner.

8. The Derrick Stack Sizer.

This is a very clever device that provides significant fine screening area within a small footprint. Derrick does it again.

9. Alternative anodes for copper electrowinning.

Alternative anode technology introduced by Freeport-McMoRan and Republic Anode Fabricators at Chino (New Mexico) and El Abra (Chile) has helped reduce the energy consumption for electrowinning and is eliminating lead from EW tankhouses.

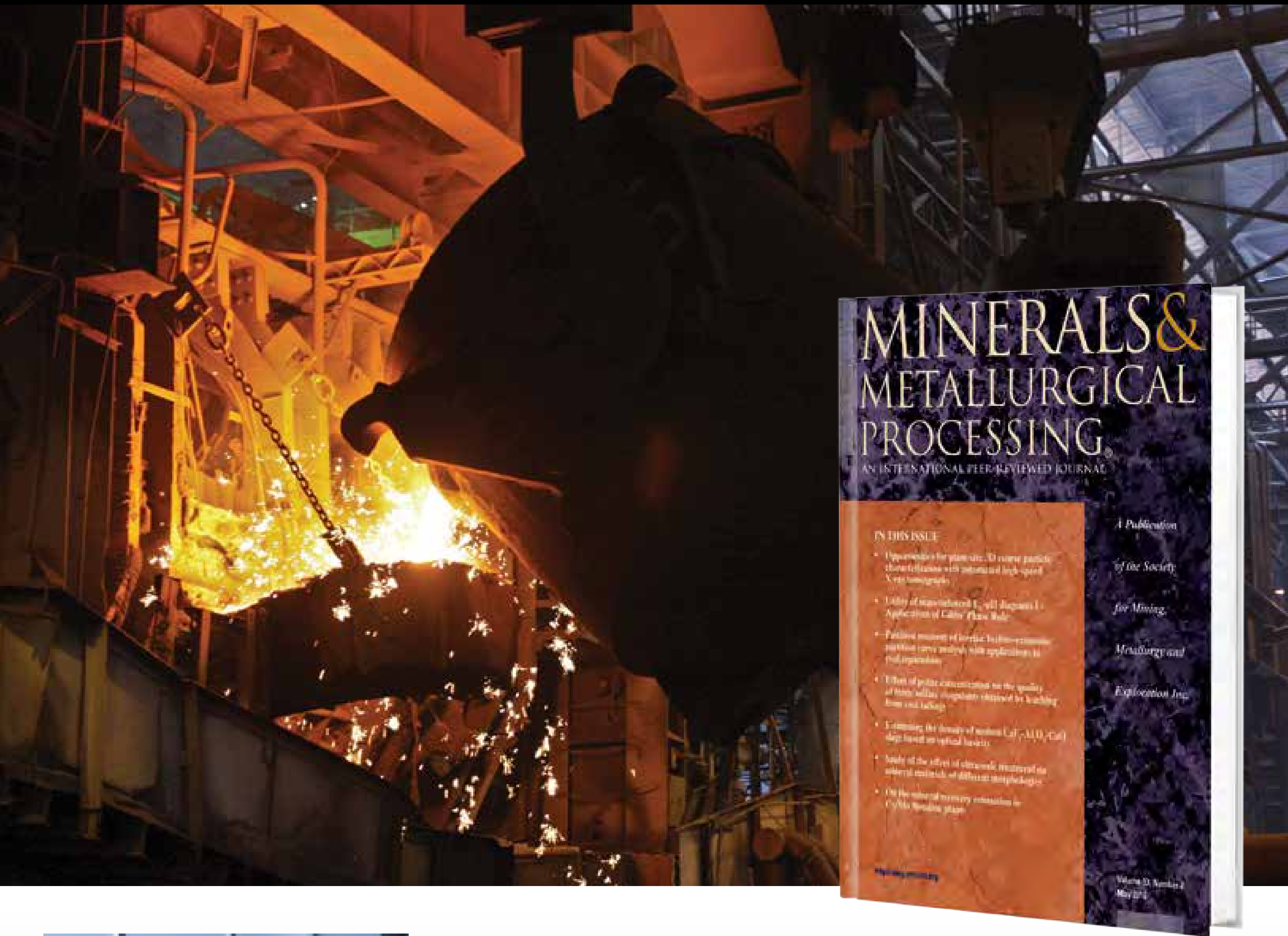
10. Thiosulfate leaching.

Barrick Gold has developed and implemented "CaTS" (calcium thiosulfate) leaching for gold extraction and recovery from highly carbonaceous, pre-robbing refractory sulfide ores at Goldstrike in Nevada.

Top 10 – The future? (Caution: This list is highly speculative and opinion-based)

1. Ore pass-convey versus truck haulage.
2. Co-disposal of tailings with waste rock.
3. HPGR followed by stirred milling.
4. Heap leaching of primary sulfides.
5. Primary separation at coarser sizes (for example, flotation).
6. Multi-stage HPGR before flotation or heap leaching.
7. Ore sorting at fine sizes.
8. Continuous online SEM to provide for diagnostic mineralogy.
9. Replace the cyclone (or use them better).
10. *Your idea goes here.* ■

Making Research Relevant.



Our focus on industry research makes *Minerals & Metallurgical Processing (M&MP)* unique among peer-reviewed journals. In addition to academia and government entities, a high proportion of the papers we publish each year come from respected industry researchers, and both industry and academia are well represented on the editorial board. In addition to peer-reviewed papers, *M&MP* publishes occasional reviews, invited features and technical notes (shorter case studies).

If you are an engineer, scientist, researcher, educator or minerals industry professional, this is the one journal you can turn to for research that is relevant to you and what you do each and every day. It is a must read for industry professionals like you.

To view examples of published papers, go to **http://mmp.smenet.org**. To subscribe, go to **http://mmp.smenet.org/subscribe.cfm** or contact our Customer Service team by email at **cs@smenet.org** or by phone at **1-800-763-3132** (toll-free in the U.S.) or **+1-303-948-4200**.

SME Society for Mining, Metallurgy & Exploration

www.**smenet**.org
#Minerals #Metallurgical