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(peer-reviewed and approved)

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The need for critical minerals has increased dramatically over the past 15 years, fueled by the growth of green energy and national security concerns. On page 20, Richard Otoo, Virginia McLemore and Evan Owen examine the minimum concentrations needed to advance exploration of critical minerals. Cover image from Shutterstock. Cover design by Ted Robertson.

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Mining and tunneling have much in common;
Synergies between the fields are on display at WTC

Bill A. Hancock
2025 SME President

One of the privileges of being SME President is the opportunity to delve more deeply into subject matters with which I am only somewhat familiar. This mineral processor attended the May 11-14 World Tunnel Congress (WTC) 2025 in Stockholm, Sweden that provided me with a greater understanding about the tunneling industry and why our Underground Construction Association (UCA) fits well as an SME division despite separate and distinct markets for each group.

At WTC, tunneling and mining terms, in many respects, were used interchangeably depending on the context. Until the development of tunnel boring machine (TBM) technology, hard-rock tunneling was strictly a drill-blast-waste haulage operation. Even now drill-blast techniques are important. For instance, the 26.7-km (16.6-mile) western Norway Rogfast undersea project that will reach 392 m (1,286 ft) below sea level is using drill-blast technologies through solid rock. While there apparently is no good database to reference, WTC attendees estimated that roughly 50 percent of projects are drill-blast with the caveat information that China tunneling projects, which represent many global projects, are not publicly available.

The exhibit hall was filled with suppliers promoting drill bits, shotcrete, rock bolts, computer modeling and other products that make mining engineers feel at home. TBM equipment was, of course, prominent. While not used extensively in mining, TBM techniques have been used in underground mining operations.

The tunneling industry hires mining engineers to leverage their expertise and perspective.

There are important differences between mining and tunneling. First off is the differing funding sources — tunneling projects are overwhelmingly public works projects with multiple implications: (1) once bids are let, the focus is on project completion to enable use of the facility, and (2) government projects are incredibly complicated by the public regulatory procurement process, ongoing government reporting and the need to meet all health, safety and environmental regulations. As many tunneling projects are in urban areas, projects are complicated by working around existing underground utilities, tunnels and long-forgotten underground structures, and with multiple third-party stakeholders.

Safety Share | Ladder safety. Before using a ladder, always inspect it for damage. Look for cracks, bent rungs or missing feet. Never use a damaged ladder. Make sure the ladder is rated for your weight and the type of work you are doing.

Set up the ladder correctly. For extension ladders, follow the 4-to-1 rule: for every 4 ft of ladder height, place the base 1 ft away from the wall. Ensure the ladder is on a stable, level surface and fully extended with all locks engaged. Never place a ladder on boxes, barrels or other unstable bases to gain extra height.

While climbing, maintain three points of contact — two hands and one foot, or two feet and one hand. Face the ladder and keep your body centered between the side rails. Avoid overreaching; instead, climb down and reposition the ladder.

Never carry tools in your hands while climbing. Use a tool belt or hoist materials up after you are in position. And remember, ladders are meant for one person at a time — never exceed the load limit.

Mining is subject to market vagaries, ore reserve confidence and no future guarantees.

As with mining, the tunneling industry has workforce issues, maybe even more critical. While civil engineering is the backbone of the tunneling industry, as a specialty area there are only a handful of universities that actually focus on teaching tunneling technologies, and it is typically only on a graduate level. UCA is very focused on strengthening these programs to recruit students to these programs and eventually the tunneling industry. These jobs are predominantly urban based, which is appealing to students and career professionals.

I think the overarching takeaway from my recent exposure to the tunneling world is that there are so many potential synergies between mining and tunneling that are virtually untapped because we operate in completely different markets. In my term as SME President, I would like to see greater sharing of knowledge and experience between our mining and tunneling cousins. Let me know your ideas on how we can improve SME membership value by sharing more ideas between mining and underground construction.

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US aims to create higher rare earth pricing system

U.S. EFFORTS to break China's dominance of the rare earths market and to drive investment in its own industry have moved up a gear with a Washington-backed plan to create a separate, higher pricing system, *Reuters* reported.

The West has struggled to weaken China's grip on 90 percent of the supply of rare earths, in part because low prices set in China have removed the incentive for investment elsewhere.

Miners in the West have long called for a separate pricing system to help them compete in supplying the rare earths group of 17 metals needed to make super-strong magnets of strategic importance. They are used in military applications such as drone and fighter jets, as well as to power motors in electric vehicles and wind turbines.

Under a deal made public recently, the U.S. Department of Defense (DoD) will guarantee a minimum price for its sole domestic rare earth miner MP Materials, at nearly twice the current market level.

Las Vegas-based MP Materials already produces mined and processed rare earths and said it expects to start commercial magnet production at its Texas facility around the end of this year.

Analysts say the pricing deal, which takes effect immediately, should have global implications — positive for producers, but may increase costs for consumers, such as automakers and in turn their customers.

"This benchmark is now a new center of gravity in the industry that will pull prices up," said Ryan Castilloux, managing director of consultancy Adamas Intelligence.

The DoD will pay MP Materials the difference between $110/kg for the two most-popular rare earths and the market price, currently set by China, but if the price rises above $110, the DoD will get 30 percent of additional profits.

Castilloux said other indirect beneficiaries of the pricing system may include companies such as Belgian chemicals group Solvay, which launched an expansion in April.

"It will give Solvay and others the impetus to command a similar price level. It will give them a floor to stand on, you could say," Castilloux added.

While Solvay declined to comment, other rare earth miners, developers and their shareholders welcomed the news.

Aclara Resources is developing rare earths mines in Chile and Brazil, as well as planning a separation plant in the United States. Alvaro Castellon, the company's strategy and development manager, told *Reuters* the deal added "new strategic paths" for the company.

MP Materials, which suffered a net loss of $65.4 million last year largely because of China's low pricing, will build up magnet production at its Texas plant initially to 1,000 t/a, later expanding to 3,000 t/a.

Under the deal, the DoD will become MP's largest shareholder with a 15 percent stake, and MP Materials will construct a second rare earth magnet manufacturing facility in the United States, eventually adding 7,000 t/a. In total, production would be 10,000 t/a — equaling U.S. consumption of magnets in 2024.

That does not include, however, the 30,000 t imported by the United States already installed in assembled products, according to Adamas Intelligence.

It predicts annual global demand for rare earth permanent magnets will more than double over the next decade to about 607,000 t, with the United States seeing the strongest percentage annual growth rate in coming years at 17 percent. ■

MP Materials partners with US Department of Defense

MP MATERIALS Corp. announced that it has entered into a transformational public-private partnership with the U.S. Department of Defense (DoD) to dramatically accelerate the build-out of an end-to-end U.S. rare earth magnet supply chain and reduce foreign dependency.

With a multibillion-dollar package of investments and long-term commitments from DoD, MP Materials will construct the company's second domestic magnet manufacturing facility, called the "10X Facility," at a soon-to-be-chosen location to serve both defense and commercial customers. Once the new facility is completed, expected to begin commissioning in 2028, MP Materials' total U.S. rare earth magnet manufacturing capacity will reach an estimated 10 kt (11,000 st). The company also expects to add additional heavy rare earth separation capabilities at its Mountain Pass facility in California, solidifying its status as a national strategic asset where high-purity rare earth materials are extracted, separated and refined all in one location.

"This initiative marks a decisive action by the Trump administration to accelerate American supply-chain independence," said James Litinsky, founder, chairman and chief executive officer of MP Materials. "We are proud to enter into this transformational public-private partnership and are deeply grateful to President Trump, our partners at the Pentagon, and our employees, customers and stakeholders for their unwavering support and dedication."

Rare earth magnets are one of the most strategically important components in advanced technology systems spanning defense and commercial applications. Yet today, the United States relies almost entirely on foreign sources. This strategic partnership builds on MP Materials' operational foundation to catalyze domestic production, strengthen industrial resilience, and secure critical supply chains for high-growth industries and future dual-use applications.

The agreements comprise a comprehensive, long-term package, including convertible preferred equity, warrants, loans, and price floor and offtake commitments, that extend for more than a decade. ■

Freeport-McMoran poised to gain from Trump's copper tariff against peers with few options

FREEPORT-MCMORAN could see a $1.6-billion boost to annual profit if President Donald Trump's copper tariff materializes, a benefit driven by the firm's role as the largest U.S. producer with more expansion options than rivals, *Reuters* reported.

Responsible for 60 percent of U.S. copper output, Phoenix-based Freeport has since the 19th century cultivated U.S. mine projects that have decades of growth potential without the need for fresh permitting. Other companies have struggled due to the stubborn reality of American mining: It takes years to build a U.S. mine.

Trump announced a 50 percent tariff on imports of the metal used in construction, electronics and nearly every part of the economy. It would be the first time Washington has imposed a copper tariff if enacted by Trump's Aug. 1 start date. The initial announcement, which pushed Freeport stock up 5 percent, sparked questions about where Trump hopes to procure the metal, given long-standing hurdles to building mines and smelters, and few options outside of Freeport's seven U.S. copper mines.

"The longer-term aim of the Trump administration may be for the U.S. to be fully self-sufficient in copper, but mines take too long to develop for this to be achieved in less than a 10-year time horizon," Jefferies analyst Chris LaFemina told *Reuters*.

The United States imports roughly half of its copper needs, mostly from Chile, Canada and Peru. China is the world's largest smelter and consumer, with global demand poised to jump at least 60 percent by 2050, according to the International Energy Agency.

Jefferies singled out Freeport as the company expected to benefit most from Trump's tariffs. Controlling four of the five largest U.S. copper mines, Freeport sells all of its U.S. product inside the country, more than any other company. The copper is sold at U.S. Comex copper prices, which have jumped since Trump first suggested potential tariffs in February, boosting the company's bottom line.

Freeport in April estimated it would reap a profit windfall of at least $800 million annually from higher prices should a copper tariff take effect. The estimate was based on U.S. copper prices of $4.84/lb, a premium of roughly 60 cents/lb to benchmark LME copper prices. The premium is now roughly double, equating to about $1.6 billion in additional annual EBITDA for Freeport, the company told *Reuters*. It earned $10 billion in EBITDA in 2024. Freeport declined to comment on the full tariff plan until it could review details.

U.S. refined-copper imports have jumped more than sixfold since 2014, even as production slipped 20 percent, according to U.S. Geological Survey data. The country has nearly 30 years' worth of supply within its borders.

As mines age, they must expand or be replaced. Yet mines are deeply unpopular across much of the United States, resulting in drawn-out regulatory decisions. It takes an average of nearly 29 years to build a U.S. mine, the second-longest time globally behind Zambia, a 2024 study from consultancy S&P Global showed.

Unlike consumer-goods factories, which can be built in a year or two, mines require geological exploration, a permitting process that can stretch longer than a decade, and sometimes face opposition from Indigenous or conservation groups. Construction can take more than three years. ■

Newswatch contents

US issues expedited permit for proposed Tennessee coal mine

THE TRUMP administration said it permitted a proposed coal mine in Tennessee under an expedited process aimed at accelerating federal environmental reviews of energy projects, *Reuters* reported.

In a statement, the U.S. Department of the Interior (DOI) said it granted approval for Hurricane Creek Mining LLC to mine coal on Bryson Mountain in Claiborne County, TN. The mine will produce up to 1.4 Mt (1.8 million st) of coal over the next decade, the agency said. The site was previously mined at various times between the 1950s and 2010.

The rushed permit is aligned with President Donald Trump's goal to increase coal mining as part of his energy dominance agenda.

The project is on private land but under federal law must be permitted by the DOI's Office of Surface Mining Reclamation and Enforcement.

In April, the DOI said it would implement an emergency permitting process for energy and mining projects, slashing approval times that typically take months or years to 28 days.

The department took another action this week to support coal. Its Bureau of Land Management said it is taking public comment on opening up coal leasing on public lands in the Powder River Basin in Montana and Wyoming. Comments would be taken through Aug. 7 on opening up lands that former President Joe Biden put off-limits to leasing. ■

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MP Materials and Apple announce $500 million partnership to produce recycled rare earth magnets in US

MP MATERIALS and Apple announced a definitive long-term agreement in which Apple will invest $500 million into the rare earths mine operator.

MP Materials will supply Apple with rare earth magnets manufactured in the United States from 100 percent recycled materials.

Under the agreement, MP Materials will supply Apple with magnets produced at its Fort Worth, Texas, facility — known as Independence — using recycled rare earth feedstock processed at MP's Mountain Pass site in California.

The feedstock will be sourced from post-industrial and end-of-life magnets, marking a major milestone in both companies' long-standing efforts to create sustainable, domestic supply chains.

The investment is part of a broader push by Apple to bring the production of its coveted iPhones to the United States and boost U.S. manufacturing amid a push from the Trump administration to cut reliance on China.

China halted rare earths exports in March following a trade spat with U.S. President Donald Trump that showed some signs of easing even as broader tensions underscored demand for non-Chinese supply.

Earlier, MP Materials agreed to a multibillion-dollar deal with the U.S. Department of Defense (DoD) to boost output of rare earth magnets and help loosen China's market control of the magnets.

For nearly five years, Apple and MP Materials have been piloting advanced recycling technology that enables recycled rare earth magnets to be processed into material that meets Apple's exacting standards for performance and design.

Building on this technical collaboration, MP will construct a commercial-scale, dedicated recycling line at Mountain Pass enabling the processing of a range of inputs, including magnet scrap and components recovered from end-of-life products.

In addition, to fulfill this agreement with Apple — and in line with its public-private partnership with the DoD — MP Materials will significantly expand the capacity of its Fort Worth magnetics facility.

Magnet shipments are expected to begin in 2027 and ramp up to support hundreds of millions of Apple devices. MP Materials and Apple will also innovate together to accelerate technological advancements in magnet production, as well as end-of-life recovery.

"We are proud to partner with Apple to launch MP's recycling platform and scale up our magnetics business," said James Litinsky, founder, chairman and chief executive officer of MP Materials.

"This collaboration deepens our vertical integration, strengthens supply-chain resilience, and reinforces America's industrial capacity at a pivotal moment," Litinsky said. "Rare earth magnets are essential components in smartphones, computers, wearables and other electronics, as well as vehicles, robotics and energy systems."

"This agreement advances MP's mission to restore the full rare earth supply chain to the United States while raising the global standard for sustainable production. By recovering rare earth elements from recycled materials, MP aims to reduce waste, conserve natural resources, and drive cost-competitive domestic magnet production," he added. ■

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Caterpillar and Luck Stone celebrate 1 Mt hauled autonomously at Bull Run Quarry in Virginia

CATERPILLAR INC. and Luck Stone, the nation's largest family-owned and operated producer of crushed stone, sand and gravel, announced a significant milestone in their ongoing collaboration: one million tons autonomously hauled at Luck Stone's Bull Run Quarry in Chantilly, VA.

"This milestone is a powerful demonstration of what's possible when we collaborate with our customers to deliver solutions for their critical needs. Reaching one million tons hauled autonomously at Bull Run shows that autonomy isn't just for mining — it's scalable, reliable and ready to transform the aggregates industry. We're proud to collaborate with Luck Stone to lead that transformation," said Denise Johnson, group president of Resource Industries at Caterpillar.

The achievement marks a first for Caterpillar in the aggregates industry and underscores the success of

Caterpillar's autonomous haulage system (AHS) in a quarry environment. The milestone demonstrates the safety and productivity of autonomy beyond traditional large mining applications.

"At Luck Stone, our mission is to ignite human potential, and this project is an example of what's possible when people, purpose and progress come together. We're grateful to Caterpillar and confident that operators across the country will have a similar experience," said Charlie Luck, president and chief executive officer of Luck Companies.

The collaboration began with a shared vision to transform quarry operations through cutting-edge technology.

Bull Run Quarry became the first site in the aggregates industry to deploy Caterpillar's autonomous Cat 777 trucks, supported by a full autonomy technology stack and site integration services.

Since the initial deployment, the collaboration has focused on validating autonomy along with the people and processes in conditions that are typical in quarry operations but distinct from mining.

Caterpillar and Luck Stone continue to explore opportunities to expand autonomy across additional sites and applications. The success sets a precedent for the broader aggregates industry and reinforces the companies' commitment to innovation and operational excellence. ■

Sandvik and Glencore expand partnership to include Newtrax collision-avoidance technology

SANDVIK MINING and Glencore International AG have expanded an existing partnership to include the Newtrax original equipment manufacturer (OEM)-agnostic proximity detection and collision avoidance technology, supporting Glencore's ambition to become a leader in safety.

Under the expanded partnership, Sandvik can deliver its fully OEM-agnostic Newtrax Collision Avoidance Safety technology and the Newtrax Mining Data Platform (MDP) to complement operational safety and efficiency and continue to optimize performance across Glencore's underground mixed fleet.

Implementation of these solutions on Sandvik and third-party equipment is currently underway at Glencore's Kamoto Copper Co. operations in the Democratic Republic of the Congo and its Raglan nickel mine in Canada.

The Newtrax product offers a scalable, OEM-agnostic safety and data solution designed to meet the evolving needs of modern underground mining operations. The system supports multiple levels of protection, from proximity detection systems to fully automated collision avoidance systems, and integrates seamlessly with the Newtrax MDP. This combination supports mines, regardless of their digital maturity, to enhance safety, gain real-time operational insights and drive productivity across mixed equipment fleets.

"Glencore is committed to incorporating technologies that can help create a workplace free from fatalities and injuries and improve operational efficiency," said Mark Davis, chief executive officer of Copper Africa at Glencore.

"The integration of Newtrax systems reflects our focus on safety and innovation at all levels of our global operations."

Proven in mines worldwide, the Newtrax solution plays a vital role in preventing incidents and improving safety and reliability across Sandvik and third-party equipment. Designed to address the unique safety challenges of underground mining, its advanced proximity detection capabilities support customers like Glencore to achieve and exceed their safety and productivity goals.

The existing partnership already encompasses Sandvik equipment, spare parts and rock tools. With the addition of Newtrax safety solutions, the partnership adds solutions contributing to safer and smarter mining. ■

US buyers of critical minerals bypass China's export ban by rerouting shipments via third countries

UNUSUALLY LARGE quantities of antimony — a metal used in batteries, chips and flame retardants — have poured into the United States from Thailand and Mexico since China barred U.S. shipments last year, according to customs and shipping records, which show at least one Chinese-owned company is involved in the trade, *Reuters* reported.

China dominates the supply of antimony as well as gallium and germanium, used in telecommunications, semiconductors and military technology. Beijing banned exports of these minerals to the United States on Dec. 3 following Washington's crackdown on China's chip sector.

The resulting shift in trade flows underscores the scramble for critical minerals and China's struggle to enforce its curbs as it vies with the United States for economic, military and technological supremacy.

Specifically, trade data illustrate a rerouting of U.S. shipments via third countries — an issue Chinese officials have acknowledged.

Three industry experts corroborated that assessment, including two executives at two U.S. companies who told *Reuters* they had obtained restricted minerals from China in recent months.

The United States imported 3,834 t of antimony oxides from Thailand and Mexico between December and April, U.S. customs data show. That was more than almost the previous three years combined.

Thailand and Mexico, meanwhile, shot into the top three export markets for Chinese antimony this year, according to Chinese customs data through May.

Neither made the top 10 in 2023, the last full year before Beijing restricted exports.

Thailand and Mexico each have a single antimony smelter, according to consultancy RFC Ambrian, and the latter's only reopened in April. Neither country mines meaningful quantities of the metal.

U.S. imports of antimony, gallium and germanium this year are on track to equal or exceed levels before the ban, albeit at higher prices.

Ram Ben Tzion, co-founder and chief executive officer of digital shipment-vetting platform Publican, said that while there was clear evidence of transshipment, trade data did not enable the identification of companies involved.

"It's a pattern that we're seeing, and that pattern is consistent," he told *Reuters*. Chinese companies, he added, were "super creative in bypassing regulations."

China's Commerce Ministry said in May that unspecified overseas entities had "colluded with domestic lawbreakers" to evade its export restrictions, and that stopping such activity was essential to national security. It didn't respond to *Reuters* questions about the shift in trade flows since December.

The U.S. Commerce Department, Thailand's commerce ministry and Mexico's economy ministry did not respond to similar questions.

U.S. law does not bar American buyers from purchasing Chinese-origin antimony, gallium or germanium. Chinese firms can ship the minerals to countries other than the United States if they have a license. ■

Sandvik to deliver loaders and trucks to Oyu Tolgoi

to support the copper-gold mine's underground ramp-up

AS UNDERGROUND operations ramp up at Oyu Tolgoi, Sandvik Mining is supplying 17 loaders and two trucks to support the copper-gold mine in Mongolia's South Gobi Desert.

The underground equipment supply includes eight Toro LH410 loaders, seven Toro LH515i loaders, two Toro LH517i loaders and two Toro TH551i trucks. Deliveries are slated to begin in October 2025 and continue through November 2026.

One of the world's largest known copper-gold deposits, Oyu Tolgoi is jointly owned by Rio Tinto (66 percent) and the Government of Mongolia (34 percent).

The operation started as an openpit mine in 2011, with sustainable underground production commencing in March 2023.

With openpit and underground block cave operations, Oyu Tolgoi is ramping up to become the world's fourth largest copper mine. The company said the ramp-up of production from Oyu Tolgoi remains on track to deliver an average of around 500 kt (505,000 st) of copper from 2028 to 2036.

"The underground development of Oyu Tolgoi plays a vital role in global copper supply towards greater decarbonization and electrification," said Steffan Herselman, general manager of underground operations at Oyu Tolgoi. "Though continued positive results with our ongoing trials of Sandvik battery-electric vehicles are taking place, until we are operationally ready and have the required infrastructure to support a BEV fleet, the need to invest in proven, conventional underground load and haul technology is required for the ramp-up."

Sandvik is the sole supplier of loaders and trucks at Oyu Tolgoi.

The mine currently operates a fleet of 58 Sandvik loaders, trucks and bolters.

Sandvik loaders and trucks have consistently delivered industry-leading performance for Oyu Tolgoi. They combine powerful, reliable operation with minimal downtime, delivering cost efficiency and helping to maintain peak productivity even in demanding conditions. ■

Rio Tinto and Hancock to invest $1.6 billion
to develop Hope Downs 2 iron ore project in Australia

RIO TINTO and Hancock Prospecting will invest $1.6 billion to develop the Hope Downs 2 iron ore project in Western Australia's Pilbara region.

The Hope Downs 2 project has now received all necessary state and federal government approvals.

The two new above-water-table iron ore pits will have a combined total annual production capacity of 31 Mt (34 million st) and will sustain production from the Hope Downs Joint Venture into the future.

"Approval of Hope Downs 2 is a key milestone for Rio Tinto, as we invest in the next generation of iron ore mines in the Pilbara," said Rio Tinto Iron Ore chief executive Simon Trott.

"These projects are part of our strategy to continue investing in Australian iron ore and to sustain Pilbara production for decades to come, supporting jobs, local businesses, and the state and national economies," he said. "The Pilbara has been critical to global steel supply for more than 60 years, and we are committed to ensuring it remains so well into the future."

Rio Tinto has engaged with the Nyiyaparli, Banjima and the Ngarlawangga Peoples, along with relevant government stakeholders, to ensure the responsible management of heritage and the environment in the development of the project. The project includes new nonprocess infrastructure precincts, railway crossings and haul roads, as well as realigning a 6-km (10-mile) section of the Great Northern Highway.

Ore mined at the two sites will be transported to Hope Downs 1 for processing, with first ore from the deposits and associated infrastructure scheduled for 2027.

More than 950 jobs will be created during construction and, once operational, the Hope Downs 2 project will help sustain a workforce of about 1,000 full-time-equivalent roles at Greater Hope Downs.

Hope Downs 2 is part of Rio Tinto's tranche of replacement projects that underpin the company's ongoing commitment to the Pilbara, and which will have combined total capacity of about 130 Mt/a.

During the next three years (2025-2027), Rio Tinto expects to invest more than $13 billion in new mines, plant and equipment.

The company has a clear pathway to achieve and sustain mid-term system capacity of 345 to 360 Mt/a from its Pilbara iron ore business, with a prefeasibility study also underway on the Rhodes Ridge project, the Pilbara's best undeveloped iron ore deposit. ■

Mali military helicopter airlifts gold
from Barrick-owned Loulo-Gounkoto complex

A MALIAN military helicopter airlifted gold from the Barrick-owned Loulo-Gounkoto complex three sources said, days after *Reuters* reported that a court-appointed administrator planned to sell the site's bullion to finance operations.

A Bamako court appointed a provisional administrator to restart operations at the West African country's largest gold mining site, nearly six months after Barrick Mining suspended them amid tense negotiations over the implementation of a new mining code.

Barrick said it was forced to suspend operations in mid-January after Mali's military-led government blocked its exports for two months, detained some of its executives and seized three tons of bullion. It also launched arbitration at the World Bank to try to resolve the dispute.

A brown and green helicopter touched down at the site's tree-lined landing strip. Its passengers were escorted by the mine's security team to the plant, where the gold room is located, the first source said.

The helicopter took off some five hours later with the bullion on board.

"Any plan by the provisional administrator to restart operations or sell gold from the site would be not only illegitimate but also ill-advised," Barrick said in a statement.

One ton of gold — worth about $107 million — had remained in the site's storeroom since January, when three tons of gold were removed to be stored in a bank vault on the orders of a Malian judge, the first source said.

The full ton was taken, the second source said.

The provisional administrator, former health minister Soumana Makadji, has said he plans to finance the mine's operations by selling gold, the first and third sources and a fourth person said. The first three sources said the airlifted gold would be sold for this purpose.

While drilling and other extractive activities have not yet begun, operations at the site's plant — which processes ore stocks into gold — restarted, the third and fourth sources and another person said.

According to internal estimates seen by *Reuters*, it will take between 11 and 13 days from the restart of the plant to the production of the first gold bars. ■

Komatsu commissions first diesel trolley truck;
Power Agnostic 930E was unveiled at MINExpo 2024

KOMATSU announced that it has commissioned and begun field trials for the first diesel trolley truck in its new Power Agnostic (PA) series. In collaboration with Boliden, the Power Agnostic 930E truck was deployed at Boliden's Aitik Mine in Gallivare, Sweden, marking a major step forward in the journey toward decarbonizing surface mining operations.

Unveiled at MINExpo 2024 in Las Vegas, the truck garnered significant attention for its modular, future-forward design. The truck displayed on the show floor was earmarked for Boliden's Aitik copper mine, marking the first truck to undergo mine site testing. Now operating at one of Europe's largest and most productive openpit copper mines, this next-generation haul truck is set to undergo a 12-month field trial.

Built on Komatsu's new modular platform, the Power Agnostic 930E offers flexibility and future-proofing. The PA platform enables customers to begin with diesel power and later transition to alternative energy sources such as battery-electric or hydrogen fuel-cell technology, depending on their operational needs, technology readiness, and pace of decarbonization efforts. The integration of diesel trolley assist functionality further enhances performance by reducing fuel consumption and emissions, while paving the way for a future electrified mine.

"Integrating the Power Agnostic 930E into our fleet reflects Boliden's ambition to be at the forefront of sustainable mining," said Jonas Ranggard, senior project manager, Boliden. "Partnering with Komatsu on this pilot helps us explore innovative solutions that align with our climate goals while continuing to deliver productivity and performance. We see great potential in this technology and look forward to where it can lead us next."

As a founding member of Komatsu's Greenhouse Gas Alliance, Boliden is reinforcing its commitment to a more sustainable future. The upcoming trial will enable Komatsu and Boliden to gather detailed operational insights and learnings to advance haulage decarbonization efforts further. "This is more than just a technical achievement, it's a meaningful step forward in our joint commitment towards zero-emission mining," said Jeroen De Roeck, senior mining manager, Komatsu Europe. "By commissioning the first diesel trolley truck in our Power Agnostic series at Boliden's Aitik Mine, we are turning vision into reality." ■

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Minimum concentrations of critical minerals for exploration: How good is good enough?

by Richard E. Otoo, Virginia T. McLemore and Evan J. Owen

Photo from Shutterstock

The Salar de Atacama Mine in Chile has among the world's largest and highest-grade brine lithium deposits.

Disruption in critical minerals supply chains has resulted in the evaluation of various types of mineral deposits for critical minerals potential. Much of the study on critical minerals focuses on occurrence and characterization, and there is little research addressing what concentrations of critical minerals in a mineral deposit are required to make an exploration target into an operating mine.

Understanding the cut-off grades of ore deposits being actively mined is one means to determine if concentrations in an exploration target are high enough. Cut-off grade is defined as the minimum amount of mineral contained in a ton of ore that is sent to the processing plant. Among many factors, cut-off grade depends upon the size and type of the deposit and mining operation, the processing technique and market prices. This research does not aim to define cut-offs for determining if a mineral deposit is economic. Rather, it defines estimates of concentrations of critical minerals that could be considered good enough for further exploration. For example, the Mountain Pass carbonatite deposit in California uses a cut-off grade of approximately 2 percent total rare earth oxide (TREO) for its mining operations. However, the lower-bound industry cut-off grade for rare earths is around 0.8 percent TREO. Therefore, for

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Table 1

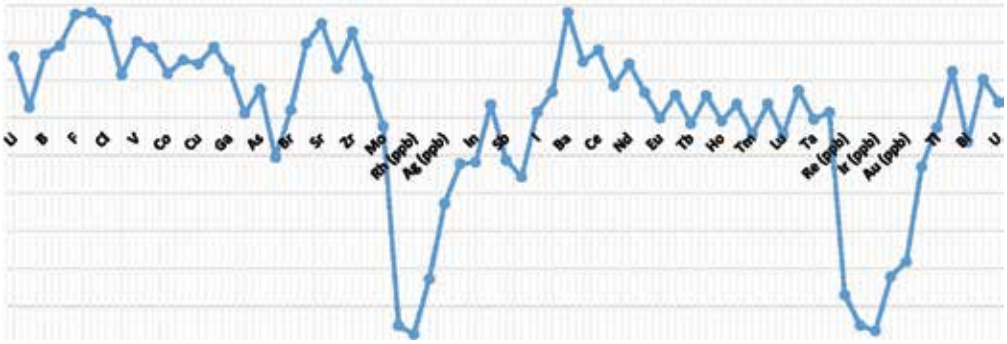
Concentration of trace elements within the upper continental crust (compiled from Rudnick and Gao, 2003; Hu and Gao, 2008).

Element (ppm, except where noted)	Shaw et al. (1967, 1976)	Gao et al. (1998)	Taylor and McLennan (1985, 1995)	Wedepohl (1995)	Rudnick and Gao (2003)	Hu and Gao (2008)	Recommended values (ppm)
Li	22	20	20		21	41	41
Co	12	17	17		17.3	15	15
Ni	19	38	44		47	34	34
Cu	14	32	25		28	27	27
Zn	52	70	71		67	75	75
As		4.4	1.5	2	4.8	5.7	5.7
Cd	0.075	0.079	0.098	0.102	0.09	0.06	0.06
Se		0.15	0.05	0.083	0.09		0.09
Rb	110	82	112	110	84	94	94
Sr	316	266	350		320		320
Y	21	17.4	22		21		21
Au (ppb)	1.81	1.24	1.8		1.5		0.00015
Ag (ppb)		55	50	55	53		0.0053
Ga	14	18	17		17.5	18.6	18.6
Ge		1.34	1.6	1.4	1.4	1.3	1.3
In			0.05	0.061	0.056	0.066	0.066
Cs		3.55	4.6	5.8	4.9		4.9
Ce	65.6	66.4	64		63		63
Hg	0.096	0.0123		0.056	0.05		0.05
Ti	0.524	1.55	0.75	0.75	0.9	0.55	0.55
Be	1.3	1.95	3	3.1	2.1	1.9	1.9
Zr	237	188	190		193		193
Nb	26	12	12		12	11.6	11.6
Mo		0.78	1.5	1.4	1.1	0.6	0.6
Sn		1.73	5.5	2.5	2.1	2.2	2.2
Sb		0.3	0.2	0.31	0.4	0.075	0.075
Ta	5.7	0.74	1	1.5	0.9	0.92	0.92
W		0.91	2	1.4	1.9	1.4	1.4
Pb	17	18	17	17	17		17
Bi	0.035	0.23	0.13	0.123	0.16	0.23	0.23
Th	10.3	8.95	10.7		10.5		10.5
V	53	98	107	53	97	106	106
U	2.45	1.55	2.8		2.7	2.6	2.6

exploration purposes, setting a grade threshold at 70 percent of this lower-bound cut-off can be considered justifiable for comparable deposit types. Similarly, a concentration of 500 ppm (0.05 percent) TREO may serve as a realistic exploration target for coal-hosted rare earth element (REE) deposits, given their distinct geological setting and extraction considerations.

Figure 1

Graphical plot showing concentration of trace elements (ppm, except where noted) within the upper continental crust (compiled from Rudnick and Gao, 2003; Hu and Gao, 2008).



Introduction

According to the U.S. Geological Survey (USGS), a critical mineral is one that is essential to the economic well-being of a nation and whose supply may be disrupted due to geological, geopolitical or environmental factors (Nassar et al., 2020). For example, REEs are critical to the production of electric-vehicle motors as well as wind turbines, yet China's share of their global production rose to more than 95 percent in 2010 (IEA, 2021). China's share has since declined, with production quotas dropping to nearly 70 percent by 2023 (Statista, 2023). This and similar situations with many of the critical minerals raise deep global concerns about supply-chain vulnerabilities (Bauer et al., 2011).

Critical minerals are used in the production of renewable energy, electronics, agricultural products and common household items (McLemore, 2020). As the global demand for these minerals continues to grow, it is not sufficient to rely solely on scaling up production from existing operations. While increasing production from known deposits can provide short-term relief, long-term resource security requires discovering new, economically viable mineral resources.

One of the most effective ways to secure future supply is through mineral exploration, which increases the global inventory of critical minerals and also minimizes risks posed by market monopolies and political instability. The major challenge of mineral exploration lies not only in identifying mineralized deposits but also in determining whether discovered concentrations are sufficient to warrant further investigation and development. A fundamental concept in this decision-making process is using cut-off grade.

In this article, cut-off grade refers to the minimum concentration of minerals required to justify further exploration efforts based on factors such as type and size of mineral deposit, mining and processing technologies, associated byproducts/coproducts and the market price of these minerals. Typically, economic cut-off grades are used to determine whether a mineral deposit can be mined profitably. However, this article focuses on preliminary cut-off grades needed to establish whether the amounts of critical minerals within a deposit are high enough to justify further exploration and detailed evaluations. By comparing mineral deposit grades, size, production and extraction technology, and other economic factors with established and active mines, exploration teams can estimate cut-off grades that justify further exploration.

Crustal abundance

Crustal abundance refers to the average concentration of an element within the Earth's crust. Concentrations of common elements may be expressed in percent, while trace elements are usually expressed in parts per million (ppm) or even parts per billion (ppb). In mineral exploration, crustal abundance values serve as a way to compare how enriched or depleted a particular element is within the Earth's crust. By comparing crustal abundance to an element's concentration within a deposit, exploration geologists can begin to set thresholds to identify anomalous targets. Such anomalies also suggest geological processes that concentrated these elements, forming potential mineral deposits models (Moon et al., 2006).

Table 1 and Fig. 1 (compiled from Rudnick and Gao, 2003; Hu and Gao, 2008; Park et al., 2012) illustrate the concentrations of trace elements (in ppm, except where noted) within the upper continental crust.

Cut-off grade in mineral exploration

Cut-off grades are not fixed and are influenced by a variety of dynamic factors including commodity prices, operating and processing costs, metallurgical recovery rates and mine planning strategies. As a result, determining the appropriate cut-off grade is critical for maximizing the economic value of a mineral deposit. Understanding the cut-off grades of mineral deposits being actively mined is one way to determine if concentrations in an exploration target are high enough.

Unlike economic cut-off grades, which

determine whether a mineral deposit is profitable to mine, preliminary cut-off grades provide an early-stage filter to determine whether a deposit warrants continued investment. This is necessary for exploration teams to determine whether to allocate more resources for further exploration work based on how the project compares with metrics from similar existing projects in active production.

Determinants of cut-off grade

The size (tonnage) of a mineral deposit plays a key role in defining cut-off grade. Large deposits will generally provide more flexibility to mine lower grades due to economies of scale, which could make lower-grade deposits with large tonnages economically viable. Conversely, small deposits require higher cut-off grades in ensuring profitability due to cost in mining and processing smaller volumes of ore.

Variations in mining and processing methods also affect cut-off grades of different mineral deposit types. Brine lithium deposits, such as Salar del Hombre Muerto in Argentina and Salar de Atacama in Chile, contain lithium in saline groundwater, which generally relies on solar evaporation to concentrate lithium over time. Lithium-bearing pegmatites contain lithium as spodumene or other lithium minerals where traditional mining and processing techniques are required to develop the deposit. Due to the lower cost associated with brine deposits, they generally have lower cut-off grades, generally around 200 mg/L (Zheng et al., 2023), whereas pegmatite lithium deposits require higher cut-off grades, generally between 0.4 and 1 percent lithium oxide (Li_2O) (Patriot Battery Metals, 2023; U.S. Securities and Exchange Commission, SEC, 2023), due to the high cost of mining and processing of the ore.

Furthermore, the cut-off grade of a mineral deposit can be affected by the economic value of its associated byproducts and coproducts. For instance, niobium, uranium or zirconium can be recovered as byproducts in some REE deposits. These byproducts tend to increase the profitability of the deposit and can reduce the cut-off grade of the primary REE. The Bayan Obo deposit is the world's largest REE resource and also contains iron and niobium as coproducts. Revenues from the iron ore production ultimately subsidize the REE production cost, thereby reducing the economic burden on REE extraction (Castor and Hedrick, 2006).

Methodology

In determining the cut-off grade of critical minerals for further exploration work, a review of mineral deposits that are active operating mines of either the same or similar types was conducted. These deposits were classified into three categories (low, medium and high targets) based on their economic cut-off grades. This classification serves as a benchmark for establishing thresholds for exploration cut-off grades.

Exploration-grade thresholds are set at 70 percent of the lowest cut-off grade observed in operating mines of similar or comparable deposits. By benchmarking to known operating grades, this ensures exploration efforts align with realistic economic and operational standards, thereby minimizing the risk of pursuing subeconomic grades (Rendu, 2014).

Comparison with existing mineral deposits

In determining the exploration cut-off grade for critical minerals, it is essential to compare prospective deposits with known operating mines of either the same or similar types of deposits. This process of benchmarking will help set realistic expectations for determining cut-off grades reasonable enough to justify further exploration. For example, the Mountain Pass deposit, which is among the significant REE deposits in the world, is a carbonatite REE deposit with TREO cut-off grade between 2 and 3 percent (SEC, 2021) and an average grade of approximately 8 percent (NS Energy, 2020). The Bayan Obo deposit in China is the largest REE deposit in the world, accounting for about 70 percent of global REE production (Statista, 2023). It is also a carbonatite deposit with an average grade of approximately 5 percent TREO (Castor and Hedrick, 2006). While its TREO cut-off grade is not explicitly stated, it is expected to be lower than that of the Mountain Pass deposit, because it is larger. Comparatively, similar deposits with TREO cut-off grades around 1 percent may be considered significant, particularly when sustained by favorable recovery rates and large-scale operations.

Lithium deposits occur either as brine or pegmatite deposits whose concentration of lithium is usually reported as Li_2O percent for pegmatite deposits or milligrams per liter (mg/L) in brine deposits. The Salar de Atacama Mine in Chile has one of the largest and highest-grade brine lithium deposits in the world and an approximately 800 mg/L cut-off grade (SEC, 2023). According to a 2023 SEC pre-feasibility study for the Silver Peak lithium operation in Nevada, a cut-off grade of approximately 50 mg/L has been adopted for several lithium brine projects in North

America. Setting an exploration cut-off grade of approximately 50 mg/L for a brine deposit could still be considered prospective, particularly with improved extraction technology. The Greenbushes Mine in Australia, which is the largest and highest-grade pegmatite lithium deposit, has between 0.5 and 0.7 percent Li_2O (SEC, 2023). Similar projects with cut-off grades around 0.4 percent Li_2O might still be considered attractive for further exploration, depending on deposit size, mining and processing methods as well as other economic factors.

Preliminary conclusion

Incorporating established cut-off grades as benchmarks for mineral exploration strategies can enhance the effectiveness of target prioritization and increase the chances of successful mines. This approach can be achieved by categorizing deposits of active mines into low, medium and high targets based on their cut-off grades, which provide a structured framework for exploration. By regularly updating benchmarking data to reflect evolving market conditions, operational costs and technological advancements, exploration grades can be set at 70 percent of the lowest cut-off grade of operating mines to ensure that potential deposits compare with operational thresholds. ■

Acknowledgments

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Women making great strides
and reshaping the mining industry

by Carrie Smith, Associate Editor

Mining has historically been one of the most male-dominated industries in the world. From underground operations to executive boardrooms, the presence of women has often been slim. Women had often been excluded from operational, leadership and decision-making roles, both by cultural norms and systemic barriers.

According to PwC's Global Mine Report (2023), women represent around 14 percent of the global mining workforce. Leadership representation, however, remains sparse, with S&P Global's 2023 report showing women holding approximately 12 percent of C-suite positions and only 3 percent of senior leadership roles globally. These figures reflect persistent gaps, but they also highlight the progress driven by a new generation of women transforming the industry.

As a global expert in tailings management, Morrison's expertise has been instrumental in shaping international best practices.

Despite the gender imbalance among mining workers, women have continuously made grand strides within the industry, resulting in pivotal changes. At the forefront of this transformation is Kimberly Morrison, one of several women who have played pivotal roles in shaping the mining sector.

Morrison's industry journey

Morrison, chief technical officer (CTO) at ATC Williams, has distinguished herself as a global expert in tailings management, a critical area for mining safety and sustainability.

As tailings safety becomes a defining environmental, social and governance (ESG) issue in mining, Morrison's expertise has been instrumental in shaping global best practices. Her technical knowledge, combined with advocacy for sustainable solutions, positions her as a leading voice on environmental responsibility in mining. Morrison's work not only safeguards communities and ecosystems but also advances the industry's social license to operate.

Her path to success embodies an inspiring archetype for others in the industry to follow. As a role model, she has displayed the importance of combining technical knowledge with visionary leadership, the power of mentorship and the drive to break down outdated stereotypes about who belongs in mining leadership.

Morrison's career in mining is a story of passion, resilience and a relentless pursuit of technical excellence.

Growing up on a small farm in rural Missouri, Morrison developed an early connection to the outdoors — a passion that shaped her career ambitions. "I wanted a profession that would allow me to spend time out in the field, not confined to a desk," she said. That desire led her to pursue a bachelor's degree in geological engineering at the University of Missouri-Rolla, now Missouri University of Science & Technology (Missouri S&T), followed by a master's degree in civil-geosystems engineering from the Georgia Institute of Technology.

Morrison's entry into mining was unexpected. After joining a Denver-based consulting firm post-graduation, she began working on federal water supply projects. But her master's research on cone penetration testing unexpectedly led her to a forensic evaluation of a tailings facility.

"At the time, I wasn't even familiar with the term 'tailings.' That project, born out of a need for my specialized expertise, marked my unexpected but ultimately impactful entry into the mining sector," she said.

That formative experience set the stage for what would become her defining area of expertise — tailings management.

"My journey has been arduous and challenging, but I've learned an important truth: with every door that has closed, another has opened, often leading to even greater opportunities," said Morrison.

Today, as the CTO of ATC Williams in Melbourne, Australia, Morrison is one of the most prominent voices globally on tailings governance and sustainable mining practices.

ATC Williams, an industry leader in tailings, water and waste management, welcomed Morrison in July 2025 to lead its technical standards, talent development growth and comprehensive training programs.

Her journey has included influential roles such as leading the global tailings function at Newmont, where she was instrumental in implementing the Global Industry Standard on Tailings Management (GISTM), and serving as an adjunct faculty member and interim director

Women In Mining

14%
Of women are represented in the global mining workforce

12%
Of women hold C-suite positions

3%
Of women have senior leadership roles globally

40%
Of mining companies have implemented formal diversity and inclusion policies

72%
Of mining companies lead in women's empowerment and initiatives

25%
Greater likelihood of above-average profitability is associated with more diverse executive teams

of the Tailings Center at the Colorado School of Mines in Golden, CO.

Morrison's profile grew significantly when she led the development and served as managing editor of SME's *Tailings Management Handbook: A Lifecycle Approach*. "This undertaking not only elevated my personal profile but also further solidified my expertise in the field," she said.

Morrison's experience includes forensic evaluations of numerous tailings failures, fueling her determination to push for improved technologies and governance. "These experiences, coupled with my disappointment in the industry's historical lack of attention and insufficient funding for tailings management, fueled my drive to become a changemaker," she said.

Yet her path has not been without barriers. Like many other women in the industry, Morrison experienced inequality and mistreatment in the work environment. "I've frequently found myself in environments that were not always welcoming or equitable, encountering barriers that went far beyond subtle biases," she recalled. During her interview with *Mining Engineering*, Morrison shared experiences of being underpaid compared to male colleagues, being professionally undermined and facing blatant discrimination.

"I've personally faced instances of unequal pay, professional sabotage and blatant discrimination, even when I was demonstrably the most qualified," said Morrison. "These are not just anecdotes; they are realities that some women continue to navigate."

However, resilience has been her cornerstone. "When you know your subject matter inside and out, it provides an undeniable foundation for confidence, regardless of external perceptions," she said. She credits her technical expertise and drive for new opportunities, even when uncomfortable. Additionally, she cultivated a strong professional network, including a 34-year long friendship with Missouri S&T geology professor Francisca Oboh, whose guidance helped shape her career.

"I've learned the importance of embracing resilience as a mindset," said Morrison. "This means viewing setbacks not as failures, but as opportunities to learn and adapt. It's about developing the inner strength to bounce back from adversity, persist through challenges, and remain focused on making a positive impact."

For Morrison, mentoring and uplifting women in mining is now a central mission. In recent years, she has made significant efforts to connect with various women in the industry, focusing on mentoring, supporting and empowering other women, especially those new to the field.

Though working for a rewarding and impactful industry, mining still presents its own unique challenges for women. Morrison's advice to women considering mining is direct and hard-won — be resilient, build a diverse and supportive network, and never stop learning.

"Being exceptionally good at what you do will be your most powerful asset, giving you the confidence and credibility to overcome any doubts," she said. "Your knowledge and skills are your shield and your sword."

Looking ahead, Morrison believes the mining industry must take concrete steps to become more inclusive. "To truly attract and retain women, the mining industry must aggressively tackle systemic barriers and foster genuine inclusivity," she emphasizes. For her,

A 2023 McKinsey report on diversity and inclusion found that companies with more diverse executive teams are up to 25 percent more likely to achieve above-average profitability.

this means enforcing equitable pay, creating safe and supportive work environments, and implementing formal mentorship programs.

"Attracting and retaining women is not just a matter of fairness; it's a strategic imperative for the mining industry," she stressed.

Morrison is committed to shaping the future of tailings management through technical rigor, sustainability and workforce development. She stands as a testament to how expertise, resilience and a commitment to driving change can redefine not only individual careers but the standards of an entire industry.

Why diversity is important

Challenges remain in the journey for women in mining. Cultural biases and stereotypes about mining as "men's work" persist, reinforced by the often remote and physically demanding nature of the job. According to World Bank's 2023 Business Case for Gender and Mining study, 28 percent of women reported harassment, which remains a significant hurdle to retention and advancement. In addition, 53 percent of women reported experiencing bullying, as compared to 43 percent of men.

According to the same study, women report fewer opportunities to advance than their male colleagues, and there is a perception that men can advance by getting on-the-job experience while women are expected to come in with the experience to advance. In addition, mentorship and sponsorship opportunities for women remain limited, especially for those aspiring to senior operational roles. Inflexible work environments, particularly in remote operations, further complicate efforts to retain and promote female talent.

However, a 2019 survey by the International Labour Organization found that 57.4 percent of company responses agreed that gender diversity initiatives improve business outcomes, S&P Global reported in 2023. Among the responses, 60.2 percent reported increased profits and productivity, while 54.4 percent reported greater creativity, innovation and openness.

Industry-wide efforts, such as the rise of Women in Mining (WIM) networks and formal corporate diversity policies, are helping to foster a more inclusive environment. According to the 2024 WIM Brazil Report, 68 percent of mining organizations have formalized commitments to diversity, equity and inclusion, with 40 percent of mining companies implementing formal diversity and inclusion policies and a majority engaging in women's empowerment initiatives. Moreover, mining companies lead in women's empowerment, accounting for 72 percent of initiatives in this area.

The business case for diversity in mining is clear. Despite the barriers, there is growing recognition of the benefits that diversity brings to the mining sector. McKinsey & Co.'s 2023 report on diversity and inclusion found that companies with more diverse executive teams are up to 25 percent more likely to achieve above-average profitability.

Attracting more women to the sector is essential. The global energy transition, coupled with decarbonization efforts, is reshaping mining's future workforce needs. Skills in sustainability, governance and digital technologies are in demand, areas where women are increasingly gaining visibility and influence. For sustained progress, the mining sector must continue investing in education, mentorship programs, flexible working conditions, and workplace safety tailored to women's needs.

The future of the industry

As the industry stands at a pivotal moment driven by rapid changes, the skills and leadership styles women bring are critical for innovation and sustainability.

Leaders like Kimberly Morrison not only break glass ceilings but also set new standards for how mining companies operate responsibly and profitably in modern-day scenarios.

Like Morrison's story, the stories of key industry women inspire a future where diversity is not an exception but a norm, encouraging the next generation of women to pursue careers that shape the future of mining worldwide.

Mining stands at a pivotal crossroads. The pressures of net-zero emissions, social responsibility and technological disruption demand a more inclusive and diverse workforce. Morrison's contributions, among others, illustrate that women are not just participating in mining's future, they are defining it.

As companies deepen commitments to diversity, equity and inclusion, the sector can unlock its full potential by ensuring that leadership at every level reflects the breadth of talent available. The path forward requires continued investment in mentorship, flexible work environments, and policies that address workplace harassment and cultural biases.

The stories of trailblazing women like Morrison serve as a call to action for the industry: The future of mining is diverse, sustainable and driven by leaders of all strides.

Visit *Mining Engineering's* website at me.smenet.org to read more about other women trailblazers in the mining industry and more. ■

Improved drill-and-blast designs
free $3.6 million of ore for surface copper mine

by Tácio Ferreira and Liz Diaz

Capstone Copper's Pinto Valley Mine faced challenges in recovering rock and ore on final walls because of geotechnical constraints that require restrictions on methods for loading blastholes adjacent to the pit boundaries to preserve wall stability. The operation had been using the same drill-and-blast designs for years. With changing geology, such as harder rock, as mining progressed, material was being left unmined in final walls because of poor breakage. The amount of unrecovered, unprocessed ore was estimated at 345 kt/a (380,000 stpy) generated from an average of 60 final wall blasts performed annually. The engineering team from Capstone and Dyno Nobel engaged to minimize the amount of material left on the final pit walls.

This article presents how data were collected and design standards reviewed, and the opportunities that were found to improve ore recovery from pit final walls without increasing drilling and blasting costs. The results collected from implementing the new design on two benches showed the potential for extra revenue of approximately $3.6 million generated annually from reducing final wall unrecoverable underbreak by nearly 71 percent on the mine's highwalls.

Figure 1

Visual evidence of unrecovered material attached to the highwall on the south side of the Capstone Copper Pinto Valley Mine (left), and schematic cross-section illustrating unrecoverable underbreak and reduced catch-benches (right).

Introduction

The Pinto Valley Mine is located approximately 123 km (80 miles) east of Phoenix, in Globe, AZ, and has been in operation since 1972. Pinto Valley is a copper porphyry deposit. The primary host rock is the Precambrian-age Lost Gulch Quartz Monzonite (equivalent to the Oracle Granite or Ruin Granite).

The deposit's economic mineralization is a hypogene ore body with chalcopyrite, pyrite and minor molybdenite as the only significant primary sulfide minerals. The openpit mine extracts and processes copper ore locally with the capacity to process 60 kt/d (66,000 stpd). The operation produces a primary copper sulfide concentrate and a byproduct molybdenum concentrate (Capstone Copper, 2024).

The mine uses traditional hard-rock mining methods (drilling, blasting, loading and hauling) to extract the ore and transport it to the processing facilities.

A series of drill-and-blast standards and rules were developed over the years of operation to meet requirements for fragmentation (diggability and processing) and slope stability (vibration limits). The drill-and-blast bench heights at the mine are 13.7 m (45 ft). Where slope stability allows, single 27.4-m (90-ft) benches are mined with two passes of 13.7-m (45-ft) benches. Single-pass, pre-split lines help prevent damage and keep a cleaner highwall.

With the primary objective of maintaining highwall stability near final pit walls, the mine faced challenges associated with material unrecovered on the walls over the years. This generated loss of revenue from unrecovered, unprocessed ore.

Other issues such as extra time spent on trying to recover the hard material on the walls using secondary breakage techniques (for example, hydraulic hammers and excavators) that were often unsuccessful; coarse fragmentation near the wall;

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Figure 2

Coarser fragmentation observed near the wall on the top 13.7 m (45 ft) of a bench that has been pre-split down to the full 27.4-m (90-ft) depth. Notice coarser material near the bench crest.

reduced catch bench functionality; and wall stability problems (such as overhangs) were also common and visible on the walls mined years prior (Fig. 1).

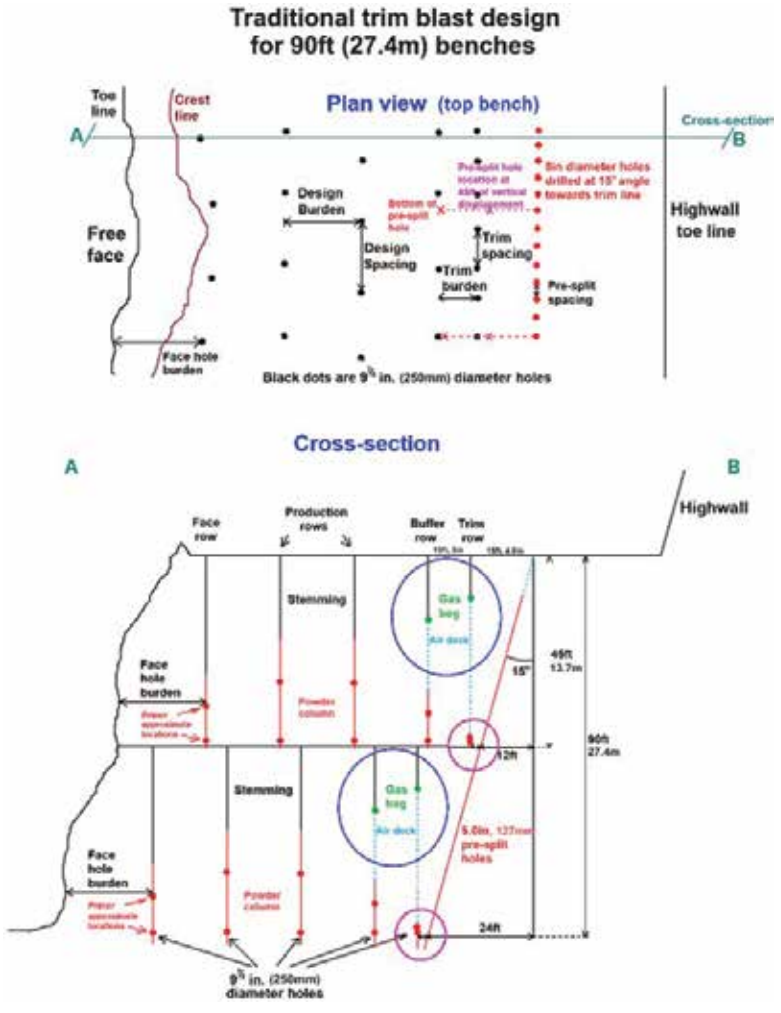
Methodology

To address the problem, the Capstone Copper Pinto Valley Mine engineering team and Dyno Nobel engaged to perform a detailed evaluation of the trim-blast designs used over the years at the operation and conduct field measurements to verify if the performance observed was aligned with the drilling and blasting plans.

The steps taken in the project entailed the following: (1) Review drill-and-blast designs to evaluate if any immediate opportunities exist to enhance them and improve fragmentation, and therefore recovery of the material left on the walls. (2) Collect field data, including drill operators' feedback, to evaluate the quality of pre-splitting techniques and potential influence in the results. (3) Test and assess design alternatives in two benches of the mine for a period of approximately six months.

Figure 3

Plan and cross-section views of the traditional trim-blast designs used at Capstone Copper Pinto Valley Mine for 27.4-m (90-ft) final bench heights.



Results

The results obtained during this project are summarized as follows:

1. The review of the trim-blast designs revealed two main concerns:
   - The low powder factor and resulting potential and usually observed poor fragmentation on the top, back side of the blasts, near the highwall (see coarse material in Fig. 2, generated from the blue circle area of low powder factor in cross-section of Fig. 3).
   - The proximity of the toes of the trim row holes to the pre-split line of approximately 0.9 m (3 ft) (see pink circles in cross-section of Fig. 3).
2. The Capstone Copper Mine engineering and DynoConsult teams conducted pre-split drill hole deviation (inclination and orientation) measurements and interviews with drilling operators to evaluate the potential impact of pre-split drilling quality on trim-blasting operations. The results are shown in Table 1.

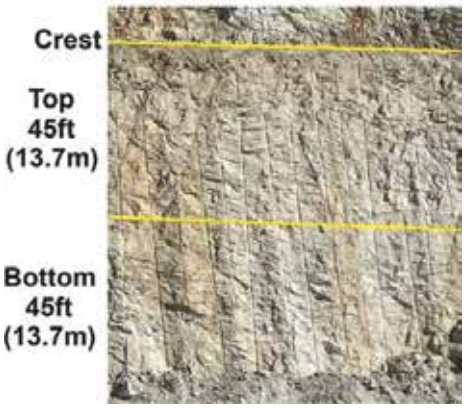
Table 1

Boretracking data collected from pre-split holes showing spectrum of average angle of inclination from 14.8 to 18.7 degrees and corresponding changes in design length (depth) and bottom walk from collar (horizontal distance between collar and bottom of pre-split hole).

Face height (ft)	Angle of inclination (degree)	Final hole length (ft)	Bottom walk from collar (ft)	Comments
45	14.8	46.5	11.9	Top bench: Approximately 3 ft forward walk variance between holes
45	15.0	46.6	12.1	
45	18.7	47.5	15.2	
90	14.8	93.1	23.8	Bottom bench: Approximately 7 ft forward walk variance between holes
90	15.0	93.2	24.1	
90	18.7	95.0	30.5	

Figure 4

Image of pre-split hole traces on 27.4-m (90-ft) bench face showing significant deviation on bottom portion compared to the top 13.7 m (45 ft).



ts showed that the spectrum of pre-split hole deviation could interfere directly with the design and execution of trim blasts in front of them — especially for the bottom, second 13.7-m (45-ft) pass, where the deviation (walk of the pre-split holes) was more accentuated (see Fig. 4 for a visual reference and Fig. 5 for detailed schematics of the issue).

On one hand, the pre-split holes can intersect trim row holes, if drilled later than the trim blast holes in front of them. On the other hand, if drilled and blasted earlier, pre-split holes can directly affect the area where the trim holes will be drilled in the future by creating a pre-fractured surface that can work as an "energy-loss conduit." The second case is the most common sequence of events at the Pinto Valley Mine.

The behavior observed in Fig. 5 matches two important observed behaviors:

1. The behavior observed in Fig. 1, where the nonbroken knobs on the wall were generally observed at the bottom 13.7 m (45 ft) of the 27.4-m (90-ft) full bench, and less frequently but still possible on the top 13.7 m (45 ft).
2. Occurrences of pre-split holes venting out of trim row holes when the pre-split lines were drilled after trim blast holes had already been drilled ahead of them.

From this point forward, the team working on the project identified that two paths could be pursued to mitigate the issue of unrecovered material being left on the walls:

1. Adjust trim-blast designs to accommodate inherent pre-split drilling accuracy limitations.
2. Improve pre-split hole drilling quality (minimize drill hole deviation) as much as possible.

The focus of the project team was to create an alternate design option while coaching the pre-split drillers on how important the drilling quality was for the overall results achieved. The new design created for the trim blasts is shown in Fig. 6. Figure 7 shows a visual comparison of results achieved where the new design was used with the previous results obtained in multiple benches above with the traditional designs.

To quantify the monetary impact of the

Figure 5

Cross-section of traditional trim-blast design with the addition of pre-split holes deviation spectrum.

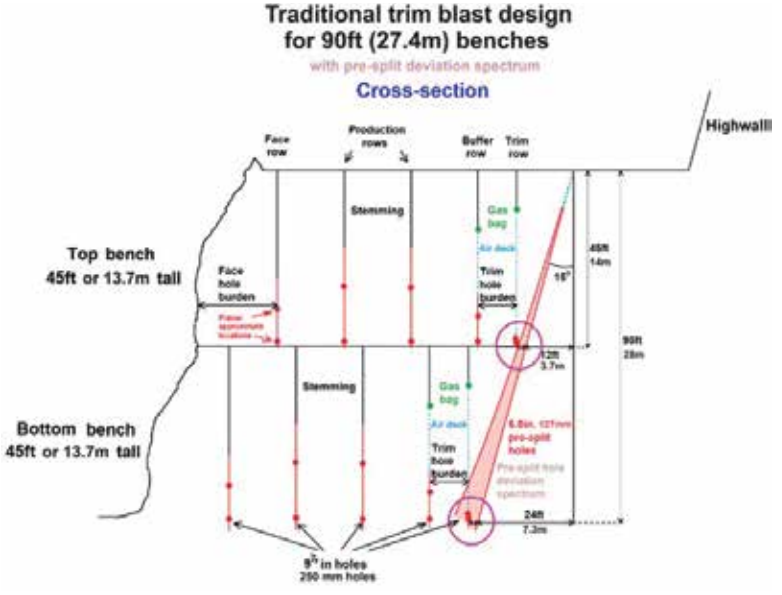


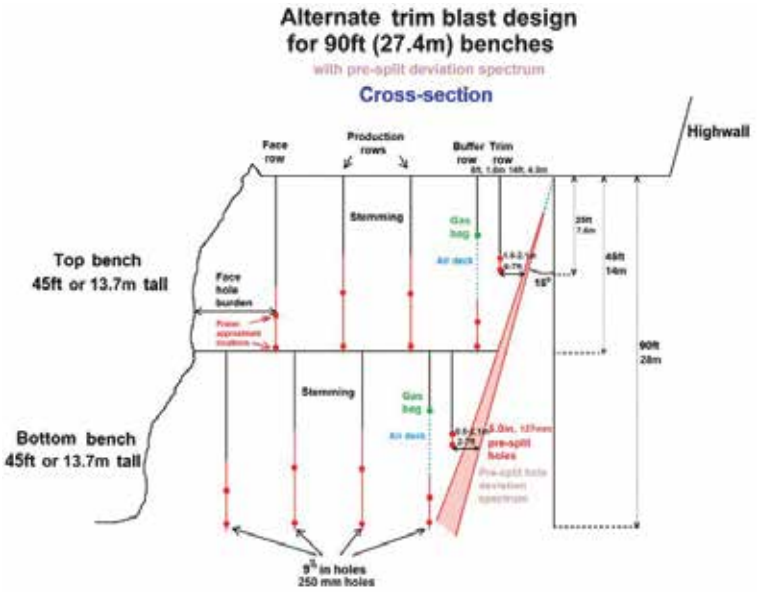
Table 2

Estimated gains in tons, copper pounds and extra revenue generated from three average-grade scenarios.

Parameter	Underbreak tons lost, to be recovered with new design	Potential recovery if new design used	Revenue to be recovered (@ $3.60/lb) using 0.111 percent grade (lower-grade scenario)	Revenue to be recovered (@ $3.60/lb) using 0.187 percent grade (mid-grade scenario)	Revenue to be recovered (@ $3.60/lb) using 0.255 percent grade (higher-grade scenario)
Net gain from using new design to recover 71.2 percent more tons from walls	270,780	100 percent	$2,168,942	$3,637,253	$4,963,780

Figure 6

Alternate cross-section design to accommodate drill-hole deviation.



improvements, the final wall shown in Fig. 7 was used as a sample. The volume and average copper grades of the knob-like shapes were extracted with the aid of Maptek's Vulcan mine planning software. The results showed an average 71.2 percent decrease in unrecoverable underbreak on the benches where the new design was used. Figure 8 illustrates the observed improvements in material recovery obtained with the alternate design.

For an average of 60 final-wall blasts per year recorded in the recent years at the mine, we estimated unrecoverable tons to be near 345 kt/a (380,000 stpy). With that, the amount of extra material to be recovered with the alternate design tested was estimated at 245 kt (270,000 st) of ore at average grade of 0.187 percent copper (Cu, average grade of the knobs quantified in the study).

The gain with improved ore recovery was estimated at $3.6 million yearly with the average numbers considered in the study for final-wall blasts conducted yearly and expected average grade of 0.187 percent Cu (Table 2).

Furthermore, the new design is estimated

Figure 7

Visual evidence of the decrease in unrecoverable underbreak in the areas of the bench where the new design was used successfully.

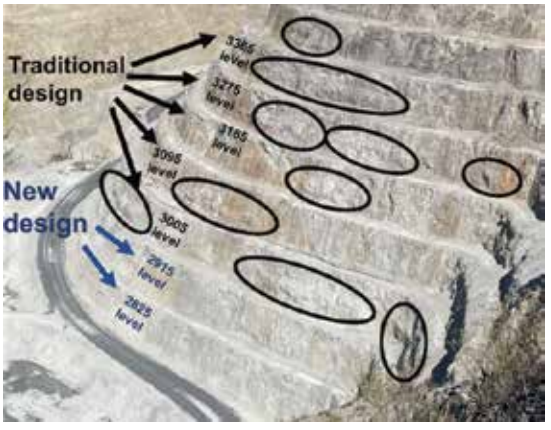
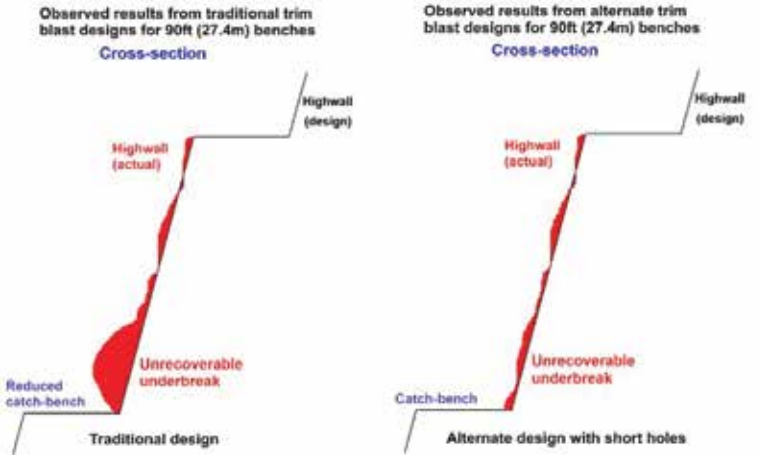


Figure 8

Schematics of observed improvements in material recovery obtained with alternate design.



to save approximately 2 percent on drilling and blasting costs near the highwalls. This cost reduction comes from a reduction in drilling footage per ton of rock extracted due to using short holes in the trim row, and a much-reduced need for gas bags as accessories for air-decking. This was done without altering the pre-established geotechnical constraints on maximum pounds per delay allowable near geotechnically concerning areas.

Conclusion and future work

The main findings of this work were the cause-and-effect relationships between pre-split drilling quality and its potential impact in traditional designs practiced at Capstone Copper's Pinto Valley Mine. The team was able to decrease by 71.2 percent the amount of material losses by using alternate drill-and-blast designs that were created considering field-collected drilling-accuracy data.

The increase in material recovery is estimated to bring into production nearly one million pounds of copper into the mine's yearly production, considering an average grade after all recoveries applied of 0.187 percent Cu. Using a currently conservative price of $3.6/lb of copper, this equates to approximately $3.6 million in extra revenue a year in benefit for the operation. The positive monetary impact comes with a series of other harder-to-quantify benefits, such as cleaner walls and more effective catch benches.

Trim blasts' drilling and blasting costs were decreased with the new design, by drilling less per ton blasted using short trim holes and decreasing the need for accessories (blast bags) by nearly two-thirds on those blasts.

Enhancements to the alternate design presented here remain a potential for future work. Further effort to improve pre-split drilling accuracy can and should still be investigated. The use of different drill bit types, stabilizing drill pipes, and tools for angle setup could also be evaluated to decrease drill-hole deviation. ■

Acknowledgments

The authors would like to recognize the value added by multiple professionals that supported this work, including, but not limited to, the Capstone Copper's Pinto Valley Mine management and engineering teams, Mike Kotraba and Sid Erikson.

Reference

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MMEF to celebrate industry honorees at Mining Hall of Fame banquet

The 43rd Annual American Mining Hall of Fame Awards Banquet and Fundraiser, sponsored by the Mining and Minerals Education Foundation (MMEF), will be held Dec. 6 in Tucson, AZ.

Each year, the MMEF honors a slate of individuals and companies who have made notable contributions to the advancement of the mining industry. This year's distinguished nominees are:

Kathleen L. Quirk, president and chief executive officer and a member of the board of directors of Freeport-McMoRan Inc. is the 2025 Hall of Fame Inductee. Quirk joined Freeport in 1989 and had responsibility for a broad range of corporate functions, including tax, investor relations, corporate development and treasury before being named chief financial officer in 2003. She was named president of Freeport in 2021 and became a member of the board of directors in 2023. As a senior member of the company's executive team for more than 20 years, she has been instrumental in Freeport's strategic planning and execution of company goals. During that period, Quirk was named Best CFO in Metals and Mining by *Institutional Investor Research* magazine on numerous occasions. She holds a bachelor of science in accounting from Louisiana State University.

Steve Holmes, chief operating officer for First Majestic Silver, is a Medal of Merit recipient. Holmes is responsible for overseeing all operational functions at the mines and for projects. Prior to joining First Majestic Silver, Holmes held the position of vice president, joint venture portfolio at Barrick Gold Corp., and was responsible for overseeing Barrick's interest in their global joint venture operations and projects. He previously served as the chief operating officer for KGHM International, operations vice president at the Sierra Gorda copper mine in Chile and has acted in general management roles at Asarco and Freeport-McMoRan at multiple sites, which included leading FMI's mine technology group. He is a graduate of The University of Arizona with a degree in mining engineering and earned his MBA at Western New Mexico University.

Dawn Meidinger is a Medal of Merit recipient and is a partner at Dorsey & Whitney LLP with multidisciplinary experience in permitting, exploration and mining, renewable energy and linear projects, and handling all aspects of NEPA, NHPA and ESA compliance for those initiatives on public lands. An advocate for the importance of mining and minerals in our daily lives, she has broad transactional experience related to due diligence, land-use planning, earn-in, farm-out and joint venture agreements in conjunction with the development of mineral exploration targets and permitting mining operations. Meidinger has a J.D. from Arizona State University, Sandra Day O'Connor College of Law and a B.S., cum laude, justice studies from Arizona State University.

Jessica (Jess) Scanlan will receive the Medal of Merit for Young Professionals. She is a digital strategist, content creator, and founder of


Kathleen L. Quirk


Steve Holmes


Dawn Meidinger


Jessica Scanlan

MineLife Media. Named to Women in Mining UK's 2024 WIM100 list, Scanlan partners with mining companies and industry organizations to enhance their digital presence and public engagement. She is a passionate advocate for improving mining's public perception and regularly creates educational mining and geoscience content through her "Rock Record" series and geotourism initiatives. She combines her technical background with modern communication strategies to help bridge the gap between the mining industry and the public, while advocating for positive industry change. She earned her degree in geological engineering with an emphasis in mining from Montana Tech.

Call & Nicholas Inc. (CNI) will receive the Industry Partnership Award. CNI is an international mining consulting firm that specializes in geological engineering, geotechnical engineering, and hydrogeology. It has been providing a wide range of engineering services to the mining industry for 45 years with an outstanding reputation built on the expertise and integrity of its staff and their dedication to excellence.

Four individuals who played key roles in mining's history will also be recognized:

Sir Alfred Chester Beatty (1875-1968) was an American-British mining magnate and philanthropist. Beatty graduated from Columbia School of Mines in 1898 with master of engineering and doctor of science degrees and immediately went to Colorado to work in the mines. He joined Guggenheim Exploration Co. in 1906 as consulting engineer and assistant general manager, during which time Guggenheim acquired a 25 percent interest in Bingham Canyon. He went on to serve as a director of Nevada Consolidated Copper Co., Ray Consolidated Copper Co. and Chino Copper Co. He moved to England and founded Selection Trust in 1914 with interests in Russia, Ghana, Sierra Leone and Rhodesia. Through Rhodesian Selection Trust Ltd., he developed the Bwana M'Kubwa and Mufulira mines in current-day Zambia as well as properties in the Democratic Republic of the Congo.

Clara Clark (1876–1959) and **Isabel Little** (1883–1936) were in the first class to graduate as mining engineers in 1904, becoming Montana Tech's first female mining engineering graduates. When the Montana School of Mines opened, Clark was the first student to enroll. Upon graduation, she represented Montana at the American Mining Conference, discovered ore deposits in neighboring states and held the inaugural meeting to form the Montana School of Mines Alumni Association. Heralding from Baltimore, Little came to Butte following her high school graduation. Little became fascinated with mining engineering doing classwork at the Ophir, Colusa Parrot and Neversweat mines. After graduation, she spoke of the hardships she experienced in the underground mines as a woman and of the miners who were reluctant to allow women underground. She worked as an assayer, a mining consultant, and was ahead of her time as a promoter of women in mining engineering.

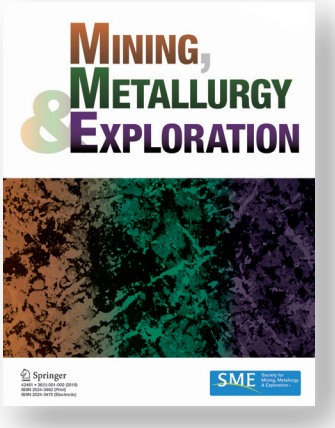
Neil B. Prenn (1942–2023) was born in New York City, raised in rural southern California, and received an engineer of mines degree from the Colorado School of Mines in 1967. He went to work for Cyprus Mines Corp. at its main office in Los Angeles. After seven years in Los Angeles from where he toured and reviewed numerous projects, he was transferred to the Cyprus Pima Mine in Arizona, where he held increasingly responsible positions and went through two sizable expansions. Prenn subsequently worked on many projects of varied minerals. In 1987, he started Mine Development Associates, which was sold to the principal employees in 2016. The employees resold the company in 2019 to RESPEC. Prenn was awarded the AIME Charles F. Rand Memorial Gold Medal in 2022.

MMEF, formerly known as the Mining Foundation of the Southwest (MFSW), is a nonprofit organization dedicated to promoting education and public understanding of the mining industry and its related disciplines.

MMEF seeks sponsors to advance its mission, raising funds designated to support the foundation's education program operated through The University of Arizona School of Mining & Mineral Resources.

Chris Earnest and Joshua Page serve as its educational outreach coordinators (K-12), creating educational materials and leading demonstrations and activities for students and the public to help stimulate interest in and understanding of mineral resources and the mining industry. ■

Extended abstracts from the SME journal Mining, Metallurgy & Exploration



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Invited Extended Abstracts

A risk-based pillar design approach combining stochastic continuous and discontinuous modeling in an underground stone mine

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Keywords: Pillar design, Risk, Discrete element modeling, Stochastic modeling, Reliability method, DFN, LiDAR

This study introduces a comprehensive risk-based pillar design methodology that integrates LiDAR and photogrammetric surveys with stochastic discrete and continuous numerical modeling. The framework quantifies pillar failure probability by combining strength and stress variability through the reliability method. Stochastic discrete element modeling (DEM) revealed that variability in intact rock strength plays a more significant role in pillar strength uncertainty than the spatial variability of discontinuities. A finite volume model (FVM), using the point estimate method, was applied to assess stress variability across a real mine layout, accounting for changes in rock elastic properties. Field validation using laser scanning and drone surveys confirmed strong agreement between simulated and observed pillar behavior, demonstrating the method's applicability for site-specific ground control design.

Introduction

Pillar collapse is a high-consequence, low-frequency event in underground mining. Given the significant risk associated with these failures, design approaches that incorporate variability and uncertainty should be favored over traditional deterministic methodologies. This work presents a risk-based pillar design framework that enables the estimation of probability of failure by integrating stochastic modeling of pillar strength and stress estimation. The methodology was implemented in a dipping underground limestone room-and-pillar operation and validated using laser

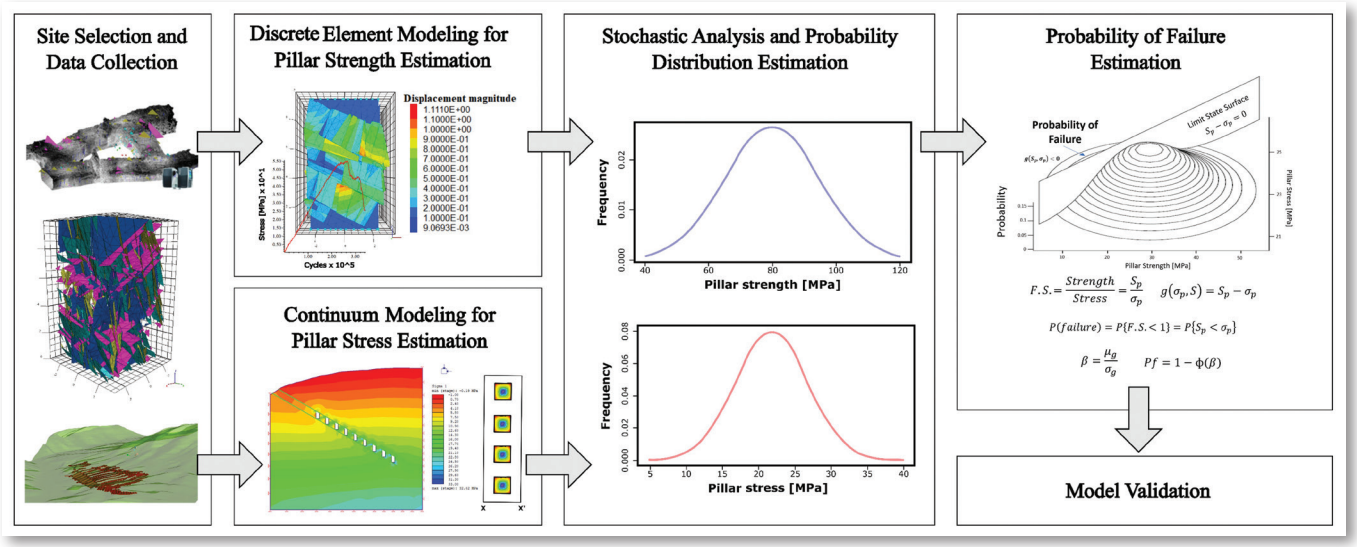

Fig. 1 Proposed workflow for the integration of laser scanning and stochastic modeling in the case study mine.

scanning and photogrammetric survey data.

Methodology

Pillar strength was estimated using the bonded block method (BBM) in 3DEC, combined with filtered discrete fracture networks (DFNs) derived from site-specific discontinuity mapping. Models were calibrated against the National Institute for Occupational Safety and Health (NIOSH) empirical pillar strength formula using intact rock parameters from laboratory testing. Simulations were conducted for three pillar geometries — width/height (W/H) ratios of 0.5, 0.8 and 1.0 — with 15 stochastic realizations per case.

A parallel pillar stress analysis was performed using a finite volume modeling (FVM) approach in 3DEC. The model accounted for the variability in rock mass deformation properties and three horizontal-to-vertical stress ratio scenarios (K_0 = 0.5, 1.0 and 1.5). The point estimate method was used to evaluate the influence of input variability on pillar stress distribution.

Stochastic strength and stress outputs were then combined using the reliability method. Pillar probability of failure (Pf) and factor of safety (FoS) were calculated using the limit state function defined as the difference between pillar strength and stress.

Results

The stochastic DEM simulations demonstrated that discontinuities reduced pillar strength slightly, with fractured pillars achieving 95 to 98 percent of the strength of intact models. However, the variability introduced by discontinuities was low, with coefficients of variation (COV) between 1.3 and 1.6 percent, compared to 13.3 percent COV from intact uniaxial compressive strength (UCS) variability. The average fractured pillar strength for 0.8 W/H geometry was 34.6 MPa.

Stochastic stress modeling revealed stress variability across the mine geometry. Pillars at greater depths and beneath topographic highs experienced higher average vertical stresses. Three stress scenarios yielded different maximum stress values, with scenario 3 (K_0 = 1.5) reaching up to 23.4 MPa. By applying the reliability method, the probability of failure for each pillar was estimated. Under the highest stress scenario, the maximum Pf observed was 0.83 percent, with 17 of 72 pillars showing a FoS below the standard 1.8. A negative logarithmic relationship between FoS and Pf was observed. Based on this trend, the study proposes a 0.05 percent Pf threshold as a potential design criterion aligned with the conventional 1.8 FoS recommended by NIOSH.

Model validation

One of the pillars within the case study mine (CSM) was selected for a validation exercise using terrestrial LiDAR and drone-based photogrammetric surveys. The scanned pillar was modeled using the same BBM + DFN approach under simulated in situ loading conditions representative of the mine. The model predicted maximum displacements on the order of 2.99 mm, with higher deformations occurring at corners where intersecting discontinuities were present. These locations correlated with areas of observed scaled loose rock in the scanned point cloud.

Table 1 — Stochastic DEM fractured pillar strength comparison with NIOSH empirical strength results.

W/H ratio	Fractured pillar strength			Fractured pillar strength / NIOSH intact pillar strength	Fractured pillar strength / NIOSH CSM pillar strength
	Average (MPa)	Standard deviation (MPa)	COV (percent)		
0.5	29.7	0.42	1.41	0.95	1.05
0.8	34.6	0.54	1.56	0.96	1.06
1	37.7	0.49	1.29	0.98	1.08

Discussion

The proposed methodology incorporates geomechanical variability into both the strength and stress estimation components of pillar design. While dis-

continuities do influence strength, their contribution to variability was limited compared to the uncertainty introduced by intact rock UCS. This observation is consistent with earlier research indicating that DFN size filtering and rock bridge continuity can reduce conservatism in strength predictions.

The use of the reliability method enabled to quantify pillar failure risk through estimating the probability of failure. While this parameter is not currently part of stone pillar design standards in the United States, it provides a more complete representation of design uncertainty. In the absence of formal acceptance criteria, the derived relationship between FoS and Pf can serve as a basis for defining acceptable risk thresholds.

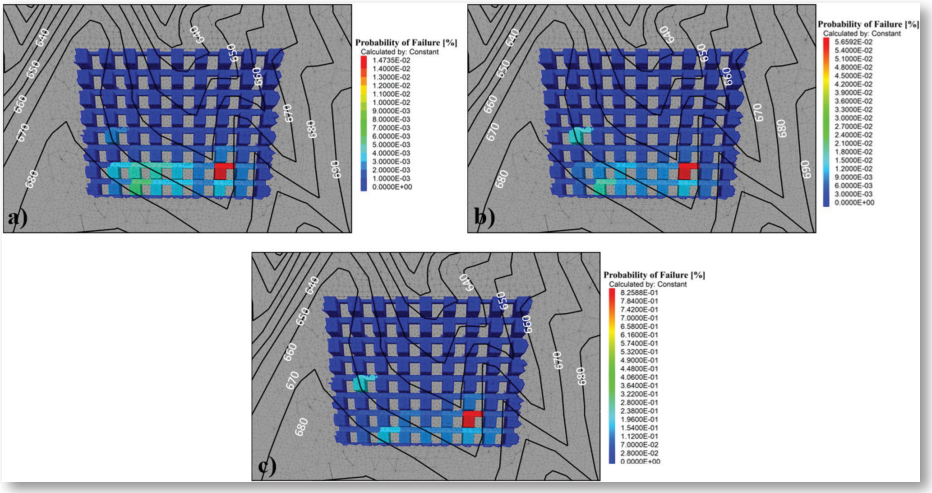

Fig. 2 Top view of the simplified CSM model colored by probability of failure for each stress scenario: (a) stress scenario 2: $K_0 = 0.5$, (b) stress scenario 1: $K_0 = 1.0$ and (c) stress scenario 3: $K_0 = 1.5$.

By integrating this methodology into ground control management plans (GCMPs), mining operations can better document, monitor and respond to evolving geotechnical conditions. The framework is compatible with performance-based design and aligns with international best practices in risk-informed ground control.

Conclusion

This work presents a validated risk-based pillar design approach that integrates stochastic discrete and continuous modeling with a reliability-based failure assessment. The methodology enables the estimation of failure probability and supports informed decision-making by addressing geotechnical uncertainty explicitly. Results from this study demonstrate that while discontinuities affect strength, intact rock variability is the dominant factor in uncertainty characterization. The framework can serve as a practical tool to improve the safety and reliability of pillar designs in underground stone mining. ■

References

A list of all references is available in the full paper.

End-users' perspectives on digitalization and automation — Insights from the Swedish mining industry

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Keywords: Digitalization, Automation, Mining industry, Skill gap, Machine maintenance

Mining is progressing toward increased automation and digitalization, enhancing safety and efficiency and simultaneously changing the nature of work. This paper examines the impacts, challenges and opportunities associated with automation and digitalization in the mining industry from the perspective of end-users, highlighting why their insights into technology development and further education may be crucial for the sector. Overall, end-users expressed a broadly positive attitude toward digitalization and automation, although they pointed out that not every task can be automated. Machine and road maintenance is seen as the most difficult to automate. The findings underscore the significance of involving end-users at an early stage in the development and implementation of technologies, as their perspectives can improve technical solutions and foster more favorable attitudes toward them. They also reveal that as new systems are introduced, digital skills, technical knowledge and the ability to adapt will become ever more critical. This emphasizes an increased need for further education to enable workers to effectively manage new technologies as they are introduced. Consequently, mining companies should strategically address learning, skill development and continuing education during working hours, offering flexible and diverse learning opportunities to prevent knowledge disparities among individuals and work teams within the mine.

Background

The mining industry has progressed through successive industrial revolutions, from manual and isolated operations to today's semiautonomous and fully autonomous systems. Autonomous systems can react without human intervention, but human expertise is still vital. For example, mixed-fleet automation and artificial intelligence (AI) rely on humans' knowledge to work efficiently, but bringing automated and human-driven processes together will change how workflows are designed and carried out. Digitalization boosts productivity, safety and the overall work environment, but the transition can bring temporary productivity losses. As mining moves toward more digitalization and automation, it will entail new skill requirements for the workforce. This necessitates upskilling and reskilling mine workers so they can keep pace with technological developments and perform their jobs.

The mining industry recognizes the need for new competencies, but further education remains challenging. Two key questions persist concerning the optimal approach to further education and determining the competencies needed in the future. Abrahamsson and Johansson [1] argue that mining will require more abstract knowledge as automation increases, while Marszowski and Iwaszenko [2] suggest that new working methods will create new decision-making paths, with production workers making more rapid decisions. Workers will need both formal knowledge, such as geological, computer and technical skills, and generic knowledge [3] — for example, analytical, teamwork, communication and digital skills [4].

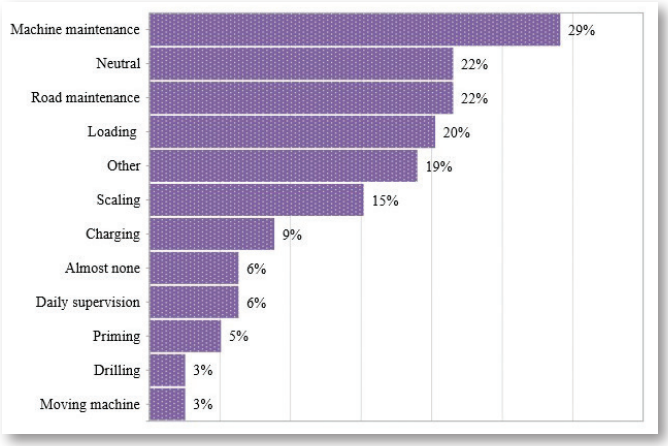

Fig. 1 What activities at the mine do you think will not be automated?

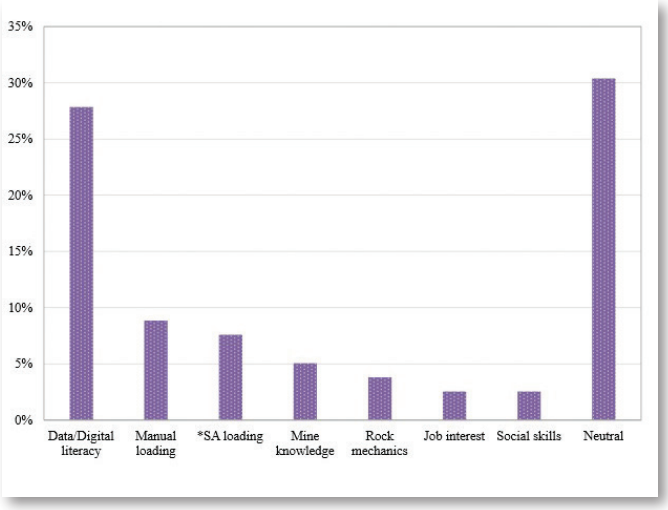

Fig. 2 What new skills will future operators require? (*SA = semiautonomous)

Methodology

This study synthesizes two independent research studies at LKAB and Boliden's mines in Sweden to gain a comprehensive view of end-user views, experiences and attitudes toward new technologies in their work. The first study was a survey sent out to 120 LHD loader operators at LKAB to quantify their opinions and experiences of automation and digitalization.

The second study used participatory workshops with 12 production workers at Boliden's Garpenberg and Aitik sites to collect rich, qualitative insights. Each data set was first analyzed separately. We then carried out a joint inductive secondary analysis, iteratively comparing and triangulating emerging themes across both sources. By combining the results of the survey and the workshops, the study uncovers consistent patterns in the empirical material, which can guide the design of further education programs in the mining industry.

Results and discussion

The respondents of this study acknowledge the significant transformation due to extensive technological development. The results indicate that most end-users hold a positive view of increasing digitalization and automation in their daily work. However, many respondents also expressed skepticism about the feasibility of automating every aspect of mining operations. For example, the LHD operators' perspectives on activities in the mine that could not be automated were captured in an open-ended question (Fig. 1).

As shown in Fig. 1, machine maintenance was cited as the least automatable activity by LHD operators (29 percent) and production workers agreed this would remain a key manual task. Other activities deemed by the LHD operators as difficult to automate included road maintenance (22 percent), loading (20 percent), scaling (15 percent) and charging (9 percent).

Even though not all tasks are expected to be automated, the implementation of new technologies will necessitate new and varied skills and competencies. The results show that LHD operators and production workers share some views, and differ in others, regarding which skills and competencies will be in demand in the future. When asked what skills future LHD operators will need, the majority highlighted digital and data literacy (28 percent) followed by manual loading (9 percent) and semiautonomous loading (8 percent) (Fig. 2).

Production workers concur that basic computer literacy is essential and predict growing demand for advanced competencies in electrification, IT, automation, hydraulics and networking as machinery becomes more complex. Many foresee hybrid roles, such as electricians handling battery

systems and mechanics with IT expertise, while respondents from both groups believe that "rock knowledge" remains indispensable. However, the production workers emphasize social skills more than LHD operators, highlighting cooperation, communication and group work. The production workers identified potential skill gaps, due to insufficient opportunities of further education during working hours. Lastly, both production workers and LHD operators highlight the significance of further education and training, emphasizing cross-departmental collaboration and collegial learning.

Conclusions

Based on the findings:

- Most end-users view digitalization and automation positively, while a minority expressed concerns. This highlights the need to involve end-users earlier when implementing technology to enhance solutions and facilitate broader acceptance.
- Although views differed on how much work can be automated, both LHD operators and production workers agreed that machine maintenance is the hardest task to automate. Human expertise will therefore remain essential, justifying continued investment in miners' further education.
- The end-users foresee digital literacy, social skills, communication and "knowledge of the rock" as future skill requirements. This highlights the challenge of keeping pace with the requirement of new skill sets as miners need both traditional and modern skills.
- All end-users emphasize the growing importance of education due to rapid technological advancement. Mining companies should address learning and skill development during work hours, offering flexible learning options to prevent knowledge gaps between individuals and teams. ■

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Evaluating geomechanical uncertainty and slope reliability analysis in openpit mine planning and optimization

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Keywords: Geomechanics, Pit optimization, Limit equilibrium method, Slope stability, Uncertainty

Openpit mining requires careful planning to ensure both safety and profitability. One key challenge is determining how steep the openpit slopes can be without risking collapse. This is difficult because the strength of the underground rock varies and is not fully known. In this study, we examined a gold deposit in Alaska to find the best slope angles that balance safety and profit, considering geomechanical uncertainty. We used data on rock quality, called rock quality designation (RQD), to estimate how strong the rocks are, focusing on properties like cohesion and internal friction. By running thousands of simulations that account for the uncertainty in these properties, we evaluated the likelihood of slope failure at different angles. We found that slopes up to 48° are very safe, with no expected failures and a projected profit of $2.684 billion. Steeper slopes, like 56°, could increase profits to $2.935 billion but come with a 23 percent chance of failure. This shows a trade-off: steeper slopes may yield more profit but also carry higher risks. Therefore, mine planners must decide how much risk they are willing to accept for potential financial gains.

Introduction

In openpit mining, understanding the geomechanical properties of rock masses is essential for safeguarding both safety and economic efficiency. Neglecting these properties can lead to slope failures, resulting in equipment damage, production delays and financial losses. A key challenge is determining the optimal slope angle: steeper slopes reduce waste removal and increase profitability but also raise the risk of instability. Slope stability is commonly assessed using the factor of safety (FoS), which compares resisting forces to driving forces along potential failure surfaces. Traditional methods for calculating FoS include limit equilibrium, finite element and discrete element analyses. However, these approaches often assume homogeneous rock conditions, overlooking the natural variability in rock properties. This variability introduces geomechanical uncertainty, complicating the design of stable slopes. To address this, engineers use exploration data — such as geological surveys and drilling — to estimate rock properties, though data limitations persist. Typically, deterministic models average these properties across geomechanical domains, potentially masking local weaknesses. Recent studies have incorporated stochastic modeling and reliability-based analyses to better account for uncertainty in slope stability assessments. Despite these advancements, integrating geomechanical uncertainty into pit optimization remains limited. This research aims to bridge

Table 1 — Statistical properties for each rock type regarding RQD values.

Rock type	No. of samples	Mean RQD (percent)	Standard deviation	Variance	Coefficient of variation	Maximum	Upper quartile	Median	Lower quartile	Minimum
CAM	702	23.71	21.84	476.97	0.92	147.84	38.03	20.24	3.68	0
UPS	3,030	21.78	22.31	497.9	1.03	109.73	37	16	0	0
MVC	1,739	36.95	26.77	716.61	0.72	101	58.66	37.8	12	0
LOS	1,666	15.63	19.57	383.16	1.25	128	26	8	0	0
All rock types	7,138	24.33	24.11	581.72	0.99	128	41.32	18.51	0	0

that gap by incorporating slope reliability into openpit design, balancing safety and profitability.

Materials and methods

This study focuses on an openpit gold deposit in Alaska, utilizing data from 145 core drill holes totaling 42,932 m. The geological setting comprises nine rock types, with four primary ones — Cambrian (CAM), Upper Sediments (UPS), Main Volcanics (MVC) and Lower Sediments (LOS) — being economically significant. Due to limited geomechanical data, RQDs from 27 drill holes served as the primary input for assessing rock strength parameters.

The methodology encompasses four main steps: (1) Geological modeling and grade estimation: A 3D geological model was developed using 1-m composites and ordinary kriging for gold grade estimation, based on a 15 m × 15 m × 10 m block model. (2) RQD modeling and slope stability analysis: Histograms and probability density functions (PDFs) were generated for RQD values of each rock type. These were converted into unit weight, cohesion and friction angle using established correlations [1]. The Bishop simplified method, implemented via Rocscience Slide2, was employed for slope stability analysis. (3) Slope reliability analysis: Markov chain Monte Carlo (MCMC) simulations were conducted to account for geomechanical variability, producing distributions of FoS and corresponding probabilities of failure. (4) Openpit optimization: Various slope angles were analyzed to determine ultimate pit limits using the maximum flow-minimum cut algorithm, balancing economic returns with slope reliability.

Results

The deposit comprises four primary rock types (CAM, UPS, MVC and LOS), typically arranged vertically from top to bottom in the sequence CAM → UPS → MVC → LOS, with occasional variations due to faulting. Gold grades across the deposit are generally low, averaging 0.012 g/t, with sporadic higher-grade zones exhibiting high nugget effects. Among the rock types, MVC displays the highest average gold grade at 0.020 g/t, aligning with its igneous origin. Statistical analyses reveal a positively skewed gold grade distribution with high coefficients of variation, indicating significant variability and necessitating robust estimation methods.

The RQD values vary notably among rock types, with MVC exhibiting the highest mean RQD of 36.95, suggesting higher rock quality, while LOS has the lowest at 15.63, indicating poor rock quality (Table 1). All rock types show left-skewed RQD distributions with long right tails (Fig. 1). Exponential distributions best fit the RQD data, as confirmed by log-likelihood evaluations, and were utilized for subsequent Monte Carlo simulations in slope stability assessments using the limit equilibrium method. The number of random samples was determined by observing the convergence of the mean FoS value (Fig. 2).

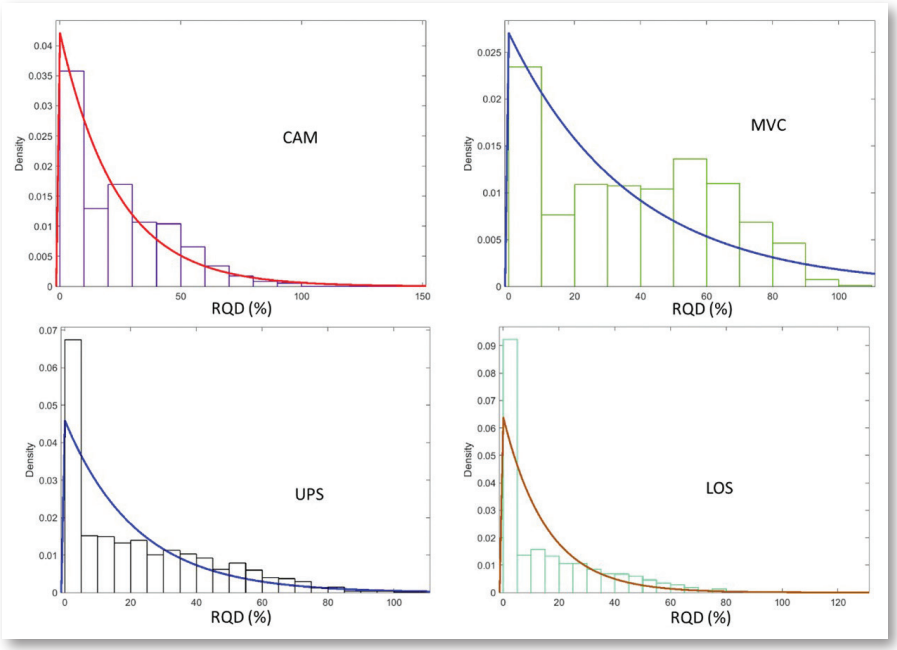

Fig. 1 RQD histograms and the fitted PDFs for all four rock types.

Slope stability and the associated cash flow analysis of the optimized pit were evaluated using both deterministic and stochastic approaches across nine slope angles ranging from 37° to 56° (Table 2). For slope angles between 37° and 48°, the mean FoS from the stochastic model remains high (9.1 to 9.8), with a 0 percent probability of failure and 100 percent slope reliability. This indicates that these slopes are stable under both deterministic and stochastic analyses. As a result, the economic value of the pit increases from $2.234 billion at 37° to $2.684 billion at 48°, reflecting the benefits of steeper, stable slopes

that allow for greater pit optimization and resource extraction.

However, beyond 49°, the mean FoS drops significantly, and the probability of failure increases. For instance, at 49°, the probability of failure rises to 12 percent, with a corresponding slope reliability of 88 percent, and an economic value of $2.721 billion. As the slope angle increases to 56°, the failure probability reaches 23 percent and reliability falls to 77 percent, though the economic value of the pit continues to rise, reaching $2.935 billion. This trend underscores the importance of accounting for geomechanical uncertainties in slope design. More information is available in the full paper.

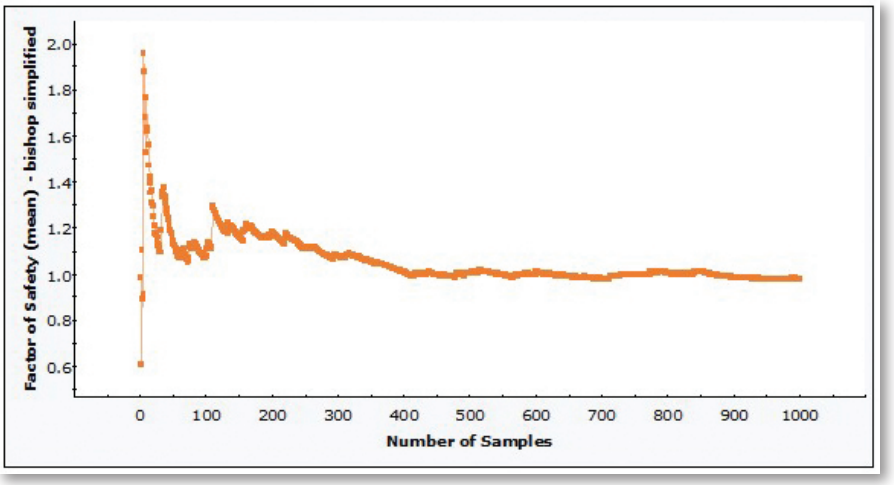

Fig. 2 Convergence plot of mean factor of safety (FoS) from stochastic slope stability analysis with number of Monte Carlo samples for slope angle of 49°.

Conclusions, limitations and future research

This study integrates geomechanical uncertainty into openpit mine planning by employing stochastic slope stability analysis. Key findings indicate that while deterministic models suggest high slope stability across various angles, stochastic analyses reveal increasing failure probabilities with steeper slopes. Notably, at 49°, the failure probability rises to 12 percent, with marginal economic gains beyond 48°, where a 100 percent reliability and $2.684 billion value are observed. Therefore, a 48° slope angle is recommended for conservative designs, balancing stability and economic return. Limitations include the model's simplifications, such as the exclusion of rock fractures, freeze-thaw effects, and consideration of only a single failure mechanism.

Future research should incorporate advanced numerical methods, multiple failure modes and site-specific analyses to enhance reliability and applicability of the findings. ■

Table 1 — Slope angle, mean FoS from stochastic model, probability of failure, reliability of slope and the economic value from the optimized pit.

Slope angle (°)	Mean FoS from stochastic model	Probability of failure (percent) with FoS threshold 1.2	Reliability of slope (percent) with FoS threshold 1.2	Deterministic FoS	Economic value ($ billions)
37	9.8	0	100	6.2	2.234
39	9.6	0	100	6.1	2.326
42	9.3	0	100	5.92	2.462
48	9.1	0	100	5.79	2.684
49	3.64	12	88	5.774	2.721
50	3.6	21	79	5.77	2.741
51	3.51	21.8	78.2	5.75	2.787
54	3.55	22.5	77.5	5.7	2.895
56	3.56	23	77	5.6	2.935

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Utilization of coal wastes for the production of ceramic materials: A review

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Mining, Metallurgy & Exploration (2025) 42:1001–1023, https://doi.org/10.1007/s42461-025-01195-3

Keywords: Ceramics, Coal ash, Coal waste, Geopolymers, Sustainability, Waste management

This literature review provides an overview of the methods and patterns observed in the usage of coal ashes and refuse to produce sintered ceramics, glass ceramics, concrete and geopolymers. Coal refuse and combustion residuals

contain valuable aluminosilicates and oxides that align with the feedstocks traditionally used in ceramic production. The use of coal waste in the production of ceramic and related materials offers significant financial and environmental benefits, aligning with the growing demand for sustainable materials in construction and manufacturing while reducing the need for the coal industry to construct and maintain impoundments. The fine particle size, reactivity and high metal oxide content in fly ash improve particle packing and facilitate sintering or alkaline reactions, making it suitable for diverse ceramic applications. Bottom ash and coal refuse are coarser and less reactive, generally requiring additional processing such as milling, magnetic separation or calcination to enhance their suitability.

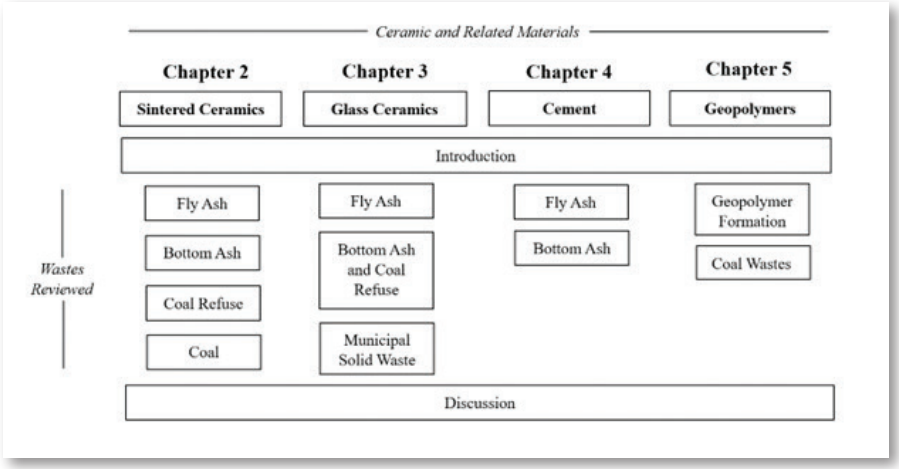

Fig. 1 Organization map.

Introduction

More efficient coal cleaning technologies combined with the development of less accessible coal reserves have resulted in an increase in the production of coal refuse. Coal combustion residuals (CCRs), including fly ash and bottom ash, are one of the largest industrial waste streams in the world and will continue to grow with increasing global coal consumption. These coal-related wastes are often stored in impoundments, which require capital investment to develop, involve long-term maintenance and liability, and can present environmental issues if not effectively managed. The documented increase in both the frequency and severity of impoundment failures since 2000, coupled with regional trends toward more frequent and intense precipitation events that may contribute to failures and mass flows, indicates the need to consider alternative waste storage methods to mitigate financial and environmental risks.

Purpose

This review summarizes research trends on the use of coal-related wastes as feedstocks for ceramic and ceramic-like materials. The scope of the reviewed literature includes topics in traditional sintered ceramics, glass ceramics, concrete and geopolymers. Production methods, material properties and environmental implications are examined to assess the feasibility of integrating fly ash, bottom ash and coal refuse into these applications. Figure 1 depicts the organization of the literature review.

Sintered ceramics. Fly ash and bottom ash are commercially used in brick production, with pilot-scale projects exploring their use in tiles. When mixed with clay, 40 percent bottom ash can produce tiles that meet ISO 13006 standards, and 20 percent bottom ash can produce ASTM-compliant bricks. Fly ash can similarly meet ISO requirements for tiles when combined with clay or used as a partial substitute for feldspar or quartz. Ash content over 50 percent generally results in low compressive strength and high porosity. Up to 60 percent coal refuse can be used with clay to produce acceptable products, though calcination or sizing can be used to improve coal refuse as a precursor material. The suitability of coal ash and refuse for sintered ceramics must be assessed on a case-by-case basis.

Glass ceramics. The study of fly ash in glass ceramics has produced materials that have achieved enhanced X-ray shielding qualities, improved celsian conversion, lower-temperature cordierite synthesis, stronger chemical resistance, and lower coefficients of thermal expansion compared to glass ceramics produced with conventional feedstocks. The particle size of fly ash and the presence of glass formers, nucleating agents and oxides in the ash allow it to be used in quantities exceeding 70 percent. Calcination and addition of supplemental glass formers can be used to address high shrinkage issues that are observed. While fly ash shows significant potential in laboratory-scale settings, its heterogeneity may limit its suitability for high-precision or specialized commercial applications. Glass ceramics have also been successfully produced from bottom ash and coal refuse, though they require additional mineral processing.

Cement. Fly ash is widely used as a partial replacement for cement in concrete, contributing to improved compressive strength, durability and heat resistance, and reduced spalling, cracking and leaching. However, fly ash can also increase curing times and slow strength development, inhibiting its use in specific applications. Bottom ash can be used in limited quantities as a substitute for sand in certain concrete formulations. Research on catalysts to increase the curing time of fly ash and the improved incorporation of bottom ash will increase the total volume of ash used by the concrete industry.

Geopolymers. Bottom ash, refuse and other aluminosilicate-bearing waste products have been used to produce geopolymers at a laboratory scale while fly ash, especially Class F, has been adopted for some low-strength construction applications. Broadly, high-alumina ashes with a large amorphous fraction exhibit ideal reactivity and produce high-strength geopolymers. Coal refuse requires calcination to remove impurities and generate metakaolin prior to polymerization. A broader acceptance of geopolymers is hindered by a lack of research on long-term durability and the

literature presents conflicting results on whether the geopolymerization mechanism immobilizes trace elements or facilitates their leaching.

Conclusion

At a laboratory scale, the heterogenous nature of coal wastes make them suitable for a diverse range of applications. However, at a commercial scale, this variability presents challenges for standardizing production and performance in novel materials. High-performance glass ceramics derived from fly ash, tiles produced from coal refuse, and the partial use of bottom ash in concrete formulations represent promising applications for commercial adoption. Further research on the preparation of coal refuse and bottom ash as ceramic feedstocks will lead to innovations that support circular economy strategies and minimize the need for large-scale waste management efforts in the coal industry. ■

References

A list of all references is available in the full paper.

Selected Abstract

Collection on Strategic Mine Planning in the Era of Climate Change

Adaptive simultaneous stochastic optimization of the Escondida mining complex, Chile

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Keywords: Strategic mine planning, Industrial mining complex, Capital investments, Operational alternatives, Stochastic mathematical programming, Mineral deposit uncertainty

This paper presents the application of adaptive simultaneous stochastic optimization with a representative branching framework to generate a strategic mining plan for the Escondida mining complex, the world's largest copper production operation. This adaptive stochastic optimization considers geological uncertainty while integrating investment and operational alternatives in the production schedule of a mining complex. Mining complexes consist of interconnected components affected by multiple sources of uncertainty. Thus, they must be optimized simultaneously in order to maximize their value, manage environmental impacts and minimize risk. Additionally, due to the extensive lives of assets and the dynamic and uncertain environment in which mining complexes operate, it is not reasonable to assume that the current strategic plan will remain optimal. Thus, an operationally feasible method to embed alternatives in the mine plan is used.

The method utilized provides a strategic plan with representative branches for future possible investment decisions. Adaptive decisions are made sequentially over time, activating costs and effects over the model. The optimization process chooses the optimal strategic production plan accordingly, as well as the investments made and their timing. The Escondida mining complex is a multielement, multipit operation with nine different processing destinations. Investment options considered are truck and shovel fleet sizing, adding a secondary crusher in one of the plants, and investing in a main crusher assigned to one of the pits. Additionally, operational alternatives at the mine and plant levels are included. The adaptive solution shows a substantial probability that the mine plan might change its design substantially due to geological uncertainty, presenting an increased expected net present value when compared to the previously developed stochastic mathematical programming formulation that does not consider adaptive decisions, thus generating a single static strategic production plan for the related mining complex. Further studies at the Escondida mining complex can consider adoptive solutions integrating capital investments pertinent to climate change issues. ■

Register now for a once-in-a-decade event in Phoenix;

Extraction 2025 in November

by Kimberly Mills, Chair, Extraction 2025 Organizing Committee

Did you attend Extraction 2018 in Canada? If you did, the second installment of this conference series is being held later this year, and you should register. If you did not attend, now is the time to get registered and find out what you missed.

Extraction 2025 will be held Nov. 16-20, 2025 at the Sheraton Grand at Wild Horse Pass in Phoenix, AZ. Extraction 2025 is a joint effort between SME, the Minerals, Metals & Materials Society (TMS) and the Metallurgy and Materials Society (MetSoc) of the Canadian Institute of Mining, Metallurgy, and Petroleum (CIM), with SME serving as the overall conference chair organization. The conference is being chaired by Kimberly Mills with support from co-chairs Nathan Stubina of MetSoc and Christina Meskers of TMS. The previous meeting, Extraction 2018, which was also the first Extraction meeting, was held jointly by these three societies seven years ago in Ottawa and was a huge success with more than 90 percent of respondents indicating interest in attending a future event.

What's special about this installment of Extraction is that the event will feature Copper 2025, Nickel-Cobalt 2025 as well as Cross Cutting Symposia to bring both groups together to share ideas and collaborate. All three societies are members of the International Organizing Committee for the Copper Conference Series and felt that including Copper in Extraction could bring these communities together.

The International Copper Conference was started in 1987 as a collaboration between Instituto de Ingenieros de Minas de Chile (IIMCh) and MetSoc. The event is typically held every four years and has always been held as a standalone or headlining event at a society annual meeting. Over the years this conference series alone has brought together members of IIMCh, MetSoc, TMS, SME, the GDMB Society of Metallurgists and Miners from Germany, the Mining and Materials Processing Institute of Japan (MMIJ), the South African Institute of Mining and Metallurgy (SAIMM), and the Nonferrous Metals Society of China (NFSOC). Being a part of Extraction allows for even broader sharing of ideas and expansion of networks. This conference has not been held in the United States since 1999 in Phoenix, AZ.

The International Symposium on Nickel and Cobalt (Ni-Co) is traditionally held by TMS every four years. The

(Continued on page 50)

Fine Grind **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mineral & Metallurgical Processing Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2025 is Tarun Bhambhani.**

SME News Contents

Vulcan is committed to

K-12 education and community engagement

by Michelle Holmes, SME Foundation Assistant

Since 1994, Vulcan Materials Company has been a steadfast supporter of the SME Foundation, beginning with its sponsorship of the former Mineral Information Institute (MII) and Government, Education, and Mining (GEM) programs. Vulcan recently received the SME Foundation's Emerald Circle Donor recognition and has contributed $500,000 in lifetime donations. This generosity continues to fuel the impact of the Minerals Education Coalition (MEC), advancing K–12 outreach and education, inspiring students and educators, and shaping the future of mining.

Publicly traded since 1957 and headquartered in Birmingham, AL, Vulcan is the largest producer of construction aggregates in the United States. With more than 423 active aggregates facilities, 70 asphalt facilities and 74 concrete facilities, Vulcan plays a vital role in supporting infrastructure development across the nation.

(Continued on page 52)

Overview and 2025 highlights of M&E standing committees

by Lia Walker, Chair-Elect, Mining & Exploration Division

SME is home to a number of standing committees that support the programming and initiatives of the Society and its divisions. Representatives for each division, including the Mining & Exploration (M&E) Division, comprise the members of the standing committees.

Many of the committees conduct an annual meeting at the MINEXCHANGE SME Annual Conference & Expo and collaborate throughout the year on important issues that are pertinent to the mining industry.

Below are 2025 highlights from two of these standing committees:

- The SME Professional Engineers Committee has the duty and responsibility of updating the SME PE Study Guide on a seven-year cycle and the *SME Mining Reference Handbook* on an annual basis for the professional engineering examination for Mining and Mineral Processing (MMP) engineering administered by National Council of Examiners for Engineering and Surveying (NCEES).

  In the December 2024 issue of *Mining Engineering*, the committee published an informative article on "Professional Engineer licensure: To license or not to license?" authored by William P. "Bill" Balaz Jr., P.E., and Russell J. Sheets, P.E., discussing the important role of professional engineers in the mining industry and encouraging students or practicing engineers to pursue a P.E. license. The committee is also focused on updating the *Study Guide for the Professional Licensure of Mining and Mineral Processing Engineers, 9th Edition* (available at https://store.smenet.org/23nh4qo/).
- The Student Member Affairs Committee provides career guidance, suggests and coordinates student activities, and exercises general supervision over SME student chapters. Members of the committee serve as judges for the annual SME Outstanding Student Chapter Contest and the SME Outstanding Student Paper Contest, undergraduate and graduate divisions.

  This vibrant and active committee had five new international student chapters developed and approved in 2024. The committee also organized student chapters for various activities, including the: (1) SME/NSSGA Competition (first place University of Kentucky, second place West Virginia University, third place Virginia Tech), (2) Metallic Design Competition (first place Missouri University of Science and Technology, second place University of Arizona, third place University of Kentucky, (3) Outstanding Student Chapter Report (winner University of Minnesota Twin Cities), (4) fall SME Membership Challenge, resulting in more than 450 new and renewed SME student members, and (5) SME Virtual Student Conference on "Connecting Mining: GenZ and Beyond."

Several other standing committees are summarized below:

- The Government Relations and Public Affairs Committee helps leverage the expertise of its membership to create a system for providing timely, accurate, fact-based and nonpartisan technical information in response to urgent inquiries from SME stakeholders on topics concerning mining, minerals and extractive industries. It has developed a structured program to create technical briefing papers for informing and educating SME audiences.
- The Journal Oversight Committee provides input and feedback on the strategic direction of SME's *Mining, Metallurgy & Exploration* (MME) journal, the quality of the journal, and inclusivity of authors and topics, and ensures the journal represents the breadth of SME.
- The Mining Engineering Committee reviews papers or finds reviewers for papers at the request of the *Mining Engineering* magazine staff. It supports the staff by providing advice and input regarding overall magazine issues, including but not limited to potential writers and topics for technical and feature articles, industry trends, potential advertisers, and issues referred to the committee by staff.
- The Sustainable Development Committee pursues two specific areas: (1) the development, monitoring and assessment of sustainable development criteria for mineral operations, and (2) the development and dissemination of best operating practices for sustainable development.
- The Inclusion & Diversity Committee promotes advancement and innovation in the mining community by strengthening inclusion and improving diversity in SME. ■

Rock in the Box **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Mining & Exploration Division. Accordingly, all material published herein is signed and reflects the individual view of the authors. It is not an official position of SME or the division. Comments by readers will be referred to that division for response. The division chair in 2025 is Jenessa L. Haarala.**

INAP's Pit Lake Database:

A resource for water-quality prediction for closure planning

by Patrick Williamson, Acid Drainage Technology Initiative-Metal Mining Sector (ADTI-MMS) Committee Chair

Since 2010, the International Network for Acid Prevention (INAP) has been working diligently on the development of its Pit Lake Database. This comprehensive resource now represents a centralized record of water-quality data for pit lakes across a range of orebody types, host rocks and climatic conditions over time. With more than 2,800 water-quality observations from 303 pit lakes and 26 orebody types, the database is a significant achievement. All the information has been collated from publicly available sources, such as publications and government records and can be fully referenced. INAP encourages stakeholders to share additional public water-quality data to further enhance this valuable resource. The Pit Lake Database is a powerful tool for mining companies, consultants and researchers. Its applications include validating pit-lake models using data from similar orebodies and climates, supporting better outcomes for water-quality prediction and advancing sustainable practices in mine water management.

Annual gathering of geochemists at MINEXCHANGE 2025.

INAP is pleased to announce a new study, awarded to Vandenberg Water Science and Mine Lakes Consulting, which aims to provide insights into the data contained within the database and to review modeling and predictive approaches that can be supported by this extensive resource. By leveraging the data, this study seeks to refine predictive methods and enhance understanding of water-quality dynamics in pit lakes.

Access to the Pit Lake Database is now available for research and project work. Contact Gilles Tremblay, INAP technical manager, at gilles.tremblay@inap.com.au to request access or to submit published data.

ADTI initiatives for 2025-2026

The ADTI is advancing several initiatives during 2025-2026 in support of the mining industry and our specialized discipline of mine waste geochemistry, including:

- A book on the biogeochemistry of mine waste (in progress), edited by Linda Figueroa and Lisa Kirk. This publication will complement the six previous books written by ADTI members on the characterization, modeling and management of mine waste and mine-impacted water.
- An initiative to recruit geology students and early-career geologists to the discipline of mine waste management. This has included a survey of SME members to determine how they came to the discipline, preparation of a list of courses that a mine waste geochemist should take, and reaching out to geology schools to determine if they have the recommended courses.
- An undergraduate field trip to acid rock drainage sites in Colorado, proposed as part of the 2026 Geological Society of America Meeting in Denver.

If you are interested in participating in the ADTI, contact Patrick Williamson at pwilliamson@intera.com or Laura Nelson at nelson@smenet.org.

In Memoriam: Dave Williams

It is with sadness that ADTI shares the loss of one of our key members, as our friend and colleague Dave Williams passed in early July. Williams was actively involved with issues related to acid rock drainage and abandoned mine lands during his more than 40 years with the Bureau of Land Management. Williams served as ADTI Chair and contributed substantially to the development of the SME-ADTI guidebooks on *Mitigation of Metal Mining Influenced Water*, in addition to mentoring many of the current ADTI members. He was presented with the AIME Environmental Stewardship Distinguished Service Award in 2021 for his work on mine site remediation. His intellect and sense of humor will be greatly missed. ■

Contractor safety is ultimately the mine operator's responsibility

by Matt Main, Communications Chair, Health & Safety Division Executive Committee

Many mining operations rely on contractors at varying levels to make mining operations successful. Contractors are involved in small, specialized projects at mining operations all the way to being responsible for the mine production. Whatever levels contractors are involved in your operation; it is ultimately the mine operator's responsibility for contractor safety. Mine operators must assess each contractor's safety programs for applicability and efficacy for the work to be completed.

Many larger contractors have comprehensive safety programs supported by dedicated safety professionals to address the hazards specific to the tasks they perform. Other contractors may be specialists in their craft, but lack the experience required to successfully work on a mine site. Operators have both a legal and a moral obligation to take a more active role in managing these contractors. Operators and contractors must partner together to reliably achieve successful outcomes. Recent statistics from the U.S. Mine Safety and Health Administration (MSHA) and the Bureau of Labor Statistics (BLS) on workplace injuries and fatalities in the mining industry indicate that contractors are more often involved than employees of the operator, with 1.5 reportable injuries per 100 full-time employees (FTE) for operators versus 2.3 reportable injuries per 100 FTE for contractors, and 10 fatalities per 100,000 FTE for operators versus 17 fatalities per 100,000 FTE for contractors. This fact underscores the importance for mine operators to take a more active role in partnering with contractors for successful outcomes.

Proper preparation by the operator is the first step to help potential contractors understand the scope of work and what resources will be required to complete the contract and achieve the intended outcomes. Well-defined work and expectations minimize rework and delays that can lead to unsafe behaviors to complete the work in the time promised. Fully understanding the safety aspects involved with the work provides the contractor with the best opportunity to design and implement effective controls to mitigate the risks.

Mine operators are well served to have a robust pre-qualification for contractors beyond and not just moving on to the contractor that offers the lowest bid. Before a contractor sets foot on site, it is essential to assess their safety performance and capabilities. This includes reviewing safety records and incident history as well as compliance history; verifying training, certifications and licenses; evaluating safety management systems and procedures as well as insurance coverages; and ensuring alignment with the company's values and expectations.

Once the contractor has been selected and the contract is put in place, operators need to partner with the selected contractors to ensure that adequate site induction and orientation are completed. When onboarding new contractors or kicking off a new project with contractors, it is recommended that all available contractor employees attend these initial orientation activities. Even though contractors are subject-matter experts in their line of work, it is unrealistic to expect them to understand the site/job-specific hazards that the contractor employees may be exposed to that require risk treatment. The site/job-specific hazards impact the contractor frontline employees the most, so it is important to ensure they are included in the initial orientation. In addition to the site/job-specific hazards and controls, it is important to discuss emergency response procedures, personal protective equipment (PPE) requirements, available resources such as safety data sheets, reporting protocols for hazards and incidents, and any other environmental, community and cultural considerations applicable to the contractor. Contractor orientation must be tailored to each contractor/scope of work to ensure that the most relevant information is being discussed before the contractor begins the job.

Contractors should develop a comprehensive health, safety and environmental plan that outlines the essential safety considerations for the work as well as clear expectations around points of contact for the contractor and the operator. The plan should encompass information about how everyone involved and affected by the work will communicate with one another. Contractor employees should have a clear understanding of how to report hazards or unsafe conditions and where to go for help mitigating these issues if they are unable to take direct action themselves. Information around when and where toolbox talks/lineout meetings take place, responsibilities for job risk assessments and workplace exams can help operators ensure that contractors are monitored and supported throughout their work. Regular check-ins and safety observations help identify and correct unsafe behaviors early.

Another tool to help operators and contractors work collaboratively is to require a permit-to-work system, especially for high-risk activities. Requiring a signed and authorized permit to work ensures that proper job risk assessments are conducted, effective controls are in place and verified, and that the work can be monitored by leaders from the contractor and the operator. ■

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SME sections get support to attend state science teacher conferences

by Rebecca Smith, Curriculum Coordinator, Minerals Education Coalition

This fiscal year, the Minerals Education Coalition (MEC) offered SME sections additional support. If SME sections attend their state science teacher conferences or other local outreach events, MEC will pay for their booth fees and provide flyers and posters that they can give out at the event. So far, SME sections have attended four events in their local community as part of this new program, and shared information about the importance of mined minerals with more than 500 members of the public.

The SME Colorado Section attended the Colorado Science Conference on Oct. 25, 2024. Free rock and mineral kits and MEC materials were provided to approximately 70 teachers by Alan Cram and Dick Beach. Beach also made a presentation to the teachers about the minerals we need for the transition to the new energy era.

Wayne Heili from the SME Central Wyoming Section coordinated with MEC to support the section's participation in several STEM/STEAM youth education events in May 2025. At two STEAM career fairs for high school seniors hosted by Central Wyoming Community College, a booth was set up to highlight career opportunities in mining and educational paths that would lead to mining careers, and Heili, J.J. Brown and Terrence Osier presented to approximately 270 high school students.

Heili and Lynn Swank also prepared an educational booth for the free Casper Science Zone STEM night. The nuclear energy-themed booth featured an interactive demonstration of the uranium in situ recovery process and highlighted Wyoming's uranium recovery industry as an important source of nuclear fuel. Youth participants were given free samples of several ore-grade minerals. More than 250 community members attended the event.

Kurt Doran and Lisa Rudstrom, chair and vice chair of the MEC Committee and members of the SME Northern Minnesota Section, presented two sessions at the Minnesota Minerals Education Workshop on June 17. They presented a "mini-Mining 101," discussed mining perceptions and curriculum connections, and conducted a hands-on gold panning activity with 18 teachers.

Rudstrom explained that they shared a key message: "If it can't be grown, it must be mined — and understanding that simple truth is essential to building an informed, responsible society that values both the resources it uses and the environment it shares."

This fall, more SME sections are planning to attend their state's science teacher conferences with MEC's support. Contact MEC at MEC@smenet.org to find out how your SME section can participate in this program. ■

J.J. Brown at the SME booth at the Wyoming event for high school students.

Alan Cram engaging with Colorado Science Conference attendees.

Lisa Rudstrom conducting hands-on activities with teachers in Minnesota.

Scholarship season opening soon

by Lorie Laessig, SME Foundation Specialist

The SME Foundation (SMEF) is committed to helping SME students achieve their educational and career aspirations. Each year, it awards multiple scholarships to student members who show a strong passion and potential for success in the minerals industry. During the MINEXCHANGE 2025 SME Annual Conference & Expo in Denver, CO, the SMEF awarded 27 scholarships, totaling $131,500. All recipients were honored at the 2025 SME Foundation Gala Dinner. Available SMEF scholarships are:

- MMSA/SME Presidential Scholarship: The Mining and Metallurgical Society of America and SME offers one or more scholarships to outstanding students whose study program encompasses any aspect of the extractive minerals industry. Up to two $5,000 scholarships may be awarded.
- Syd S. and Felicia F. Peng Ground Control in Mining Scholarship: An undergraduate and/or graduate scholarship(s) is awarded annually to encourage the development of ground control engineers and to promote the science of ground control. Up to 14 scholarships will be awarded at $5,000 each.
- J. H. Fletcher & Co. Underground Mining Scholarship: This scholarship is awarded to students pursuing an undergraduate degree in mining or minerals engineering, with a desire to use their skills to apply technology to improve safety and productivity in underground mining. Students pursuing degrees in mechanical or electrical engineering may also be considered if they are minoring in mining engineering or show a strong desire for a career in the underground mining industry. Up to two $6,000 scholarships will be awarded. Eligible recipients may apply for a second year of funding.
- Stantec/McIntosh Engineering Scholarship: A $5,000 scholarship will be awarded to one promising undergraduate student entering their junior or senior year of an accredited undergraduate degree program in mining engineering with a focus on underground mining.
- Ernest K. Lehmann Memorial Scholarship: Established in 2014 by the Lehmann Family Fund of the Saint Paul Foundation and the Minnesota Section of SME in memory of Ernest K. Lehmann, the Lehmann Scholarship is awarded annually to students pursuing an undergraduate degree in geology, geological sciences or earth sciences. Applicants must have completed their sophomore year of studies at the time of application. One $7,500 scholarship will be awarded. Eligible recipients may apply for a second year of funding.
- George V. Weisdack Memorial Scholarship: This scholarship is awarded to a student pursuing an undergraduate degree in mining engineering, mineral engineering and mineral, ore and coal processing. Applicants must have completed their freshman year of studies at the time of application and have elected or be enrolled in course work leading to a degree in the above disciplines. One $4,000 scholarship will be awarded. Eligible recipients may apply for a second year of funding.
- The Raja V. and Geetha V. Ramani Graduate Students Award: This scholarship was established in 2016 to provide support for one or more outstanding graduate students pursuing an M.S. or a Ph.D. degree in their thesis writing (Ramani Thesis Writing Award) or traveling to the SME Annual Conference to present papers based on their thesis (Ramani Travel Award). Nominees must be enrolled in the graduate study program in mining, mineral processing, geological engineering or other similar engineering fields at the time of nomination and be a student member of SME. The Thesis Writing Award recipient will receive $4,500 (which includes up to $3,000 in travel expenses). The Travel Award recipient will receive $3,000.

Applications are to be submitted online beginning on Sept. 1, 2025. The application deadline is Oct. 15, 2025. Applications that are incomplete or do not meet minimum qualifications or requirements will not be considered. For full details and specific scholarship requirements, including renewal guidelines, visit https://www.smenet.org/scholarships. ■

Fine Grind

(Continued from page 45)

last installment of Ni-Co was held in conjunction with the TMS 2021 Virtual Annual Meeting and Exhibition, so this is the first in-person meeting since the COVID-19 pandemic and it has been eight years since the last in-person meeting.

All of the organizers are excited about the opportunities for cross-commodity collaboration and learning. This event will have a more diverse group of delegates in attendance than many events we typically host, to support finding unique solutions for a more sustainable future. We feel there is truly something for everyone.

We are also excited to offer eight short courses prior to the conference, and Freeport-McMoRan Miami will be providing a tour the Friday after the conference concludes.

This is a once-in-a-decade meeting event. We look forward to seeing you in November. To register, go to https://www.extractionmeeting.org/Extraction2025/Extraction2025/default.aspx ■

$4Kby40 Challenge a success in 2025

by Michelle Holmes, SME Foundation Assistant

The 2025 $4Kby40 Challenge was a success, with two new SME members signed up for monthly giving to reach their $4Kby40 goals. A special thanks to Brooks & Nelson LLC who, once again, generously matched the $4Kby40 donations with a $6,000 contribution, including a $250 match for members who signed up for the monthly recurring donation plan. Brooks & Nelson LLC, a woman-owned, global human resource management and recruiting consulting firm based in Golden, CO is a long-time supporter of SME and the SME Foundation.

The $4Kby40 Challenge was created in 2018 to encourage and motivate philanthropic giving by young professionals under the age of 40. SME member contributions are tracked and those who donate $4,000 or more by the age of 40 will be honored for their contributions and commitment to promote our industry and the outreach goals of the SMEF.

All donors under the age of 40 are encouraged to set up a monthly, recurring gift based on how many months are left until they reach the age of 40. We thank the $4Kby40 Challenge recurring donors who donate to the SMEF each month in order to make their goal. They include:

- Richard Ahadjie.
- Jordan Anderson.
- Ruby Barickman.
- Yamile Isabel Casasbuenas Cabezas.
- Kinsley Costner.
- Brianna Drury.
- Ryan Sibley.
- Mackenzie Sorensen.

Past recipients of the $4Kby40 Challenge Award are:

- 2024 — Sam Baker, Michael and Jennifer Deal, Rosa Maria Rojas Espinoza, Troy Liddell and Kat Tew.
- 2023 — Drew Mason and Matthew Ulizio.
- 2022 — Joshua A. Patterson.
- 2021 — Matthew D. Furniss and Thomas C. Rauch.
- 2019 — Peter and Jenessa Haarala.
- 2018 — Ryan M. Murray.

Donors have the flexibility to choose the allocation of which SMEF program they wish to support. Visit www.smefoundation.org/4Kby40 and donate today. ■

NOC: Ways to get more women into mining

by Rebecca Smith, Curriculum Coordinator, Minerals Education Coalition

The National Outreach Collaboration (NOC) was honored to have Barbara Arnold, undergraduate program chair of mining engineering at Penn State University, speak June 17 on "Careers and outreach to female audiences in mining: How to generate more interest in mining careers." As an international trailblazer for woman engineers, Arnold has taken on multiple arms of service as SME President, president of the Mortar Board National Foundation, researcher and entrepreneur.

The appreciative group of 26 interested mining and minerals educational outreach providers then discussed her presentation as well as other examples of what has worked or not worked for them in conducting mining career-related outreach to female audiences.

Arnold's presentation will be available soon on the NOC Community page in SME Community. ■

Rio Tinto appoints Trott as chief executive

The board of Rio Tinto has appointed Simon Trott to succeed Jakob Stausholm as chief executive, with effect from Aug. 25, 2025.

Trott, currently Iron Ore chief executive, has a track record of exceptional delivery over 25 years in roles across a wide range of commodities and geographies, with a strong focus on values-based performance culture and strengthening partnerships with stakeholders. As Iron Ore chief executive, he has strengthened the business and improved operational performance, underpinned by safety and financial discipline; reset partnerships with key stakeholders; and secured the future growth of the business with new mine developments.

Previously, as Rio Tinto's first chief commercial officer, Trott established the group's commercial operations, unlocking efficiency and deepening strategic customer relationships. Prior to this, he held managing director roles across multiple Rio Tinto commodities and geographies.

"Simon is an outstanding leader with a deep understanding of mining and a track record of delivering operational excellence and creating value across our business. Simon and the board are aligned that Rio Tinto's next phase is about unlocking significant value for shareholders from our portfolio, driven by operational performance, and cost and financial discipline," said Rio Tinto chair Dominic Barton. "Simon came into our Iron Ore business at a time of significant challenges and has been instrumental in rebuilding culture, strengthening external relationships and setting us on a pathway for growth. Under his leadership, Iron Ore has become a center of innovation for the group, driving operational excellence, technology and operating model optimization — levers Simon can now bring to Rio Tinto at scale."

Barton added, "I want to again recognize Jakob's significant contribution to Rio Tinto at a critical time in its evolution. Under his leadership we have rebuilt relationships with key stakeholders, aligned our portfolio with the commodities where demand growth is strongest, and set a compelling growth trajectory."

The search process for the new chief executive was led by the Nominations Committee, chaired by Dominic Barton, and the appointment decision was made by the full Rio Tinto board. The process built upon routine succession planning work the board has undertaken over a two-year period and included potential internal and external candidates.

Stausholm will step down as chief executive and from the board of directors upon Trott assuming the role. Matt Holcz, currently managing director, Pilbara Mines at Rio Tinto, will be providing interim support in the Iron Ore chief executive role until a permanent appointment is made. ■

Vulcan

(Continued from page 45)

Vulcan's charitable giving, directed through the Vulcan Materials Company Foundation, is anchored in three core pillars: education, environmental stewardship, and employee engagement in community service. A significant portion of its outreach is dedicated to K–12 education. In 2024 alone, Vulcan contributed approximately $1.3 million to K–12 initiatives, including $216,000 through Matching Gifts. Additionally, the foundation provided nearly $1 million in higher education funding, complemented by $276,000 in higher-education Matching Gifts. Its support also includes 200 Adopt-a-School partnerships and 200 scholarships totaling $660,000 in funding.

Beyond financial contributions, Vulcan's hands-on involvement in education is equally impactful. Each year, more than 25,000 visitors, many of them schoolchildren, tour Vulcan facilities as part of their Earth science curriculum, experiencing firsthand how classroom concepts apply in real-world settings. In addition, Vulcan independently backs a wide range of educational and youth-focused initiatives, including the annual National Science Teaching Association (NSTA) Conference and Scouting programs. These efforts reflect Vulcan's deep commitment to fostering curiosity, learning and leadership in the next generation.

B.J. Wilsford, plant manager at Vulcan's Franklin Quarry in Tennessee, teaches local students about quarry operations, equipment and safety.

The MEC is deeply grateful for Vulcan's continued partnership. Its support empowers MEC programs to reach educators across the country and ensures that students, teachers and communities understand the importance of minerals and mining for years to come. ■

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Investments from government and industry propel MP Materials

William Gleason
Editor

It would be difficult to find a company that has ever had a better week than the one MP Materials experienced in July.

On July 10, the company announced that it had agreed to partner with the U.S. Department of Defense (DoD) in a multi-year public private partnership that would make the DoD the largest shareholder of the rare earth mining company. Among the highlights, the multibillion-dollar package will accelerate the build-out of the company's second domestic magnet manufacturing facility, the "10X Facility" and set a price floor for its output from the Mountain Pass Mine in California.

About a week later, MP Materials and Apple announced a definitive long-term agreement. Apple will invest $500 million for MP Materials to supply the company with rare earth magnets manufactured in the United States from 100 percent recycled materials.. Under the agreement, MP Materials will supply Apple with magnets produced at its Fort Worth, TX, facility — known as Independence — using recycled rare earth feedstock processed at MP's Mountain Pass Mine. The feedstock will be sourced from post-industrial and end-of-life magnets, marking a major milestone in both companies' long-standing efforts to create sustainable, domestic supply chains.

Reaction to the developments has varied, especially in regard to the deal with the DoD. Investors gave it a mark of approval and sent the company's stock price soaring. Some people view the DoD investments as a long-overdue response to the market manipulation of rare earths by China and as a neccessary step toward onshoring the domestic rare earth supply chain.

Rod Eggert, research professor and deputy director of the Critical Materials Innovation Hub at the Colorado School of Mines told me that while it was a newsworthy week for MP Materials, we should not leap immediately to broad conclusions. He did say that the agreement with MP Materials and DoD could be seen as "the next step in a more emphatic industrial policy by the U.S. government to prioritize particular sectors of the economy not just through research and development and workforce development but through direct investment."

As most readers are aware, China has dominated the rare earth sector for decades. Eggert said the United States has gradually become more agreeable to government support of mineral and material production. Previously, the support was in the form of research and development and workforce development funding, as well as through support of the World Trade Organization to help free up international trade. This development between MP Materials and the DoD goes beyond that.

"This initiative marks a decisive action by the Trump administration to accelerate American supply-chain independence," James Litinsky, founder, chairman and chief executive officer of MP Materials said in a statement.

It seems logical that the DoD would partner with the only fully integrated rare earth producer in the United States. But the scale of the involvement has caused some concern in the mining sector. The *Financial Times* reported that some industry leaders and former government officials have expressed fear that the deal gives an unfair advantage to MP Materials.

In an interview with CNBC's "Squawk on the Street," Litinsky addressed some of the concerns, saying, "This is not a nationalization. We remain a thriving public company and we now have a great new partner with our economically largest shareholder in DoD. We remain in charge of our company and we remain shareholder driven, and DoD wants that."

Government involvement and support of the domestic mining industry is not new. The United States' dangerous reliance on foreign, and sometimes adversarial nations has spurred significant investment in the mining industry for more than a decade.

But what is unique in this deal is that the DoD entered into a 10-year agreement establishing a price floor commitment. The DoD will guarantee a floor price of $110/kg for MP Materials' neodymium-praseodymium (NdPr) products stockpiled or sold, a price nearly twice the current Chinese market level.

The DoD has also agreed to ensure that 100 percent of the magnets produced at the future 10X Facility will be purchased by defense and commercial customers with shared upside.

"When it comes to the magnets we have to think about these supply chains being vertically integrated," Litinsky told CNBC. "We could have all the REEs (rare earth elements) and have them flowing, but if we can't make a magnet economically it's still going to China. The recognition is that if we are going to accelerate investment downstream with magnets, we also need to be sure there is a customer there who can provide fair economics." ■

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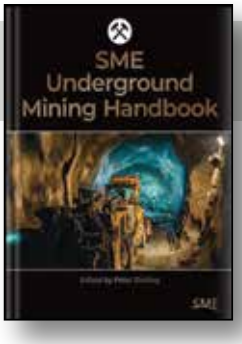

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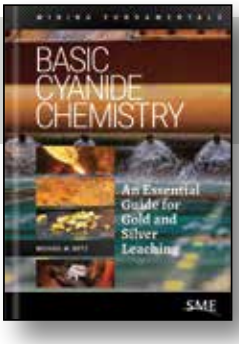

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