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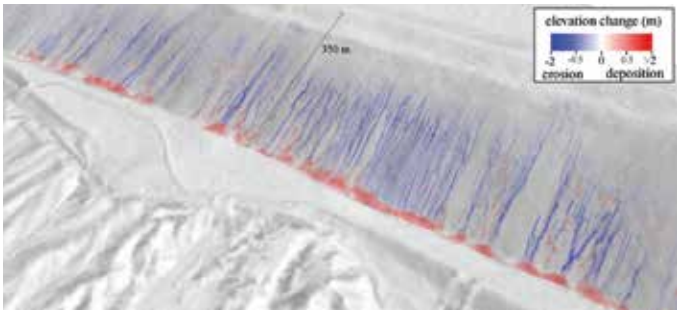

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Feature Articles

Technical-paper Abstracts from *Mining, Metallurgy & Exploration*

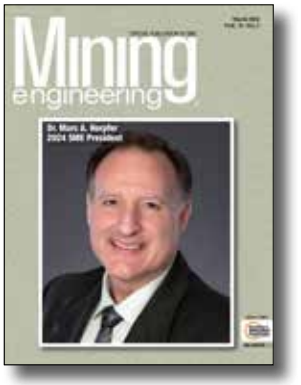
(peer-reviewed and approved)

SME News

Departments

Cover

At the conclusion of the MINEXCHANGE 2024 SME Annual Conference & Expo in Phoenix, AZ Marc A. Herpfer was installed as the 2024 SME President. Herpfer is vice president of New Technologies at Oil-Dri's Innovation Center. He has more than 30 years of "mine to market" leadership experiences in creating value from sorbent minerals via technologies. On page 14, Herpfer shares his thoughts about the mining industry and SME. Cover design by Ted Robertson.



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Talon Metals exploration application approved

TALON METALS Corp. received confirmation on Jan. 30, 2024 from the Michigan Department of Natural Resources (DNR) that its administrative board approved the company's application (through its subsidiaries) for 23,000 acres of additional mineral leases in the Upper Peninsula of Michigan.

The 23,000 acres of mineral leases augment the company's Aug. 10, 2022 announcement that it entered into an option and earn-in agreement with UPX Minerals Inc. to acquire up to an 80 percent ownership interest in the mineral rights over a land package consisting of approximately 400,000 acres located in the Upper Peninsula of Michigan. This land package was originally assembled by Henry Ford and owned for approximately 70 years by the Ford Motor Co.

The combined land package covers highly prospective terrain within 2.8 km (1.7 miles) of the high-grade Eagle Nickel Mine and is only 0.6 km (0.4 miles) from the Humboldt Mill.

On Sept. 12, 2023, the Department of Defense selected Talon for $20.6 million in grant funding from the Defense Production Act to explore and discover more high-grade nickel mineralization in Michigan and Minnesota.

"Our exploration team's sole focus is to discover more high-grade nickel deposits in the United States," said Henri van Rooyen, chief executive officer of Talon.

"Within the mineral sourcing requirements of the Inflation Reduction Act's electric-vehicle tax credits, minerals sourced domestically enjoy the highest level of preference under the law. The United States is currently dependent on foreign countries such as Russia and China for nickel, which is an untenable supply-chain vulnerability. This extraordinary context is why Talon is advancing its proposed Tamarack Underground Mine proposal through the Minnesota environmental review process while also exploring for additional high-grade deposits in both Minnesota and Michigan," he said.

"Mineral exploration and geophysics are science but also an art," van Rooyen continued. "It is not just finding a needle in a haystack; it's finding a needle in a haystack if the haystack was in a dark barn and you're wearing dark sunglasses. The haystack in this case was buried deep underground millions of years ago. Talon's experienced team is using cutting-edge technology, our own drill rigs and in-house drill teams to find more nickel in America. We are conducting drilling and geophysics in Minnesota on a 24/7 basis and are excited to get started in Michigan this spring."

"The Michigan DNR approval process included opportunity for extensive public comment. We are planning to host a community "Open House" in the spring prior to any drilling and we have had a number of information-sharing meetings with proximate tribal sovereign governments to discuss our initial area of interest for mineral exploration, seek their feedback and discuss the potential contribution of tribal knowledge in our fieldwork," said Cody Mayer, community and tribal engagement liaison for Talon.

He continued, "Exploration drilling and geophysics is essentially about understanding what Michigan has in its natural resource wealth. Having this information means policymakers are better able to plan for secure domestic supply chains in the future. If this exploration process results in the discovery of a mineable resource like the Eagle Mine, which has successfully operated in this region since 2014, it will ultimately be up to society to decide if that newly discovered resource will be extracted and contribute to domestic supply chains. For now, Talon is committed to protecting the environment during this exploration phase and being transparent with the community by sharing information about our operations, plans and exploration results." ■

Judge in Brazil orders Vale and BHP to pay $9.6 billion

A Brazilian federal judge ruled that miners Vale and BHP and their joint venture Samarco must pay 47.6 billion reais ($9.67 billion) in damages for a 2015 tailings dam burst, according to a legal decision seen by *Reuters*.

Vale and BHP said in separate statements they were not informed by the judiciary about the decision. Samarco declined to comment.

The dam collapse in the southeastern city of Mariana caused a giant mudslide that killed 19 people and severely polluted the Rio Doce river, compromising the waterway to its outlet in the Atlantic Ocean.

In the decision, judge Vinicius Cobucci wrote that the amount was fixed taking as a parameter the value of expenses already acknowledged by the companies in repair and compensation actions. He added the 47.6 billion reais need to be adjusted by monetary correction and late payment interest.

It was not immediately clear how much of the total stipulated in the sentence each company owes.

The judge wrote in the legal document that the money would be put in a state fund and used for projects and initiatives in the area affected by the dam collapse.

The companies can appeal the decision.

In the securities filing, Vale said the Renova foundation, which the companies have been using to pay for some of the repairs, had paid until last December 34.7 billion reais in socioeconomic and environmental compensation.

In its 2023 annual report, BHP noted that it had earmarked $3.7 billion to cover issues related to the accident near Mariana, in Minas Gerais state.

The parties involved in the suit have been in negotiations to seek a settlement of obligations under a framework agreement since 2021, with talks scheduled to resume next month.

The news comes only two months after a British court rejected Vale's appeal against its inclusion in a lawsuit worth at least $46 billion against Vale, Samarco and BHP due to the same dam disaster. ■

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Pentagon to develop program to estimate prices; **Artificial intelligence could help predict critical mineral demand**

THE U.S. Department of Defense (DOD) plans to develop a program to estimate prices and predict supplies of nickel, cobalt and other critical minerals, a move aimed at boosting market transparency but one that throws a new, uncertain variable into global metals markets.

The program, which received little attention after it was announced on a Pentagon website in October, is part of Washington's broader efforts to jumpstart U.S. production of critical minerals used in weapons manufacturing and the energy transition.

U.S. output lags market leader China partly because attempts to build new American mines can be heavily influenced by commodity price swings. Jervois Global, for example, announced last year it would suspend construction of an Idaho cobalt project due in part to low market prices, even while Chinese cobalt miners — financially backed by Beijing — said they would boost production of the battery metal in a bid for greater market share.

An official rubric by which Washington estimates how much a specific metal should cost, though, could confuse metals markets by creating dueling structures for determining price, according to two sources who were not authorized to speak publicly.

Traditionally, metals prices are set by futures markets and pricing agencies and reflect what buyers are willing to pay and sellers are willing to accept using supply, demand and other factors.

The Pentagon's work is being run by its Defense Advanced Research Projects Agency (DARPA) division, which was formed in response to the Soviet Union's 1957 launch of the Sputnik 1 satellite and helped develop the internet and the mRNA vaccine for COVID-19.

DARPA and the U.S. Geological Survey plan to hire one or more private contractors to develop an artificial intelligence (AI)-backed model that would construct a metal's "structural price" based on where and when it is produced, as well as labor, supply and other costs, according to documents seen by *Reuters* that describe the program, including a slide deck that DARPA presented last November to prospective contractors.

The DARPA program, known as Open Price Exploration for National Security (OPEN), is intended to boost price transparency for government agencies and commercial entities and offset the risk Washington believes futures markets and pricing agencies pose to national security, according to the documents.

The Pentagon believes commodity purchase transactions are negotiated using "opaque and flawed pricing data" that pose "substantial barriers to U.S. commercial competition," according to the documents, which referenced both futures exchanges and commercial pricing providers.

In a statement to *Reuters* on Jan. 16, DARPA said its efforts aim to "remove market opacity that can engender supply chain disruptions" and that the data will be used by government agencies and commercial entities. "The OPEN program is fundamentally about transparency," a DARPA spokesperson said.

The U.S. Geological Survey deferred comment to DARPA.

The Pentagon's efforts are

(continued on page 11)

Newswatch contents

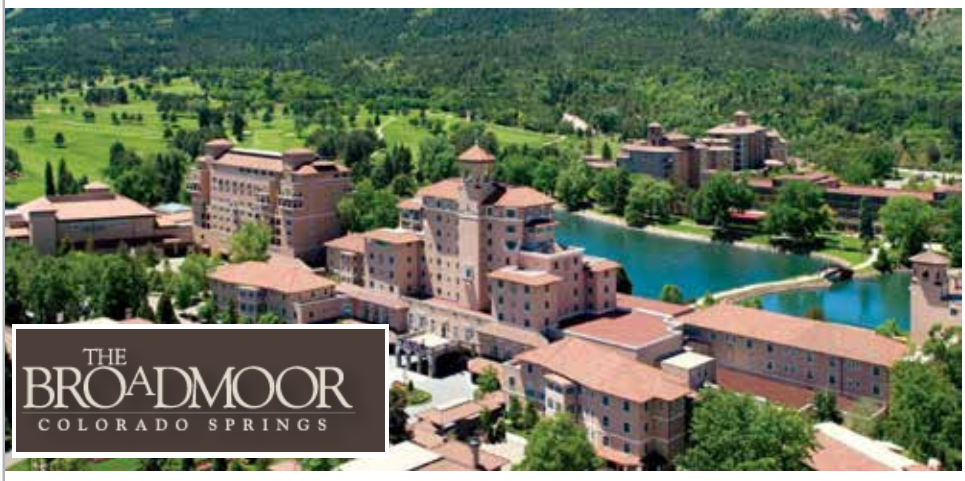
Mineral production contributed more **than $105 billion to US economy**

U.S. MINERAL production contributed more than $105 billion to the U.S. economy in 2023 — a $4 billion increase over 2022 — according to the Mineral Commodity Summaries 2024, released by the U.S. Geological Survey (USGS).

The annual Mineral Commodity Summaries is a crucial source of impartial information for both the private and public sectors. It is an invaluable tool for decision-makers determining national commerce, security and intelligence policy surrounding minerals. This in-depth report is produced by the USGS's National Minerals Information Center, a global leader in statistics and information on the worldwide supply of, demand for, and flow of minerals and materials.

The in-depth assessment of nonfuel mineral commodity data for the world includes information on the domestic minerals industry structure, government programs, tariffs, world production and five-year salient statistics for nonfuel mineral commodities that are important to the U.S. economy and national security. It also identifies events, trends and issues in the domestic and international minerals industries that impact production and consumption.

The USGS report "Mineral Commodity Summaries 2024" includes information on more than 90 nonfuel mineral commodities. ■



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South32 approves $2.16 billion investment in Hermosa; **Southern Arizona project to produce zinc and manganese**

SOUTH32'S HERMOSA project, currently the only advanced mining project in the United States capable of producing two federally designated critical minerals – zinc and manganese, received board approval of $2.16 billion in funding to develop the zinc-lead-silver deposit at its Southern Arizona project site.

South32's announcement of the approval represents the largest private investment in Southern Arizona's history, and the largest investment in the local Santa Cruz County economy to date by a factor of nearly nine times.

The first critical minerals mining project added to the United States' FAST-41 permitting process, South32's Hermosa project has the potential to be one of the world's largest zinc producers. It aims to put Arizona in the driver's seat of the clean energy race, supplying a critical mineral needed for the expansion of renewable energy and associated infrastructure.

"Today's investment decision represents a major milestone for our business and aligns with our strategy to reshape our portfolio toward commodities critical to a low-carbon future," said South32 chief executive officer Graham Kerr. "Development of the zinc deposit is the first phase of a regional-scale opportunity at Hermosa, with ongoing activities to unlock additional value from the manganese deposit."

"With the largest private investment in Southern Arizona's history, South32's Hermosa project will strengthen the domestic supply of critical minerals needed for clean energy technologies and national defense, reducing America's reliance on foreign countries and transforming the local economy," said Hermosa project president Pat Risner. "It's a win for Arizona and the nation."

With a surface footprint of just more than 600 acres and projected to use approximately 75 percent less water than other mines in the region, the operation has been designed to minimize its environmental impact. Additionally, the Hermosa project is embracing sustainability and advanced technology in its next-generation, underground mine design, utilizing automation and technology to drive efficiencies and lower operational greenhouse-gas emissions. South32's investment will fund construction of a host of key infrastructure projects needed to implement that design, including water management systems, power, site facilities, underground shaft sinking, initial underground development and other work required to begin operations around the zinc deposit.

Once completed, this infrastructure would support future potential development of other deposits at the site, including the battery-grade manganese deposit.

Used in renewable energy battery storage, wind turbines and electric vehicles, zinc is a key component in the process to galvanize steel needed for infrastructure projects like roads and bridges. Global zinc demand growth is expected to outpace production by approximately 3 Mt (3.3 million st) to 2031.

Only 6 percent of zinc is currently

(continued on page 12)

Four Rio Tinto employees killed in plane crash; **Flight crashed near Rio Tinto's Diavik Mine in Canada**

RIO TINTO announced that four team members of its Diavik diamond mine in Canada died in a plane crash in Fort Smith, Northwest Territories, Canada. Two airline crew members were also killed in the crash.

Rio Tinto said another of its employees survived the crash and was being treated for injuries in a hospital.

Rio Tinto chief executive Jakob Stausholm said: "We are feeling numb with the devastating news that we have lost dear friends and colleagues. I extend our deepest sympathy to the families, friends and loved ones of those who have been affected by this tragedy. I am heading to the Northwest Territories to be with our team and to offer our full support.

"We will be working closely with authorities over the coming days, weeks and months to support their efforts to understand the full facts of what has happened."

"It is with a heavy heart that I express my deepest condolences to the families, friends and loved ones of those who were aboard the Northwestern Air flight that crashed outside of Fort Smith today," Premier of the Northwest Territories R.J. Simpson said.

Canada's public broadcaster *CBC* reported that the plane crashed about 500 m (1,640 ft) from the end of the Fort Smith Regional Airport's runway. Joint Rescue Coordination Center Trenton said it lost contact with the plane shortly after take-off.

Rio Tinto's Diavik diamond mine is about 300 km (186 miles) northeast of Yellowknife. According to the company's website, it has been in operation since 2003.

The incident has been "very devastating" for the close-knit community, said Fort Smith's deputy mayor Dianna Korol.

"Everybody has a little piece — or somebody that they know," Korol told the *CBC*.

Both the Royal Canadian Mounted Police and the Transportation Safety Board of Canada are investigating the crash.

The crash comes a day after three people were killed and four others seriously injured in a helicopter crash in neighboring British Columbia. ■

Barrick expects strong future for Nevada Gold Mines;
Bristow says Northern Nevada is not yet a mature district

BARRICK GOLD CORP. president and chief executive officer Mark Bristow provided an update of Nevada Gold Mines (NGM) operations in Northern Nevada. Barrick is the majority shareholder of Nevada Gold Mines. Bristow said operational highlights of the past year included a record production by the post-merger Cortez and the continuing turnaround at Turquoise Ridge Mine, which is beginning to live up to its Tier One status again. The most significant development, however, according to Bristow was the completion of the Goldrush permitting process at the end of 2023. This enabled Cortez to accelerate the development of a key project which will already make a significant production contribution this year.

Bristow said far from being a mature gold district, Northern Nevada was still highly prospective for new world-class discoveries. The Barrick-owned Fourmile Mine, for example, is expected to more than triple its current mineral resource of 0.48 million ounces at 10.04 g/t indicated in addition to 2.7 million ounces at 10.1g/t inferred, as well as uplifting the grade as orebody modeling and evaluation continue with a view to commence a prefeasibility study at the end of 2024. In the meantime, brownfields exploration has delivered an exciting pipeline of near-mine growth opportunities across Carlin, Cortez and Turquoise Ridge.

"The complex now boasts a production growth profile that goes well beyond 10 years as the geologists step up the replacement of the ounces depleted by mining," Bristow said.

In line with the Barrick group's transition to renewable energy, NGM completed the commissioning of the first 100-MW phase of its solar power project in the last quarter of 2023, with the second 100 MW scheduled to come on stream in the second half of this year.

NGM also continues to invest in developing a new generation of skilled entrants to the mining industry. Last year, 270 people enrolled in its training mine, of whom 95 percent graduated. Of these, 84 percent are now employed by NGM.

NGM has similarly invested $4.5 million in the establishment of three children's learning centers in its communities aligned with its mining schedules to alleviate the shortage of childcare services in the areas around its mines.

The provision of strong childcare benefits is expected to attract younger employees, and particularly women, to an aging and male-dominated industry. Its latest social infrastructure development project is a $10 million recreation center, based on the principle that a healthier community will deliver a healthier workforce. ■

Investors challenge companies on tailings practices;
More than 100 companies have not committed to higher standards

A GROUP OF investors managing more than $25 trillion said they plan to challenge mining companies that have not yet committed to a tailings dam best-practice standard and may vote against management at upcoming annual meetings.

The Investor Mining and Tailings Safety Initiative was launched in August 2020 in response to the Brumadinho disaster in Brazil where 270 people were killed when a tailings dam collapsed.

So far 77 listed mining companies, including the world's largest BHP and Rio Tinto have signed up to a tougher code of conduct.

But 126 companies, many of them smaller, have yet to commit to the standard, leaving their shareholders, insurers and banks facing greater risk, the investor group's chair Adam Matthews told *Reuters*.

The initiative names China's Zijin Mining Group Co. Ltd, which also has mining interests overseas and has previously run into trouble with tailings dams, Saudi Arabia's state-owned miner Ma'aden, Grupo Mexico and its subsidiary Southern Copper Corp., among those companies not conforming with the standard.

In a statement to *Reuters*, Grupo Mexico said the company, including Southern Copper and other subsidiaries, is committed to "zero damage to health and safety of our employees, communities and the environment throughout the life cycle of our tailings systems," in line with the Global Industry Standard on Tailings Management.

Zijin and Ma'aden did not respond to *Reuters*' requests for comment.

"It's still concerning that you've got over 100 companies that ... haven't been responsive to the engagement we've been doing," said Matthews, who is also chief responsible investment officer for the Church of England Pensions Board, a member of the investor group.

The initiative said it wants commitments from laggard companies within the next year, and clarity on when they would implement the standard.

But Matthews said the Church of England Pensions Board would vote against any companies not conforming or complying with the standard that have annual meetings over the next few months.

"We will be voting against the chair of the company ... and we'll also consider filing a shareholder resolution as well," he said. He also said other members of the initiative could well do likewise but would make their own decision on how to vote.

To date, more than 14,000 active and legacy tailings dam facilities across 77 countries have been collated in a global public registry. ■

Li-Metal provides update for its anode pilot plant;
Plant aims to provide next-generation battery anode technologies

LI-METAL, a developer of lithium metal anodes and other battery technologies, has released an operational update for its roll-to-roll anode pilot plant in Rochester, NY. Since its commissioning earlier this year, the facility has been ramping up production of its lithium metal anode sample materials using Li-Metal's roll-to-roll physical vapor deposition (PVD) process.

This year, the facility has produced more than 3,000 m (9,850 ft) of sample material for internal and customer use. The plant can produce anode products with lithium thickness between three and 25 micrometers.

Li-Metal has completed proof-of-concept testing of silicon anode prelithiation using its PVD equipment. Once it expands to commercial-scale prelithiation, Li-Metal says it will be able to serve a broader customer base with multiple next-generation battery anode technologies, significantly expanding the addressable market for its offerings.

"Silicon anodes are an exciting next-generation battery technology that is being commercialized in parallel with lithium metal-based batteries," said Jonathan Goodman, Li-Metal's chief scientist. "A key challenge with many silicon anodes is that they experience a significant loss of battery capacity in the first charge-discharge cycle. Our silicon prelithiation work holds substantial promise as a cost-effective, performance-enhancing technology to overcome this challenge."

"Our U.S. pilot plant continues to hit key benchmarks and technical milestones," said Maciej Jastrzebski, co-founder and chief executive officer of Li-Metal. "The process productivity increases we have achieved this year play a big part in determining production economics. We have demonstrated high-rate deposition, and to our knowledge, we are operating the highest-intensity PVD lithium deposition process in the world."

Li-Metal recently completed a scoping study for the development and build-out of a small commercial-scale anode production facility. The envisioned plant will demonstrate a PVD lithium anode production line at full scale, while supplying up to a million meters per year (approximately 200 to 250 MWh) of large-format anodes for advanced product qualification and early-stage production. ■

Global miner posts 24 percent rise in annual copper output; **Production remains lower than previous forecast**

ANGLO AMERICAN reported a 24 percent rise in copper production last year to 826 kt (910,000 st), lower than a previously forecast range of 830 kt to 870 kt (915,000 to 959,000 st).

The company left its 2024 copper output guidance at 730 kt to 790 kt (805,000 to 871,000 st). The metal is used for electric vehicles and renewable infrastructure, key planks of the energy transition.

Analysts have forecast a copper deficit from this year after Panama ordered the closure of a First Quantum mine with capacity of 350 kt/a (386,000 stpy) and as major producers including Anglo, Glencore, Codelco and Vale Base Metals expect lower supply from their operations.

London-listed Anglo American in December announced $1.8 billion of spending cuts by 2026, which it is prepared to deepen in the event of worsening demand for the metals it mines.

"Various operational challenges remain, but 2024 guidance — which has been reiterated — is achievable," Jefferies analysts said in a note.

Production of rough diamonds at the company's De Beers unit fell 8 percent to 31.9 million carats in 2023. Diamond demand in major consumer China dropped last year as an economic slowdown curbed appetite for luxury items.

"Whilst there has been some improvement coming into 2024, the prospects for economic growth in many major economies remain uncertain and it may take some time for rough diamond demand to fully recover, which has led to the Group currently assessing its carrying value of De Beers," Anglo American said in a statement.

Iron ore production rose by 1 percent, while platinum group metals (PGMs) registered a 5 percent output drop, it said. ■

Pentagon: AI model will be rolled out in three phases

(continued from page 6)

not intended to set an official U.S. government metals price or replace the London Metal Exchange (LME) and other futures markets, the sources said.

However, the documents cited the LME's 2022 nickel pricing fiasco as one of the "endogenous market dynamics and anticompetitive practices [that] can make futures markets a poor source of price information."

Financial information firm S&P Global and defense contractor Lockheed Martin are among the companies that have applied, according to the sources. S&P Global, which publishes benchmark prices for metals and other commodities, did not respond to requests for comment. Lockheed Martin deferred comment to DARPA and the U.S. Geological Survey.

The AI model will be rolled out in three phases over the course of two years, according to the documents.

OPEN also aims to predict how supply could be affected by unexpected market shocks such as labor strikes, although the contractors have been told not to predict natural disasters or other specific market events, the documents showed.

Market analysts typically estimate that roughly 5 percent of global production of a metal could be disrupted each year by such unexpected shocks.

Anticipating price swings and calculating what might be an appropriate value for a metal could give Pentagon officials a formula to time purchases for national stockpiles, one of the sources said.

The Pentagon this year, for example, plans to buy 1.3 kt (1,400 st) of lanthanum, used in steel alloys, government records show. But lanthanum, one of the 17 rare earths, is not traded on futures exchanges and China's control of the sector makes it difficult to determine whether prices offered reflect market fundamentals.

A 2021 spike in the price of coal caused a 200 percent jump in prices for magnesium that the Pentagon document said "further increased the opacity of the U.S. critical material supply chain." Magnesium can be produced alongside coal and is used to make missiles and other weaponry.

It is not clear how a U.S. government metals price or supply estimate would be received by mining companies, their customers, and metals exchanges, all of whom have developed the existing market structure over hundreds of years.

Most metal is sold on long term contracts. Consumers, producers and traders often sell their unwanted metal on exchanges such as the LME, a market of last resort where prices are lower than in the physical market.

In the physical market, buyers typically pay a premium that takes into account costs such as those for transport, insurance and import taxes, above the LME price used as a reference.

Several lithium, rare earths and graphite miners have begun charging premium prices for metals produced outside of China, but those terms are contractually negotiated and not influenced by any government price schema.

The LME said it expects the use of AI to analyze metals supply and demand to grow, but noted that its own prices are based "on real-world transactions executed by market users across the globe."

"The LME's traded contracts are settled through the physical delivery of metals into our global warehouse network, ensuring LME prices fully reflect any shifts in physical market fundamentals," an LME spokesperson told *Reuters*.

Any concerns that a U.S. government "structural price" for a metal could conflict with futures exchanges and pricing providers is "beyond the scope" of OPEN's aims, a DARPA spokesperson said. ■

Europe's deepest mine to be used for battery storage; **Zinc and copper mine will host underground gravity battery**

FIRST QUANTUM'S Pyhäsalmi Mine, roughly 450 km (280 miles) north of Helsinki, Finland is set to host a giant underground gravity battery.

The zinc and copper mine, decommissioned in 2022, is the deepest mine in Europe and will be transformed into a giant battery of sorts that will store renewable energy during periods of excess production.

The Independent reported that the mine will be fitted with a gravity battery, which uses excess energy from renewable sources like solar and wind in order to lift a heavy weight. During periods of low production, the weight is released and used to power a turbine as it drops.

The gravity battery system has been developed by Scottish firm Gravitricity, which plans to use the Finnish mine as a full-scale prototype to demonstrate the technology.

"This project will demonstrate at full scale how our technology can offer reliable long-life energy storage that can capture and store energy during periods of low demand and release it rapidly when required," said Martin Wright, an executive chairman at Gravitricity.

"This full-scale project will provide a pathway to other commercial projects and allow our solution to be embedded into mine decommissioning activities, offering a potential future for mines approaching the end of their original service life."

A study last year by the International Institute for Applied Systems Analysis (IIASA) estimated that gravity batteries in abandoned underground mines could store up to 70 TWh of energy — enough to meet global electricity demands.

The repurposed mines could also provide economic benefits to the communities that previously relied on the mine for their livelihoods.

The IIASA analysts noted that mines already have the basic infrastructure for such an endeavor, while also being connected to the power grid.

"This significantly reduces the cost and facilities for the implementation of Underground Gravity Energy Storage (UGES) plants," the study noted.

"As the world generates more electricity from intermittent renewable energy sources, there is a growing need for technologies which can capture and store energy during periods of low demand and release it rapidly when required," Gravitricity's website states.

"We are developing innovative, long-life, underground technologies which store energy safely and deliver it on demand at a lower lifetime cost than current alternatives." ■

South32: Hermosa project will create up to 900 jobs

(continued from page 8)

produced in the United States and that total is forecasted to drop by 2030. Citing its importance for national security and economic growth, the U.S. government designated zinc a critical mineral in 2021.

The feasibility study for Hermosa's zinc-lead-silver deposit showed an expected initial operating life for the mine of approximately 28 years with potential for further exploration upside.

Development of the zinc-lead-silver deposit is aligned to South32's purpose to improve people's lives now and for generations to come by supporting jobs in a community where unemployment is double the state average and a quarter of residents live below the poverty line.

Once in operation, the Hermosa project across its separate zinc and manganese deposits would help transform and grow the local economy and could create up to 900 well-paying jobs and support investment in the community, if both deposits move forward as proposed. At peak operation, that includes:

- Developing a homegrown workforce with the next-generation skills needed to operate the Hermosa project. The Hermosa project has an 80 percent local workforce goal, with the vast majority of employees living and working in Santa Cruz County to ensure downstream economic benefits for the entire region.
- Supporting another 1,600 indirect and induced jobs across Santa Cruz County and 3,100 indirect and induced jobs statewide.
- Adding $1.4 billion to Arizona's economy annually with $999 million going directly into Santa Cruz County's economy. Hermosa-related economic activity is expected to nearly double Santa Cruz County's property tax base, providing funding for public schools, services and community college. ■

Heavy equipment sales were strong in 2023; **Caterpillar reports record-high share prices**

CATERPILLAR BEAT estimates with a double-digit jump in operating profit to send its shares to a record high buoyed by mining equipment sales and higher prices across its machinery divisions.

Spending on heavy machinery held steady among commercial clients. Dealer inventories fell for the first time in four quarters, by $900 million, in an encouraging sign that spending remains resilient helped by the $1 trillion infrastructure law to upgrade roads, bridges and other transportation infrastructure.

Chief financial officer Andrew Bonfield told investors on a conference call that top-line estimates would be relatively similar to last year, adding: "We believe that the bottom end of the range remains challenging, but achievable."

Retail sales in North America were up 11 percent year on year. Purchases for commercial customers in the Asia-Pacific region were down 5 percent as China's troubled property market continues to drag on sales in the region.

The company's profit margins have been helped by a $28.1 billion order backlog for construction equipment and demand from customers in oil and gas, power generation, rail and defense in the past year.

Despite drilling at North American oil rigs showing signs of weakening, the industrial powerhouse is still benefiting from higher purchase volumes for its haul trucks and other mid- to large-sized mining equipment.

Purchases of heavy machinery from construction and mining industries aided Caterpillar's full-year operating margin. Profit for the world's largest construction company in the energy and transportation segment rose 21 percent from the year prior.

Its operating profit margin increased to 18.4 percent in the fourth quarter from 10.1 percent a year earlier.

The company's fourth-quarter profit rose to $2.68 billion, or $5.28 per share, topping consensus estimates of $4.75 per share. Sales and revenue for the quarter ended Dec. 31 were in line with analysts forecasts, rising to $17.1 billion from $16.6 billion. ■

ExxonMobil will decide on lithium processing by year's end; **Company aims to become lithium producer**

EXXONMOBIL plans to decide by the end of the year which lithium filtration technology it will use in Arkansas as part of its push to become one of the world's top producers of the battery metal, an executive said.

The company last fall announced its long-anticipated plan to filter lithium from the Smackover brine formation that flows under Arkansas, with the aim of producing enough of the metal by 2030 to power 1 million electric-vehicle (EV) batteries.

The plan will require a complex mix of equipment, including at least one of a so-far unproven fleet of direct lithium extraction (DLE) technologies to filter the metal from the brine.

Exxon has built a pilot plant in Houston and spent recent months testing various DLE technologies, producing small amounts of battery-grade lithium, Patrick Howarth, head of Exxon's lithium business, said in an interview on the sidelines of the Arkansas Lithium Innovation Summit in Little Rock, AR.

Howarth, who has worked at Exxon for nearly 19 years, said the facility allows the company to test how the DLE processes interact with the rest of the vast network of equipment needed for production.

"DLE is a small part of a really complicated process that has many different steps," said Howarth. "We're really focused on how do they interact with one another."

Lithium production with partner Tetra Technologies is expected to begin in Arkansas by 2026, and by 2027 from roughly 48,562 ha (120,000 acres) Exxon owns independently.

Exxon has had early discussions with automakers about purchasing lithium, but no agreements have been made, Howarth said. ■

SSR Mining permits revoked following landslide in Turkey

FOLLOWING A landslide at SSR Mining's Çöpler Mine in Turkey that left nine workers unaccounted for, Turkey canceled the environmental licenses for the mine. Eight SSR Mining employees were taken into custody while local authorities continued to investigate the incident that took place on Feb. 13.

The incident dislodged 10 million cubic meters of earth across a 200-m (656-ft) slope.

"Search and rescue operations to locate nine missing workers following the Feb. 13, 2024 incident at the Çöpler Mine continue and all operations remain suspended. All available resources have been deployed to assist in the operation, with emergency crews and first responders working around-the-clock, utilizing advanced search techniques supported by aerial drones. Our thoughts continue to be with the families of the missing workers and the Çöpler community during this incredibly difficult time. We will continue to support the authorities on the ground in Turkey in their search and rescue efforts," SSR Mining reported on Feb. 16.

According to reports, the missing workers remained trapped under the soil on Feb. 19, and Turkey's Energy Minister Alparslan Bayraktar said that rescue efforts continued. ■

Marc A. Herpfer;
An interview with the 2024 SME President

by William Gleason, Editor

For 2024 SME President Marc Herpfer it is all about "connections and transitions." Not just the networking and peer-to-peer connections one finds through involvement with professional societies such as SME, but he believes virtually everything is interconnected. And it is those connections that will carry the mining industry, as well as SME, into a brave new future.

Herpfer has a unique professional background that includes metallurgy, meteoritics, cosmochemistry, solid-state diffusion in iron-nickel (Fe-Ni) metals as well as high-performance business-to-business and consumer research and development. His career in the mining industry began more than 30 years ago, and his involvement with SME began when his mentors told him he did not have a choice but to join "the greatest professional Society on this planet."

Since joining SME as corporate geologist for Oil-Dri Corp. of America, Herpfer has advanced in that company to become vice president, New Technologies. Within SME, he has chaired numerous committees, served on the SME Board of Directors, was Chair of the Industrial Minerals & Aggregates Division, and has been recognized with a number of SME awards.

In his term as the President of SME, Herpfer will look to encourage diversity of thought among its more than 13,000 members as he sees a future for the mining industry that will be transformed by artificial intelligence (AI) and machine learning. This revolution will reshape the world and will require professionals in the mining industry to have a broad range of talents and knowledge.

Herpfer spoke with *Mining Engineering* about his professional career, his thoughts on the state of the mining industry, and what he envisions SME's role will be in that future.

Can you tell us about yourself?

I remember as a young boy watching the Apollo 11 moon landing in 1969 and being awed by what I saw on television, and my mind was permanently imprinted when I heard that space belongs to man, and that we had just made "one giant leap for mankind." Since then, the last half-century has seen much change in our society, both for SME and human civilization. It is my belief that over the next decade our future will experience even more change and fundamental transitions than during the past 50 years.

What can we do to foster and manage this transition? It has been said that change is the fundamental process of existence, and that everything in our world is multidisciplinary and interconnected. I believe that with some critical thinking we can all help guide, in a small part, how this will occur by focusing on such connections — or better said, the interconnections between all knowledge, everything and everyone in our world.

Within all the various mining and related disciplines, we can reasonably imagine what the future might evolve into, and better connect, disseminate and apply such big ideas to affect our mutual outcome. We can start by networking and interconnecting people and their knowledge,

all to foster and accelerate the profound transitions we will be living with over the next decade and beyond.

One of my goals is to connect with and work with members to envision how we can continue to evolve SME to beneficially and directly, or even indirectly, participate in everyone's lives. How can we better ensure the future strength, prominence and vitality of SME and its role in our society? Leaders never stop learning and discovery is limitless, so the possibilities and their impacts could be profound to both grow and sustain our society. The universe awaits humanity, and hopefully in our lifetimes, we will observe mining beyond Earth … so let us seize the moment.

How do you approach the idea of change for SME?

I've always had an interest in how the "world within the world" works on the microscopic scale. Everything ultimately works on the atomic scale, and if you understand that, then it is easy to transition and make connections from one discipline to another. The fundamentals of science, technology, engineering and mathematics (STEM) remain the same. If you have the fundamentals, you can understand and adapt yourself to many different jobs that I find very interesting.

You have an interesting background in the mining industry and in particular, the industrial minerals sector. Can you expand on your career and your work with clay mineral applications?

As a little boy and even now, I seem to have this insatiable curiosity about how the world was made and how it works. This often got me into some trouble (but that's another story). Having witnessed the first man step on the moon on television, and thinking that space belongs to humankind, my dreams of touching rocks and minerals blossomed as the astronauts hammered away on the lunar surface collecting samples to return to Earth. I set my gaze below my feet and picked up stuff wherever I visited. As the years went by, my focus turned to discovering how planets and the solar system were formed by investigating all that I could get my hands on, including samples of meteorites and moon rocks during graduate work I did at Arizona State University (ASU).

When I graduated from ASU it was a tough

Herpfer: Artificial intelligence and broader connections will help define Society in the future

Dr. Marc A. Herpfer is vice president of New Technologies at Oil-Dri's Innovation Center in Vernon Hills, IL. He has more than 30 years of "mine to market" leadership experiences in creating value from sorbent minerals via technologies linked to a broad spectrum of applied sciences and industrial processes.

Herpfer works with high-performance business-to-business and consumer research and development teams that commercialize fluids purification-filtration, animal-health, pet-litter, agricultural-horticultural, petrochemical, industrial and environmental applications worldwide. He is also involved with minerals exploration and characterization.

He participated in creating the root technology of many innovative product lines and their processes (Pure-Flo bleaching clays, Select adsorbents, Calibrin enterosorbents and Verge engineered carriers). Herpfer is an inventor on patents related to bleaching clays for purifying edible oils, ethanol production media, porous ceramics in structural brick production, and nanomaterials for bacterial quorum sensing inhibition/disruption. He has published on mining sustainability, mycotoxin binders and gut-health antibacterial clays, co-edited a book titled *Functional Fillers & Nanoscale Minerals* and co-chaired the 2010 Dreyer Conference on "Specialty Clays — Geology, Production & Markets."

He conducted research in the fields of metallurgy, meteoritics, cosmochemistry, solid-state diffusion in iron-nickel (Fe-Ni) metals, and the physico-chemistry of melt microstructures formed in metal-silicate aggregates at ultra-high pressures (that is, the core-mantle boundary stuff in protoplanets).

Herpfer is active in SME and has served on its Board of Directors, and is Past Chair of the Strategic Structure & Governance Committee as well as the Industrial Minerals & Aggregates Division (IM&AD). He has served on the Government and Public Affairs Committee and numerous strategic, nominating and divisional technical committees/sessions since 1996. He is the recipient of the 2020 AIME-SME Hardinge, 2012 SME Program, 2011 IM&AD Distinguished Service, 2003 Piekarz and 1995 Young Scientist awards, among others. He is also active in the Clay Minerals Society. ■

time in the industry and academia, so when I got a job offer from Oil-Dri I accepted it, and it was a radical change of direction into a discipline that was completely different and new … but exciting!

I transitioned into mining and clay minerals technologies all due to the mentorships of SME members Hayden Murry, William Moll, Fred Heivilin, Nikhil Trivedi, Ihor Kunasz and Frank Alsobrook, who all greatly fostered connections and my transition into the mining industry. My life's work over the past three decades at Oil-Dri has been focusing on a different type of "space" … that is, the microporosity controlling sorption science (both absorption and adsorption on the atomic scale), or as I sometimes jokingly analogize to "suck and cling" on the molecular scale.

In the mining industry, remaining with one company is quite unique. Can you expand on why you have stayed with Oil-Dri for your entire career and the benefits that you have seen from staying in one spot?

I have been with Oil-Dri for more than three decades in various "mine to market" leadership experiences at both the operations and innovation centers.

My longevity here is primarily due to the unique opportunity to create value from sorbent minerals via technologies linked to a broad spectrum of applied sciences and industrial processes.

It has always been an exciting, challenging and diverse opportunity to develop new products while I get to closely work with high-performance business-to-business, consumer, research and development (R&D) and engineering teams that have commercialized fluids purification-filtration, animal-health, pet-litter, agricultural-horticultural, petrochemical, industrial and environmental applications worldwide.

As a bonus, I am involved with minerals exploration and characterization that enables such applied R&D. Over the decades, I have participated in creating the root technology of many innovative product lines and their mineral processes such as adsorbent bleaching clays for purifying edible oils and jet fuels, enterosorbents for toxin binders and gut health in animal feeds, and engineered agrochemical carriers, ethanol production media, porous ceramics for structural brick production, and nanomaterials for bacterial quorum sensing inhibition/disruption. For a scientist with a passion for clay minerals, the "spectrum of opportunities and creativity" cannot get better than that.

There are many members of SME who might not be very knowledgeable about the industrial minerals sector and the challenges of creating value from the minerals that you work with. Can you expand on what sets the industrial minerals sector apart from other sectors, and expand on the competitive nature in that sector?

Since most industrial minerals have minimal intrinsic value, unlike certain precious metals, one has to either transform them to work in any given specialty application (such as catalysts, adsorptive media or functional fillers), or alternatively one has to extract and process them at a low cost that justifies their usages in bulk commodity applications (such as construction materials).

In either case, one has to add on the "appropriate" value to them above their nonvalue while in the ground (and usually it costs money just to locate and maintain access to them). Given the numerous and various natures of all the known minerals and rocks we can mine for some use by society, it becomes readily apparent that there is often much complexity and risk to supplying all the different industries consuming them as well as their specific applications for such minerals.

For almost every industrial mineral company I know, the old sayings of "no margin, no mission" and "cash flow is king" are fundamental axioms to sustain their businesses profitably over the life span of their capital-intensive operations. So to accomplish this … one must add "value" to stuff that varies between a high-volume commodity at a few dollars per metric ton up to engineered materials that can reach many dollars per kilogram.

At SME, we tend to think about mining in terms of precious metals or energy materials, but we also need to think about all the other stuff under our feet, and how do we as an industry manipulate these raw materials we mine to help build, sustain and feed a civilization?

What are your thoughts on the state of the mining industry in general and that of the industrial minerals sector specifically?

The mining industry will and must evolve over the next decade, especially due to the profound impact caused by AI in how we discover, disseminate and apply knowledge in improving all facets of and expanding mining … which eventually may occur beyond Earth.

A part of a strong university education involves learning a baseload knowledge so that one can make cogent decisions and understand the interconnections among various technical or

scientific aspects, and/or how one aspect impacts another. Those education fundamentals allow us to connect ideas and thoughts, and eventually lead us to create new products and processes.

Today, we have all of the world's knowledge at our fingertips through our smartphones and computers, and we no longer have to do all that hard research work. AI will be able to do that work at infinitely faster speeds; it is infinitely more precise, though maybe not accurate, and can collect all of the information and put it all together. The question then becomes, what can AI do with all that knowledge? Can it actually really think and be creative and come up with an answer, or is it just the output of whoever programmed it?

The growing global need for energy, metals, minerals, materials and food will expand the search for, and extraction and utilization of such resources. Without such abundant and cost-effective natural stuff, one cannot build and feed a civilization, and hence grow and sustain a vibrant society.

What are your thoughts on the state of SME as well as your vision for the Society during your term as President?

I truly believe that in my lifetime we are on the cusp of a tremendous transition for humanity driven by science and technology that are all interconnected. For SME members the question is: How will AI impact my job in five or 10 years? Being able to figure out how we can use AI, and how we can still critically think for ourselves, will be one of the biggest challenges we face in the coming years.

I do not know what the true answer is or what the future will look like. I just know it will not be the same as the past, and change will accelerate at a much faster pace. For SME, what can we do to help guide, control or use this technology for best practices, or make the workplace safer and more efficient? How can we use AI to go to places where humans currently cannot go because the reserve is too deep in the ground or the ocean? How can we use AI to explore offshore potential or off-Earth potential such as mining the moon or asteroids?

At SME, we need to think bigger and broader as our discipline is going to be much more interconnected with other areas beyond just the classical mining, metallurgy and exploration education. Everything is interconnected technologically from a scientific perspective, and from a people and a human resource perspective.

There are many issues facing the mining industry, what will you focus on as President?

I think that AI will enable more change over the next decade than the computer revolution empowered us to accomplish over the last 50 years.

I believe there will be a new renaissance. In my lifetime I want to learn as much as I can. The broader you can go in your knowledge capabilities, and with depth and breadth on different subjects, the more likely you are able to have "a-ha" moments and make connections or come up with something quicker that is better, cheaper, faster, more interesting, more exciting or more novel.

In the next five years or the next decade, that change will be about making connections between all the various disciplines. This will be done by networking with people and making the interconnections between different knowledge facts or different knowledge bases that allow you to do or create something better or new. Then the next challenge will be how do we disseminate that information? I see SME as the global mining Society that will be at the forefront of those connections.

Any closing thoughts?

For me the glass has always been half-full, and that we do not even know yet what we do not know. I am optimistic about what the future holds for SME and all of our interconnected lives, and that together we can achieve great accomplishments. ■

Innovative approaches to building technical capability for a modern mining and metals organization

by Brendan Howard

Rio Tinto has a large, globally distributed technical workforce and needs to ensure these employees have the requisite skills to not only manage technical risk and enable safe, efficient production but also ensure they are keeping pace with a fast-changing technological landscape. Traditional approaches to learning struggle with scale and an inability to respond to the extreme diversity of capability development needs. In response, Rio Tinto has successfully introduced innovative approaches to learning and employee engagement by leveraging the power of globally distributed networks for peer-to-peer knowledge transfer and providing mechanisms to recognize, reward and retain individual technical contributors.

Table 1

Distribution of technical professionals by category. (Source: Rio Tinto)

Category	Percent of total technical workforce	Selected professional backgrounds
Asset management	37	Assorted engineers, especially mechanical
Geoscience	6	Geologists, hydrogeologists
Processing	19	Metallurgists, chemical engineers, process engineers
Mining (surface and underground)	18	Mining, software, geotechnical, civil, environmental, tailings engineers and surveyors
Integrated operations	9	Assorted engineers and data scientists
Capital, closure and research and development projects	11	Assorted engineers, scientists and researchers

Introduction

Like other mining and metals organizations, Rio Tinto is dependent on high-quality technical expertise to find, study, build, operate and close the mines and processing facilities that provide the metals and minerals that underpin modern society. Arguably, the caliber of the technical workforce together with the quality of the mineral resources represent the core sources of competitive advantage for any minerals company. As one of the largest minerals producers in the world, Rio Tinto employs a large global technical workforce, currently around 10,000 professionals, which consists of many engineers and scientists who make up approximately 20 percent of the total Rio Tinto workforce. Table 1 and Fig. 1 present some of the basic demographics of the technical professional workforce.

In addition to the traditional mining and metals professions of geologist, mining engineer and metallurgist, Rio Tinto employs an array of scientific and engineering professionals. In the past decade, there has been a substantial increase in the number of "digital" professionals, including software engineers, data engineers and data scientists. Similarly, there has been a sizeable increase in the number of environmental and social scientists in response to increasing mine closure, community and other environmental, social and governance (ESG) obligations.

More than 80 percent of the technical workforce is in Australia and North America, but Rio Tinto also has a substantial and growing footprint in Africa and Asia, with large development projects in Guinea and Mongolia (Fig. 1a). The age demographics in Fig. 1b are included to highlight the fact that approximately one quarter of the workforce will be at or approaching retirement age in the next decade.

Drivers to invest in technical capability development

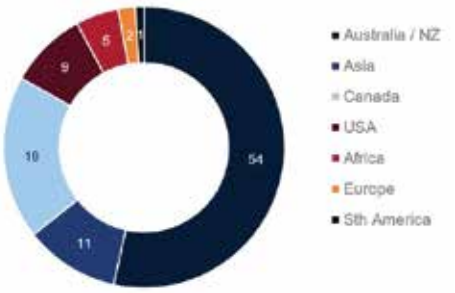
Learning underpins the Rio Tinto purpose of "finding better ways to provide the materials the world needs," and connects strongly with the company values of care, courage and curiosity (Fig. 2). The company's objectives to be the best operator, with impeccable ESG and to excel in development all require a substantial focus on capability development to be successfully delivered.

Brendan Howard, member SME, is general manager at Rio Tinto, Brisbane, Australia, email brendan.howard@riotinto.com.

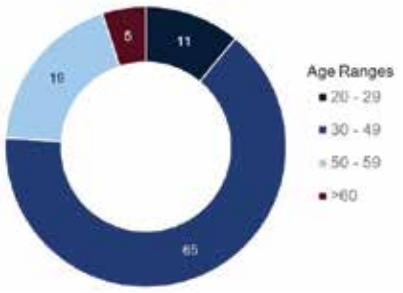
Figure 1

(a) Geographic and (b) age distribution of Rio Tinto technical workforce. (Source: Rio Tinto)

(a) Technical workforce distribution (percent)



(b) Workforce age distribution (percent)



The drivers to invest in technical capability development span a broad range of business outcomes from ensuring that the organization remains legally compliant, to safe operating practices, through to innovating and redesigning business processes and technologies to transform operational and safety performance.

The learning needs associated with the different business outcomes cover a range from highly prescriptive (for example, employees need to understand their specific obligations to be compliant with antitrust regulations) to highly complex and difficult to define (for example, we need the skills to design a zero-waste, decarbonized and fully automated mine). In Fig. 3, these business outcomes are shown in order of increasing complexity from left to right. While training on the left side leans toward executing tasks, the right side shifts more toward being able to solve increasingly complex problems in an ever-changing environment. Technical knowledge alone will not solve this, and programs aim to enhance or amplify technical capability by building skills in creative thought, future vision and collaborative intelligence through community.

The accompanying learning delivery methods range from traditional classroom or discrete e-learning modules to a more agile, creative and adaptive approach. Agility is the ability to solve all kinds of challenges as they present, which is not something typically associated with task-based training. This article is focused primarily on the right-hand side of Fig. 3.

In addition to the business outcomes described above, an investment in learning and capability development is widely recognized as a driver of improved employee engagement and retention.

Meeting the learning needs of the Rio Tinto technical workforce

There are several inherent challenges when defining an approach to satisfy the learning requirements of the global Rio Tinto technical workforce, starting with the diversity of learning needs given the breadth of technical disciplines represented and wide ranges of experience. An early career professional, fresh from university, will have a different learning needs profile from a 30-year industry veteran, possibly with multiple postgraduate qualifications.

Figure 2

The Rio Tinto purpose, values and objectives. (Source: Rio Tinto)

This is further complicated by:

- Geographic and language diversity and an audience distributed across numerous time zones, making it harder to deploy learning solutions contemporaneously at scale.
- Accelerated rate of operational technology change, meaning rapid obsolescence for learning content.
- Ongoing production demands competing for time allocated to learning, therefore requiring flexibility around when, how and where employees learn.

Figure 3

Complexity of learning needs, and associated learning delivery method.

Working with the constraints described, it is important that Rio Tinto adopts an expansive definition for what constitutes learning that leverages the inherent strengths of a global organization with access to extensive knowledge and experience across the workforce. Recent research by consultancy RedThread Research offers a picture of the diversity of learning opportunities available to organizations and their employees today (Fig. 4).

Versions of many of the learning mechanisms described in Fig. 4 are in application across Rio Tinto today. However, this article focuses specifically on three programs that respond to the inherent learning challenges and leverage organizational strengths. The design of these programs needed to be:

- Adaptive to a vast diversity of learning needs.
- Available to a global audience with different cultural and language needs.
- Accessible across different work environments and able to fit within assorted demanding work schedules.
- Able to draw upon the vast expertise contained within the large global workforce of technical professionals.

Innovative approaches to building technical capability

In addition to responding to the inherent learning challenges, three initiatives — technical communities of practice, agile Technical Network and RioExcel/RioExperts — are designed to be mutually reinforcing, and to build and protect unique sources of technical capability that provide competitive advantage for Rio Tinto (Fig. 5).

The networked technical organization — technical communities of practice. Rio Tinto is organized primarily around four product groups (iron ore, aluminum, copper and minerals), and employees typically identify strongly with their product group and receive management direction "through the line." While this approach offers many benefits, it risks forming product group silos and therefore does not capture the potential value available from employees performing similar roles in different product groups collaborating and sharing knowledge.

Rio Tinto has established several technical communities of practice, each with differing levels of maturity, across numerous technical domains including geoscience, surface mining, processing, geotechnical engineering, tailings management, asset management and several others. These forums have become powerful platforms for:

- Knowledge transfer and leading practice replication.
- Facilitating employee learning through an annual program of internal webinars, conferences and knowledge exchange through internal social-media platforms.
- Navigating career pathways, talent management for succession planning, and identifying mentors for those seeking development.
- Driving consistent global technical standards.

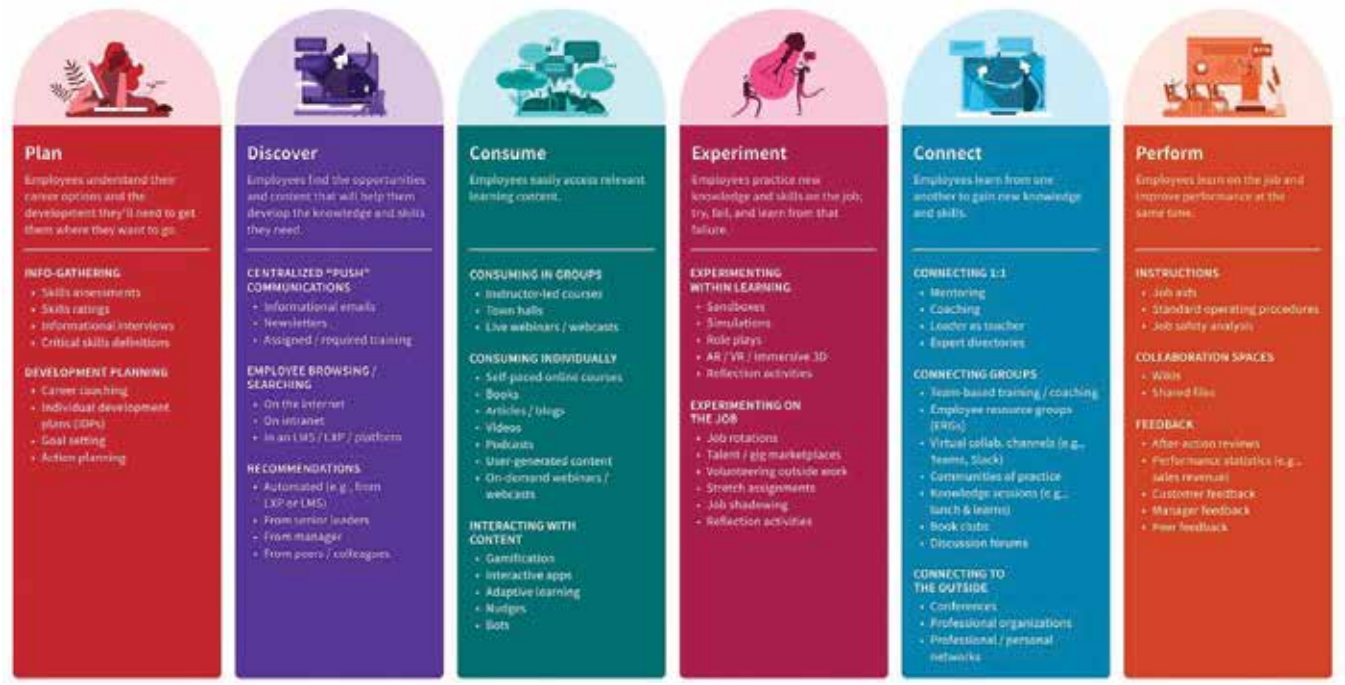
While the concept of technical communities of practice is not new, the level of maturity, vibrancy and organizational impact achieved has been significant. The more mature communities have become self-sustaining and are maintained by groups of "volunteer" employees passionate about the benefits of thriving technical communities. Participation in these communities has become a source of pride and employee engagement, and is a unique part of the Rio Tinto employee value proposition.

Although communities of practice are mostly low cost to maintain, they require a persistent investment of time, effort and leader sponsorship. One of the challenges in preserving leader support is being able to articulate the business value, which is mostly intangible.

The agile Technical Network (aTN). Across the large population of engineers and scientists employed by Rio Tinto there is an enormous depth of experience, and very likely the expertise to solve almost any technical challenge. However, the ability to find that expertise when it is needed and release it to solve the challenge has historically been limited to an employee's personal network and organizational reach. Confronted with the difficulty of finding the

Figure 4

Diversity of mechanisms that organizations apply to support learning in the workplace. (Source: RedThread Research, 2021)



right expertise, many employees would seek an external solution with accompanying additional costs.

Adult education design principles emphasize the most powerful form of learning is experience based, giving employees the opportunity to be stretched and to solve new challenges. However, the lack of visibility about these development projects, and the difficulty in connecting with willing learners at the right moment, has meant these opportunities were hard to find.

In response, Rio Tinto has established the agile Technical Network (aTN), an internal platform that allows employees to share their skills profile (current and for development) and allows employees to post short-term, ad hoc projects that call for expertise applying a consistent skills taxonomy. The aTN is effectively an internal version of the "gig" economy that applies matching algorithms to connect the supply of expertise with demand. This enables Rio Tinto to improve the level of collaboration, solve more challenges with the existing workforce, and provide greater visibility around internal personal development opportunities (Fig. 6).

Employees have embraced the concept and are attracted by the visibility around development opportunities and interesting work outside of their substantive role responsibilities. Since launching in 2021, there have been more than 1,400 employee-skill profiles posted and 132 short-term projects submitted, with 327 employees offering support. Notwithstanding the obvious benefits, substantial change management and communication effort has been required to reassure the business that employees will not neglect their substantive duties in favor of more "interesting" work accessed through the aTN.

RioExcel/RioExperts. Like most organizations with a large population of technical experts, Rio Tinto has a subset of the technical workforce that seeks career progression but is not motivated to become a "people" leader, instead preferring to focus on technical work. The RioExcel program provides a structured mechanism to assess and provide recognition and career advancement for deep technical experts while remaining an individual contributor (Fig. 7). Candidates for this recognition need to demonstrate not only the quality of their work and contribution to business outcomes, but to demonstrate their effectiveness at sharing their

Figure 5

Three mutually reinforcing initiatives for building and protecting technical capability.

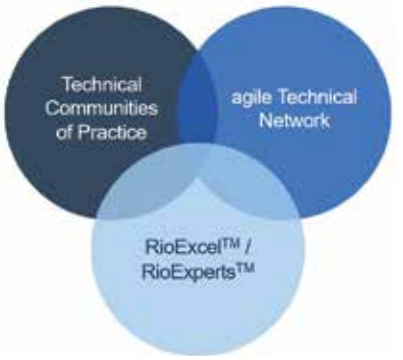
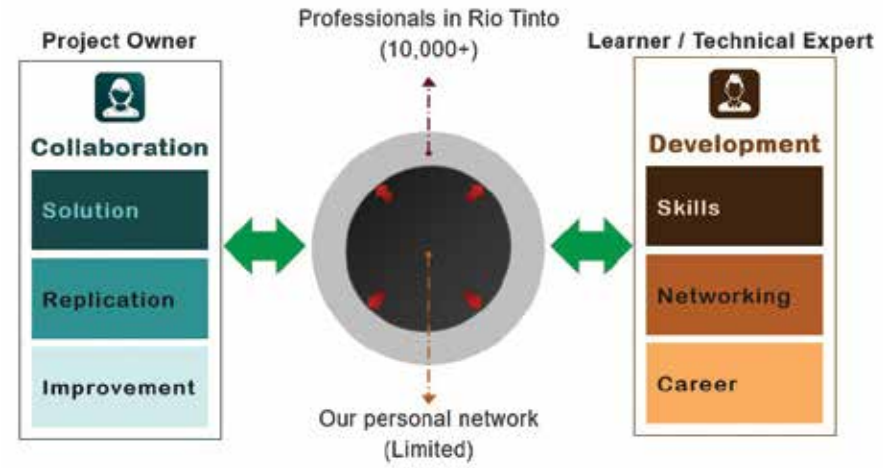


Figure 6

Concept of the agile Technical Network (aTN).



technical expertise through the communities of practice or as a mentor to the next generation of experts.

Individuals that have been successfully recognized through RioExcel are referred to as RioExperts, and these individuals are considered the custodians of the culture of technical excellence at Rio Tinto. There are currently approximately 150 RioExperts distributed globally and representing the full spectrum of technical activity and a significant human capital asset for Rio Tinto. RioExperts are expected to become a source of internal expertise that can be accessed through an internal expertise directory, helping to ensure that Rio Tinto is fully leveraging these unique skills for maximum advantage.

The RioExcel program has also provided improved attraction and retention of technical experts with attrition rates typically less than half the rate of the broader technical population.

Conclusions

While traditional forms of learning and development such as classroom and e-learning will continue to play a role, increasingly modern mining and metals organizations need to consider learning methods that are agile, scalable and adaptive to a fast-changing social, technological and regulatory landscape. In response, Rio Tinto has invested heavily in creating a networked technical organization both through the establishment of vibrant technical communities of practice and the creation of an internal expertise marketplace through the aTN. The strength of the networked technical organization has been enhanced by linking the RioExcel technical expert program as an incentive for candidates to provide leadership for the technical communities.

In addition to being relatively cost effective, this approach offers the benefit of being:

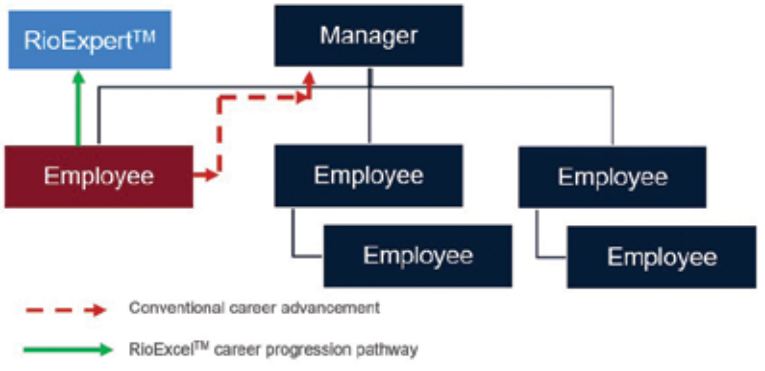
- Adaptive to a vast diversity of learning needs — something for everyone.
- Available to a global audience with different cultural and language needs.
- Accessible across different work environments and accommodates assorted demanding work schedules.
- Able to draw upon the vast expertise contained with the large global workforce of technical professionals.

Measuring return on learning investment is tricky; the ultimate measure is the quality of technical advice informing better decision-making and business outcomes. Rio Tinto undertakes employee engagement surveys every six months and collects data across a number of parameters including personal growth, which has steadily improved by approximately 15 percent in the past five years. This improvement is at least in part attributable to the three initiatives described in this article.

Future plans for maturing the technical learning ecosystem at Rio Tinto include strengthening the linkages to technical knowledge management systems, using technology to curate customized learning pathways for employees, and the establishment of a broad-based capability maturity index as a measure of technical capability trends over time. ■

Figure 7

The RioExcel pathway for recognition and career progression.



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New model for predicting the erosional performance of rehabilitated mine sites

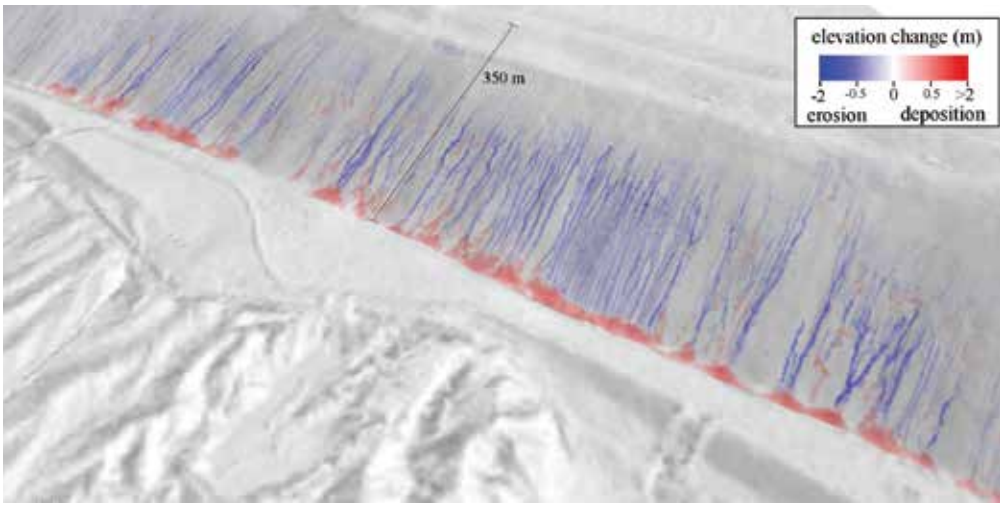
by Jon D. Pelletier, Nathan Abramson, Satya Chataut, Sriram Ananthanarayan, Dave Ludwick and Brendan P. Roddy

To avoid rill/gully erosion on steep rehabilitated mine hillslopes, mine waste can be redistributed to be less steep and have fewer areas where runoff is concentrated. In addition, the shear strength of a rehabilitated mine site surface can be increased with riprap and/or vegetation.

The mine-site rehabilitation community lacks mathematical models that predict the likely erosional performance of such rehabilitations so that they can be implemented cost-effectively and with confidence that they will work to prevent rill/gully erosion under both modern and future climates. This article describes a new mathematical model (Rillgen2D) for predicting rill/gully erosion that is informed by studying hillslope erosion processes in the laboratory and in the field at study sites in Arizona in the United States and Queensland in Australia. It highlights advances both on the forcing side of the problem (how rainfall generates runoff) and the resistance side (how certain properties of riprap contribute to shear strength). It documents three validation studies across a range of study sites (including with and without riprap, continuous-slope and benched-slope designs), which demonstrate that Rillgen2D accurately predicts where and when rills and gullies are likely to form. The intent is for this model to be widely used to predict the erosional performance of alternative rehabilitation designs to optimize performance and save money.

Figure 1

Oblique-shaded relief image of a 350-m-long tailings dam hillslope located in Pinal county, AZ with superimposed blue-white-red elevation change map of the erosion (blue) and deposition (red) that occurred during an Aug. 8, 2022 rain event that lasted approximately 30 minutes.



Problem statement

Mining activities often result in piles of waste rock and soil bounded by long, steep hillslopes that are highly susceptible to rill/gully erosion. A key goal of mine-site rehabilitation is to prevent rill/gully development and the associated transport of mine waste on such hillslopes. Rehabilitated mine hillslopes in dryland regions can be especially susceptible to rill/gully erosion because the sparse vegetation cover in such climates can limit the shear strength that resists erosion. As such, it is often necessary to modify mine-waste topography (for example, reduce slope steepness/length) and/or cover the waste material and soil cap with riprap to prevent rill/gully development. Such interventions can be costly and do not always work even when carefully implemented.

Figure 1 illustrates the rill/gully erosion that can occur on steep rehabilitated mine hillslopes. This example is a tailings embankment 350 m (1,150 ft) long and 100 m (330 ft) tall located in Pinal county, AZ. The colors represent the erosion and deposition measured by differencing high-resolution (2 cm/pixel) drone-based photogrammetric surveys of the embankment before and after a rain event that lasted approximately 30 minutes on the evening of Aug. 8, 2022 when the site experienced a peak 15-minute-duration rainfall intensity of 174 mm/h. Despite the presence of riprap with median

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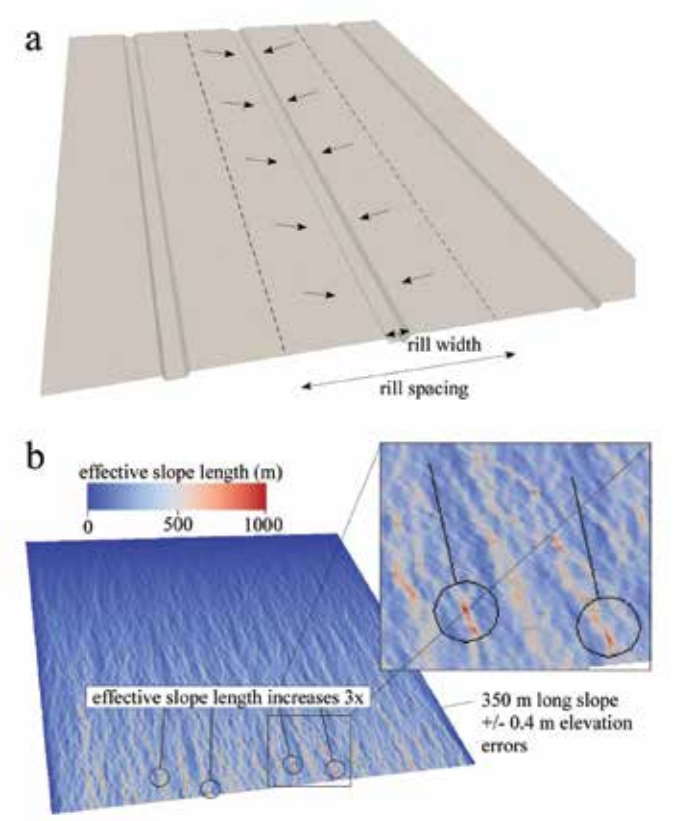
Figure 2

Comparison of how rills and gullies are modeled in (a) WEPP and (b) Rillgen2D. In WEPP, the user prescribes the spacing and width of rills/gullies and WEPP implicitly routes runoff to each, as shown by the arrows in (a). In Rillgen2D, rill/gully initiation is modeled from shear-stress hot spots — for example, the circled areas in (b) — that are explicitly resolved.



diameter of 10 cm on the lower two-thirds of the hillslope, gullies more than 2 m (7 ft) deep formed during this event, exposing and transporting waste material to the bottom of the slope.

Preventing erosion of the kind illustrated in Fig. 1 in future rehabilitated mine sites requires that proposed rehabilitation designs be assessed in terms of their potential for rill/gully development under modern and future climate scenarios. Historically, the most widely used mathematical model for rill/gully erosion on hillslopes has been the water erosion prediction project (WEPP) model (Flanagan and Livingston, 1995). Although WEPP has many positive traits, it has a limited ability to model rill/gully erosion because the user must prescribe the spacing of rills/gullies a priori — otherwise, WEPP assumes all rills/gullies to have 1-m spacing (Fig. 2a).

Clearly, the widths and spacings of rills/gullies cannot be known for any hillslope that has not yet been constructed. Rills/gullies form in response to the incipient steering of runoff into microtopographic depressions (Fig. 2b) that deepen if a threshold shear stress is exceeded, further localizing runoff in a self-enhancing feedback. The colors in Fig. 2b represent the effective slope length: that is, the upslope length that would be conveying flow to that point on the hillslope if the hillslope was planar and uniform sheetflow was occurring. Effective slope lengths greater than 350 m (1,150 ft) can occur in places where runoff has been steered and concentrated. Effective slope lengths of up to 1,000 m (3,280 ft) occur in this example on the lower half of the hillslope and are associated with approximately a factor-of-three increase in shear stress relative to the case of uniform sheetflow.

The fact that microtopography can result in enhanced shear stresses on hillslopes as illustrated in Fig. 2 and that such shear stress hot spots tend to be where rills/gullies initiate is widely recognized, but the literature contains inconsistent solutions to representing the runoff convergence/divergence that leads to such shear stress hot spots. The U.S. Nuclear Regulatory Commission (U.S. NRC, 2002, p. 41), for example, recommends that the effective slope length be estimated as the horizontal distance from the top of the slope multiplied by three, while the U.S. Environmental Protection Agency (EPA, 2012, p. 46) recommends that the same value be estimated as the horizontal distance from the top of the slope, L, multiplied by $L/4$. Rillgen2D models flow localization explicitly, avoiding any need to apply ad hoc adjustment factors.

Recently, the CAESAR-Lisflood model (Coulthard et al., 2013) has been used to model rill/gully erosion on hypothetical rehabilitated mine hillslopes (Slingerland and Dressler, 2022). One advantage of CAESAR-Lisflood over WEPP is that it explicitly routes runoff on hillslopes, including the effects of microtopography, similar to that of Fig. 2b. CAESAR-Lisflood does not explicitly include the protective effects of riprap, however, and it is unclear whether CAESAR can make predictions consistent with data from a real-world hillslope.

A new approach

In this study, field and laboratory measurements (Fig. 3) and remote sensing (for example, Fig. 1) of rainfall, runoff, erosion and related parameters (such as the angle of internal friction) were used to develop a new mathematical model (Rillgen2D) for rill/gully erosion on hillslopes. Rillgen2D accepts data for rainfall, topography (including microtopography), soil and land cover (riprap and/or vegetation) to predict where and when rills/gullies are likely to form on rehabilitated

mine hillslopes (actual or proposed designs). In the following, we emphasize two novel elements of Rillgen2D and outline the work that went into its development.

Improvements in quantifying the runoff associated with intense rainfall

Runoff data from monitoring plots (collected using the equipment illustrated in Figs. 3b-c) have been used to develop an empirical model predicting runoff based on its primary controlling factors in our Arizona study sites. In this model, runoff measured at a five-minute duration, R_5 (mm/h), is a power-law function of rainfall intensity measured at a 15-minute duration, I_{15} (mm/h), rainfall intensity measured at a one-hour duration, I_{60} (mm/h), and drainage area, A (m^2):

$$R_5 = 0.008A^{-0.13}{I_{15}}^{1.44}I_{60}^{0.75} \quad (1)$$

I_{15} and I_{60} control R_5 because more intense short-term rainfall triggers more infiltration-excess runoff, and more runoff is also likely to occur when the short-term peak rainfall occurs within a high-intensity rainfall of longer duration (one hour) that tends to saturate the soil prior to the arrival of the peak-intensity rainfall. Equation (1) was validated using runoff data from the Walnut Gulch Experimental Watershed (open circles in Fig. 4), which have similar soil types to those of our Arizona study sites.

Equation (1) can be readily applied to simulating event-based runoff for hundreds or thousands of years using the weather generator CLIGEN included in WEPP, assuming current climatic conditions. Figure 4b illustrates a simulated 100-year time series of the coefficient, $a_r = 0.008\ {I_{15}}^{1.44}\ {I_{60}}^{0.75}$ that predicts water discharge for the example station of Miami, AZ at every point on a landscape and for every event in a 100-year period when multiplied by $A^{0.87}$. The value of A at every point can be determined using several algorithms widely used for this purpose. Rillgen2D allows users to choose between the Freeman (1991) algorithm and a new algorithm developed for this project that accounts for runoff depth in addition to ground-surface slope when simulating surface water flow. Simulating possible changes in the duration and intensity of future rain events is an area of active research, but Rillgen2D users can prescribe possible or expected increases in precipitation intensities based on estimates of these changes from the published literature (for example, Prein et al., 2017).

Improvements in quantifying the shear strength associated with riprap

Several empirical models have been developed to quantify the shear strength associated with riprap. Historically, such models have been developed using the Abt et al. (2013) database, which includes 102 measurements of the threshold unit water discharge or shear stress (unit discharge and shear stress on steep slopes can be related by Eq. (7) of Eli and Gray, 2008) required for riprap failure when a filter layer is present. The most accurate current empirical model for riprap failure was proposed by Haws and Erickson (2020). Their model relates the threshold unit discharge of runoff, q_t (m^2/s) to

Figure 3

Examples of equipment used in the Arizona study sites: (a) laboratory: a tilt table for measuring the angle of internal friction of layered riprap-over-soil covers, (b) field: instrumentation at the base of hillslope-scale plots used for measuring coarse sediment load (collected in a bottom trough and subsequently weighed), runoff and fine sediment loads (measured using a tipping bucket outfitted with a turbidity sensor) and (c) field: instrumentation for measuring runoff and fine sediment in small-watershed-scale plots (including wingwalls that concentrate the runoff into a Parshall flume).

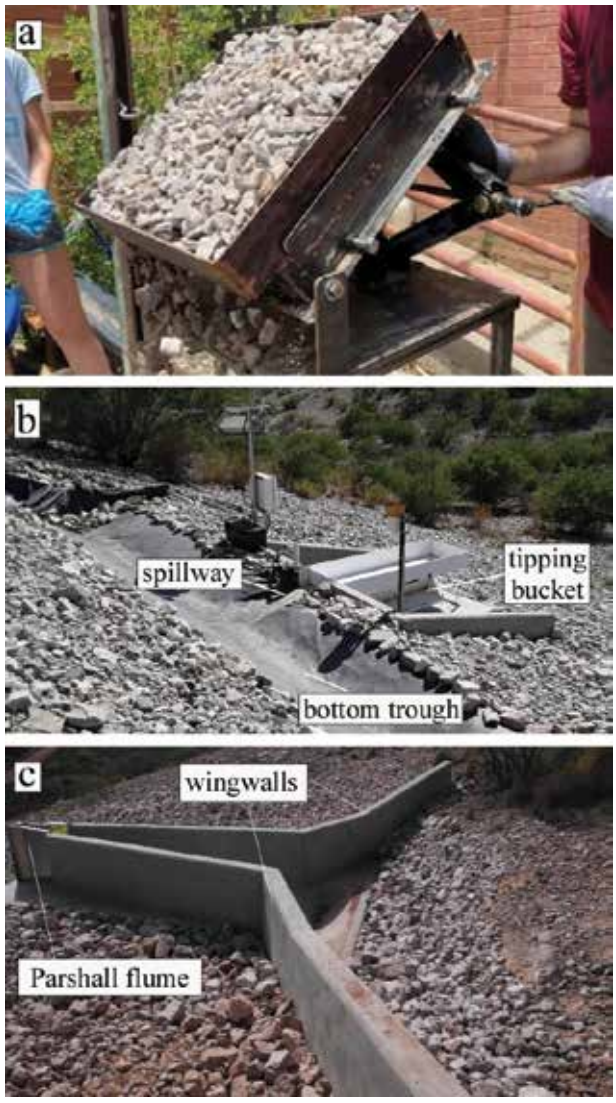


Figure 4

(a) Predicted versus observed values of R_5, as predicted by Eq. (1), for our rehabilitated mine study sites in Arizona and the Walnut Gulch Experimental Watershed (WG). (b) Simulated time series of the coefficient, a_r, that predicts water discharge when multiplied by $A^{0.87}$, for the example station of Miami, AZ.

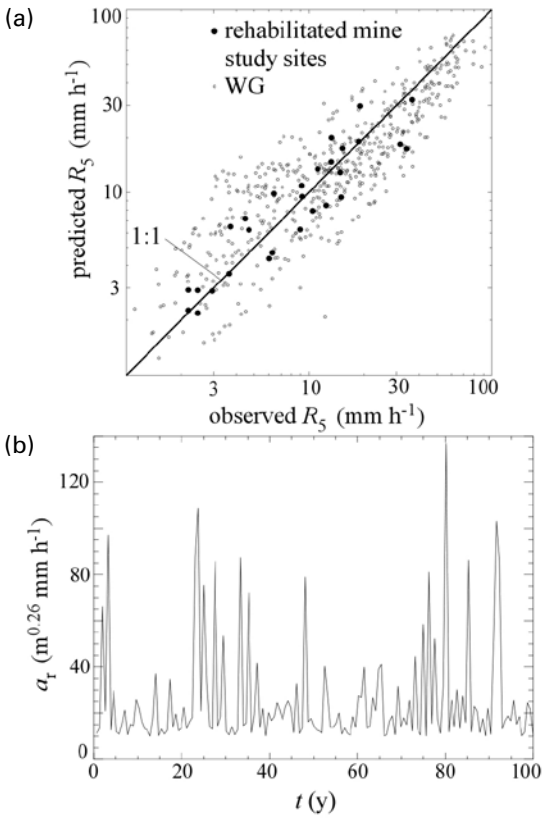
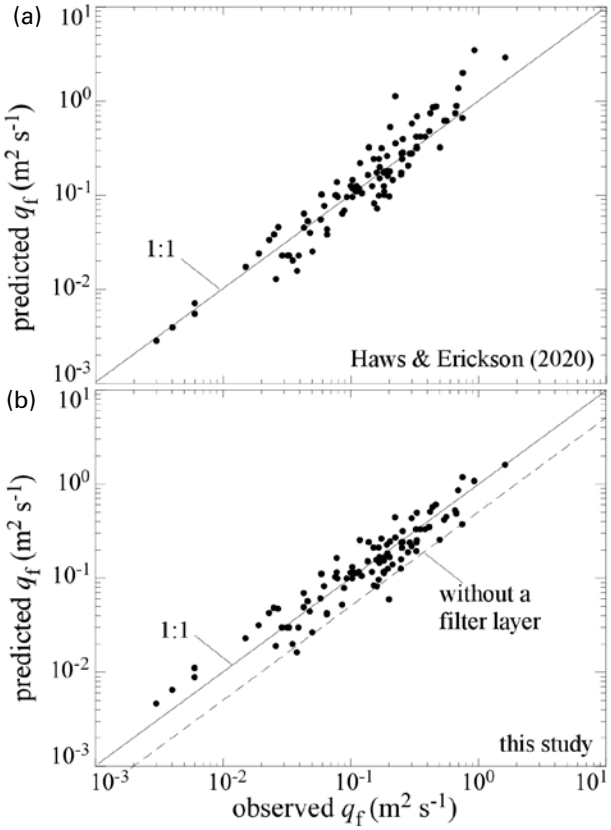


Figure 5

Plots of the predicted versus observed unit water discharge that triggers rock armor failure, q_f, from (a) Haws and Erickson (2020) and (b) Eq. (2) for rip-rap layers with (solid line) and without (dashed line) a filter layer.



the median riprap particle diameter, d_{50} (m) and slope angle, θ. An alternative model was developed that explicitly includes the angle of internal friction, ϕ:

$$q_f = c\left(\frac{\sin\theta}{\cos\theta\tan\phi - \sin\theta}\right)^{-0.86} d_{50}^{1.68} \qquad (2)$$

The value of c is 2.6 for riprap layers that include a filter layer and 1.3 for riprap layers that do not have a filter layer (the riprap is placed directly on top of soil, as is generally the case for large-scale mine rehabilitations). The factor-of-two difference between the two values of c is based on preliminary experiments of riprap failure with and without a filter layer. The root-mean-squared errors of the logarithms (base 10) of q_f predicted by the model of Haws and Erickson (2020) and Eq. (2) are 0.195 and 0.171, respectively, demonstrating the superiority of Eq. (2) (Fig. 5).

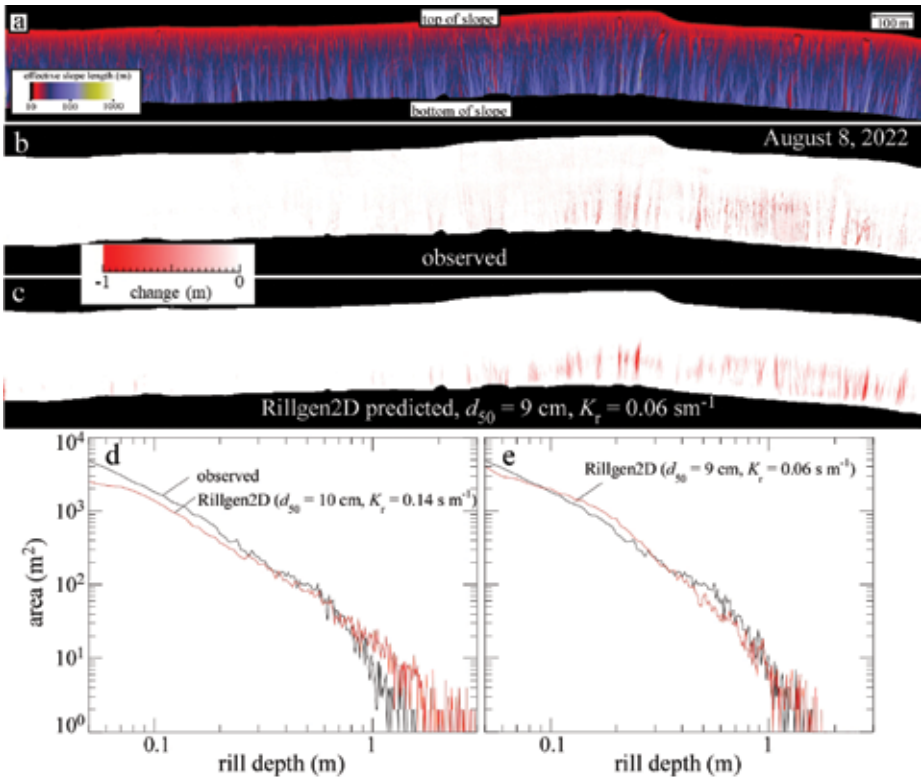
Typical angles of internal friction for angular particles are greater than 33°, but small-scale laboratory experiments we have performed on riprap layers over soil (Fig. 3a) reveal that friction angles can be as low as 30° because of the layered nature of riprap-over-soil cover systems. Three degrees of difference may seem slight, but this difference can lead to large reductions in shear strength even for slopes substantially less steep than the angle of internal friction because the denominator in the parenthetical expression in Eq. (2) approaches zero as θ approaches ϕ. The literature on mine-site rehabilitation recommends against designs steeper than 3H:1V (Weeks and Sulfate, 2007), but they cannot always be avoided (such as when embankments abut land ownership boundaries).

Validations of Rillgen2D to rehabilitated mine sites in Arizona and Australia

Three validation tests of Rillgen2D are documented to extreme rain events at the study sites in Arizona and Queensland, where approximately 1 minute per sample rainfall intensity data and approximately 0.5 m per pixel surveys of the erosion and deposition that resulted from that rainfall (similar to Fig. 1) are available.

Figure 6

(a) Color map of the effective slope length, illustrating how zones of water flow convergence tend to be where rills/gullies form. Comparison of the erosion maps (b) observed and (c) predicted by Rillgen2D for the tailings embankment illustrated in Fig. 1. Probability distributions of observed and predicted rill/gully depths for the Rillgen2D cases that best match the observed sediment yield using (d) d_{50} = 10 cm and (e) d_{50} = 9 cm.



Rillgen2D uses a time series of runoff predicted by Eq. (1) (or a user-prescribed runoff, if preferred) to relate drainage area to water discharge from runoff. Where and when the water discharge exceeds the threshold for rill/gully development, the rill/gully erosion rate at that location is modeled as the product of a rill/gully-erodibility coefficient, K_r, and the amount that the shear stress exceeds the critical value determined by Eq. (2) or, if riprap is not present, the shear strength associated with soil and/or vegetation.

Figure 6 presents the results of Rillgen2D for the rain event that occurred on Aug. 8, 2022, whose effects are illustrated in Fig. 1. The time series of runoff for this simulation was constructed using Eq. (1) and by interpolating the I_{15} and I_{60} values measured by four tipping-bucket rain gauges located across the study site. The first simulation used d_{50} = 10 cm, as specified in the as-built report for the rehabilitation. The value of K_r required to match the sediment yield measured by repeat photogrammetric survey (179 t/ha) was determined by trial and error to be K_r = 0.14 s/m. Figure 6d compares the distribution of rill depths predicted by Rillgen2D (in red) to the observed distribution (in black) for this simulation.

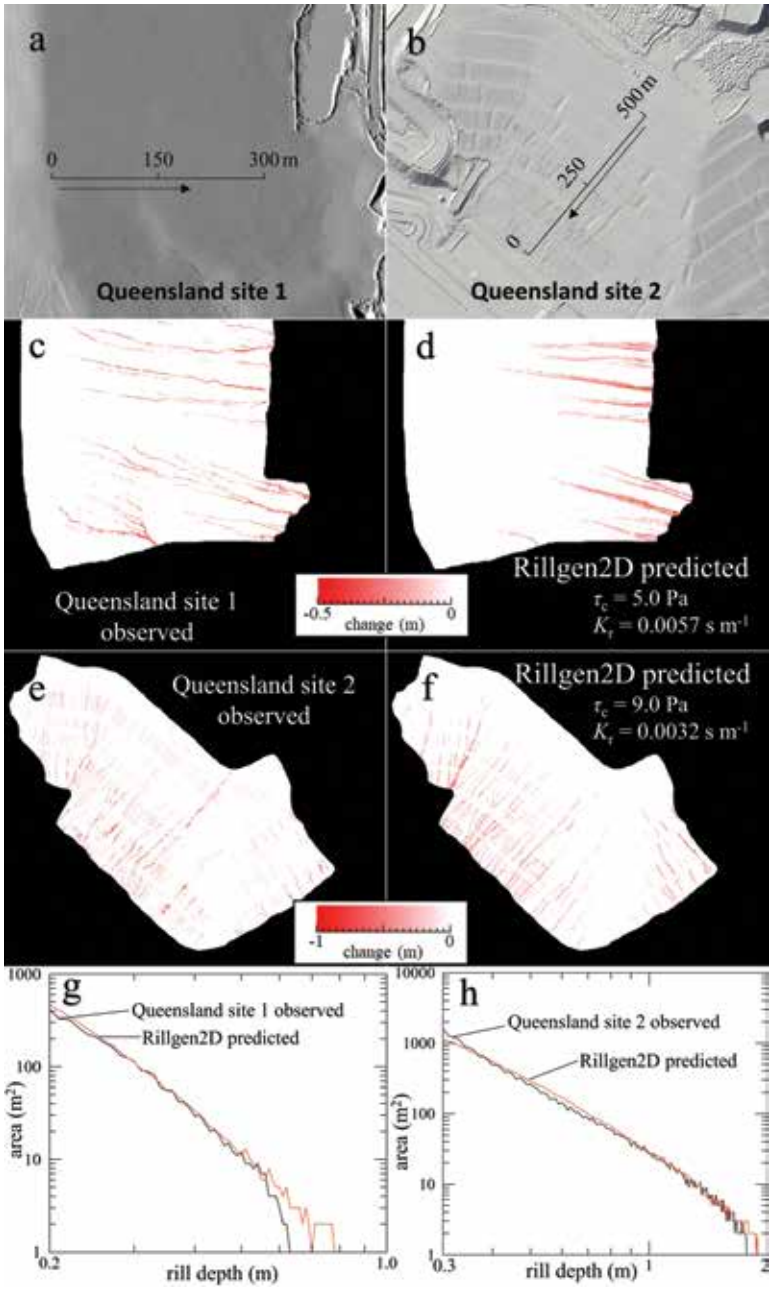
Using d_{50} = 10 cm and K_r = 0.14 s/m, the percent of the study area that is rilled/gullied is underpredicted by Rillgen2D: that is, 5 percent versus the observed 6 percent. To determine whether a smaller value of d_{50} could better match the observed data, a Rillgen2D simulation using d_{50} = 9 cm and the value of K_r (0.06 s/m) that best matches the measured sediment yield was performed. This set of d_{50} and K_r values resulted in Rillgen2D predictions that precisely match the observations both in terms of the percent area rilled/gullied (6 percent) and sediment yield (179 t/ha). Allowing a modest variation in the value of d_{50} in this validation test is reasonable considering that d_{50} can be expected to vary by 10 percent due to construction vagaries and the likely redistribution of riprap since rehabilitation in 2007. The distribution of rill depths for the d_{50} = 9 cm and K_r = 0.06 s/m simulation matches the observed rill-depth distribution closely (Fig. 6e). In contrast, the distribution of rill depths for the d_{50} = 10 cm and K_r = 0.14 s/m case underpredicts rill depths for shallow rills and overpredicts rill depths for deeper rills (Fig. 6d).

Figure 7 illustrates the analogous results for two locations in Queensland without riprap, one with a continuous-slope design and one with a benched slope design with laterals and down drains. In theory, benched hillslopes with laterals and down drains minimize the likelihood of erosion because slope lengths are short relative to continuous-slope designs. In practice, however, such systems may be less resilient to extreme rain events because even more erosion can occur than in continuous-slope designs if the laterals and down drains do not convey water as intended.

The best-fit parameter values for the Queensland site 1 are τ_c = 5 Pa and K_r = 0.0057 s/m, and and those for the Queensland site 2 are τ_c = 9 Pa and K_r = 0.0032 s/m. Qualitatively, the spatial distribution of rills predicted for both sites (Figs. 7d and 7f) are consistent with the patterns measured by repeat topographic survey (Figs. 7c and 7e). In particular, Rillgen2D successfully identifies areas of topographic convergence as particularly susceptible to rill erosion.

Figure 7

Results for the two Queensland study sites, comparing the observed erosion maps (c) and (e) to the Rillgen2D-predicted maps in (d) and (f) using best-fit parameters τ_c and K_r.



Discussion and conclusions

Although not documented in this article, we have carefully studied the statistics of the microtopography that results from modern construction/landforming practices and developed a workflow for simulating such topography (given prescribed construction tolerances) for input into Rillgen2D to aid in the design-selection process.

Work remains to successfully apply Rillgen2D to the widest range of applications. The ability to predict the shear strength associated with different vegetation types and densities is limited, for example. We would appreciate hearing from anyone interested in applying Rillgen2D to understanding why existing mine-site rehabilitations did not work as intended, choosing the optimal rehabilitation design among several alternatives, and improving our ability as a community to parameterize how cover conditions translate into model parameters such as the critical shear stress for rill/gully initiation and the rill/gully erodibility coefficient. ■

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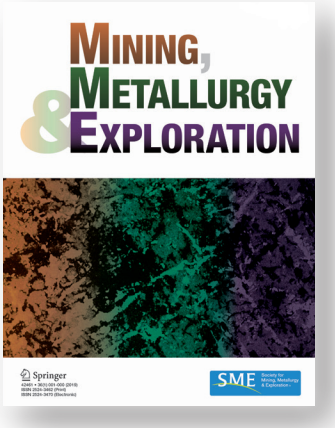

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Invited Extended Abstracts

Valorization of air-cooled EAF manganese slag in comminution processes: An investigation into the breakage characterization

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Keywords: Brazilian disc, SHPB, Ultra-high speed imaging, DIC, Slag

How does an investigation into the breakage characterization of electric arc furnace (EAF) manganese slags contribute to a more responsible usage of resources throughout the life cycle of steel products and reduction of carbon emissions? The main goal of this study is to increase the knowledge on the mechanical response of manganese slag to open the potential of pyrometallurgical residues to become secondary material in industrial applications such as infrastructure construction, fillers, binders and soil stabilization, among others.

Background

The steel industry has been an asset for the development of societies. The worldwide production of crude steel has seen a growing trend, and figures are still high: the total production of steel furnace slags in 2018 in Europe was 16.3 million tons and that of blast furnace slags was 20.7 million tons [1]. Within the production of crude steel, pyrometallurgical processes produce slags at rates of 0.25 to 0.3 tons per ton of crude iron for typical ore grades, and 1 to 1.2 tons for low-value grades from iron blast furnaces and typically 0.2 tons from steel furnaces [2]. Following the sustainability principles of the World Steel Association, incorporating pyrometallurgical byproducts in a circular economy framework is of great interest to maximize the efficient use of resources throughout the life cycles of steel products and help in the reduction of carbon dioxide (CO_2) emissions.

The current practice for managing steel slag includes the reuse of slag in product applications such as infrastructure construction, fillers, binders and soil stabilization, due to its mechanical properties. To optimize these reutilization

processes and increase the value of material data for uses such as the modeling of breakage for the upscaling and evaluation of industrial-scale recycling, an investigation of the macromechanical response and damage of manganese slag under compressive and indirect tensile loading from a mesoscale point of view is presented.

Methods

Air-cooled manganese-silicon-iron (MnSiFe) slags from EAF manganese steel production in Norway were studied under dynamic loading conditions using a split Hopkinson pressure bar machine and ultra-high-speed digital image correlation to obtain information of the displacements and strains, as well as crack initiation, fracture process and energy dissipation. Two sets of experiments were performed: (1) indirect tensile tests, commonly known as Brazilian disc (BD) tests, and (2) axial compression tests, or unconfined compression tests (UCT). A region of interest (ROI) — shown in Fig. 1 (the photographed area of diametrically loaded specimens) — was chosen for further analyses. Images were taken at frame rates of 380,000 and 663,200 fps for the UCT and BD tests, respectively.

Results

Dynamic compressive stress-strain histories of axially loaded specimens showed great variability of the overall behavior with visible differences in the stiffness and the average stress where the first visible crack was perceived. In contrast, BD results presented greater similarity among specimens. Although the ultimate compressive strength is an important mechanical property for the analysis of fracture, it is relevant to study the dissipation of energy during dynamic loading processes as well (Fig. 2).

The results show that as the strain rate increases, the total dissipated energy becomes more stable with an average value of 29 J. This information indicates a trend where specimens reaching higher strain rates dissipate a great part of the total dissipated energy before reaching peak load. The information suggests that the energy is consumed during the creation of new surfaces, as well as crack branching and friction due to relative motion between crack surfaces.

Another example where it is possible to identify the pattern of propagating cracks with the naked eye is given in Fig. 3. A crack has started close to the center of the specimen, suggesting that the effect of the inclusions does not have a major impact on the macroresponse and the specimen holds high tensile stresses in a zone around its geometrical center.

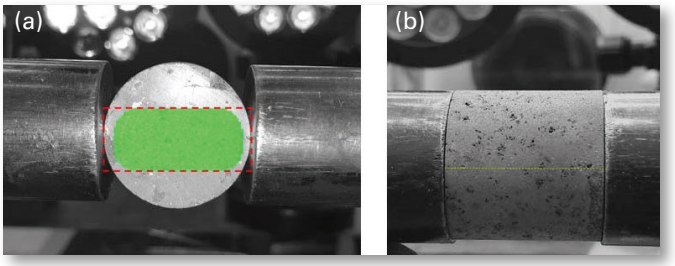

Fig. 1 Setup on the split Hopkinson pressure bar machine for (a) Brazilian disc specimens, showing the region of interest (ROI) as the dotted line and highlighted area, used for deformation analyses, and (b) UCT specimens.

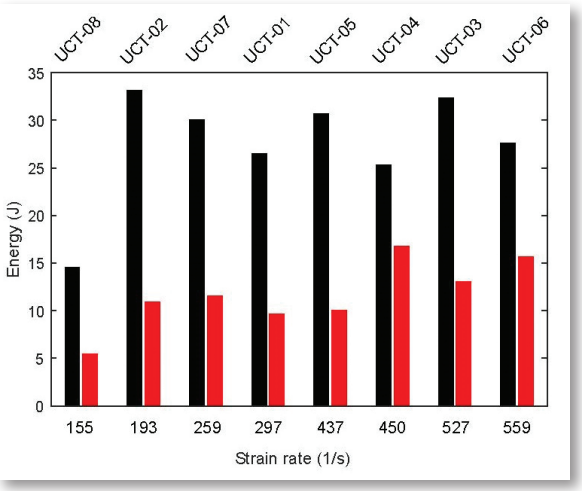

Fig. 2 Total dissipated energy, U_d (black), and dissipated energy up to peak load, U_{peak} (red), as a function of the strain rate for axial compression samples.

Discussion

Comminution is an expensive process in terms of en-

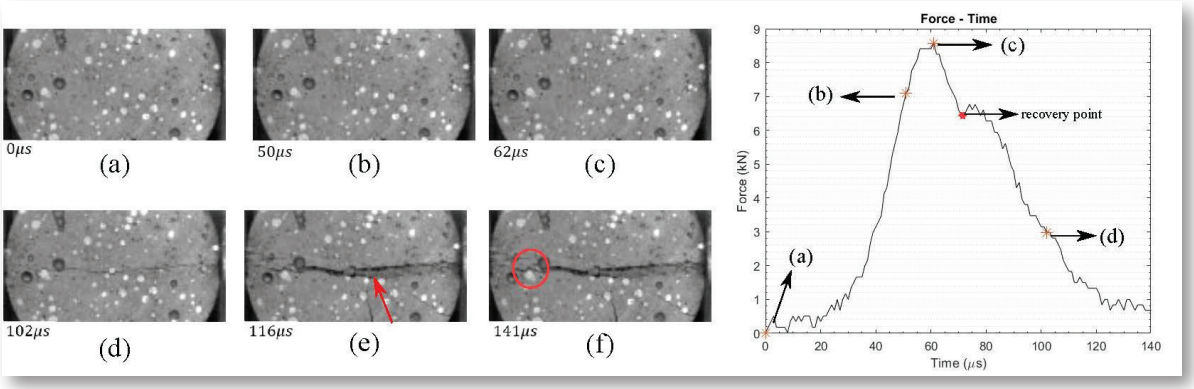

Fig. 3 Stages of fracture of specimen BD-09 with high amount of inclusions randomly distributed: (a) contact point, (b) first visible crack, (c) failure point, (d) visible superficial damage and (e), (f) unstable propagation of the cracks along the specimen.

ergy required because the resistance to create new surfaces tends to increase as the particle size diminishes.

Results from both axially and diametrically loaded specimens exhibited a staggered progress that started with an initial preloading, seen as a delayed increasing signal, followed by evolving internal damage and, finally, ending in failure. Superficial cracks were visualized from the high-speed images, suggesting that internal effects might have taken place. This points to compression-expansion transitions within the porous and heterogeneous matrix, resulting in possible volumetric effects and progression to unstable crack propagation.

The findings of this study suggest that the variability of the points where the first visible crack was perceived might be strongly related to loss of cohesion during the compression of the specimen. The localization of microcracks and formation of shear planes are predominant factors of the failure process of brittle materials.

In addition, differences in the values of dissipated energy are related to the amount of energy consumed after failure, where further crack branching and unstable propagation of cracks weaken the structure, showing a softening effect after the peak point.

Conclusion

Manganese slag is a complex material in texture, composition and mechanical response, but it has great potential for crushing using equipment already installed at steel production facilities (and mines, if the market opens up even more). The results can also be useful for the calibration and validation of numerical models to optimize the energy consumption of comminution processes. With the increase of knowledge of the fracture process of material, opportunities unfold to introduce byproducts into a circular economy and contribute to the reduction of CO_2 emissions. ■

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Review Article

Blockchain technology and the mining industry: A review

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Keywords: Mining industry, Emerging technology

Blockchain technology is one of the prominent disruptive technologies that are being implemented in several disciplines. The application of blockchains in the mining and mineral industry can provide utility to several processes especially when the industry is undertaking digital transformation. The governing principles of blockchain technology are applicable in undertaking transformation in several processes within the mining industry. This study investigates the applications of blockchain technology within the realms of the mining industry and identifies key areas of implementation. A systematic review of publications on academic platforms relating to blockchain technology in the mining industry did not retrieve a considerable number of articles. Consequently, a thorough review of white papers and articles authored by individuals on use cases within the mining industry is compiled and presented in this review article. This review article identifies all the potential areas within the mining industry where blockchains could provide value and improve processes through their implementation. The broad area of implementation of blockchains includes supply chain, traceability in spares parts, contract management, regulatory compliance and cybersecurity.

Background

Mining corporations across the globe are attesting to digital transformation for benefits including enhanced pro-

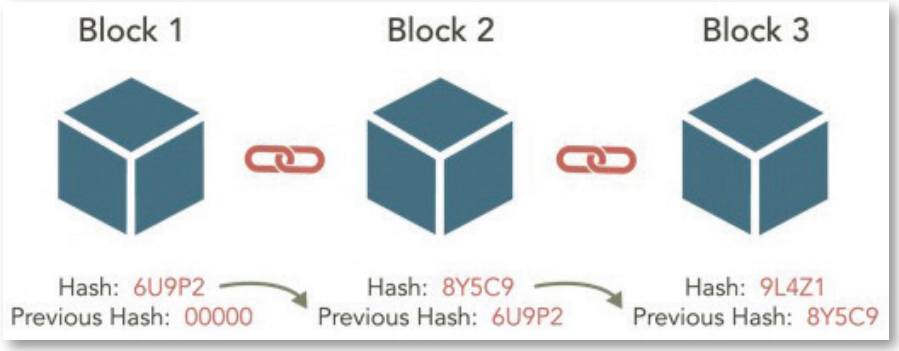

Fig. 1 Typical structure of a block in blockchain.

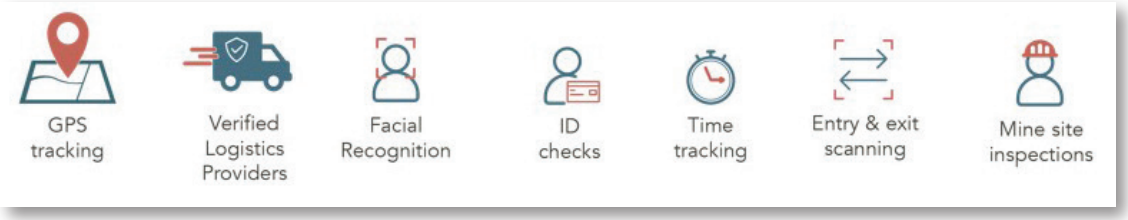

Fig. 2 Blockchain application in supply-chain management.

ductivity, safer operations and operational gains. Leveraging emerging technologies including automation, artificial intelligence, advanced visualization and data analytics brings about improvements to unit operations along the entire process chain. Blockchains were introduced to enhance digital trust by decentralizing databases and providing a secured distributed ledger to record transactions across many computers. Blockchains employ a massively distributed network of individual users so that central databases are not prerequisites to manage data flow. Blockchains consist of a chain of blocks with each block containing multiple transactions that are conducted as a distributed database that can be extended through additional blocks. The typical structure of a block within a blockchain consists of multiple transaction histories, timestamps, the hash value of the previous block, and a nonce for verifying the hash. The slightest change to a block's data undermines the hash and blocks following it and alerts the network of the attempted changes. Figure 1 shows the structure of a block in a blockchain.

Methodology

This review article intends to summarize the current state of knowledge and implementation of blockchain technology in the mining industry. The scope of this review article is limited to outlining the use cases relating to the application of blockchain technology in the mining industry. An extensive literature review outlining application of blockchain technology in mining industry retrieves any article involving a comprehensive document. An inclusive literature review retrieved 76 documents on application and use cases of blockchains within the mining industry. Upon reading, the publications were analyzed and divided into categories based on identifiably matching themes of their application within the mining industry.

Applications of blockchains in the mining industry

The following summarizes the use cases where the implementation of blockchain technology can provide value and improve operational processes in the mining industry.

Mining supply chain. A traditional supply chain entails an assemblage of specific processes, resources and activities to bring about the delivery of goods and services. Blockchains have the potential to disrupt many of the traditional supply-chain processes including provenance and traceability of minerals, sourcing of spare parts of mining equipment, enhanced visibility across multiple companies or stakeholders, and reconciliation of ore quality across the supply chain. The absence of visibility of the supply chain beyond the first sourcing point created blind spots that enhanced disruptions beyond the control of the mining operators. All the stakeholders in the network have a clear visibility throughout all the dealings, which enhances the speed of material flow from the origin to destination by using the blockchain technology.

Contract management. The success of the operations is intertwined in the smooth relationship, flawless communication, and execution among the contractors and the mining company to meet the key mining objectives. This relates to accomplishing clear visibility of processes, defining the performance indicators, and transparency on the material and cost tracking. A blockchain network can provide an immutable ledger such that both parties can observe the specific processes that are underway and track their progress until completion. In addition, the payment gateway between the contractor and the company could be connected through the common platform to accomplish the release of payment upon achieving specific milestones. Smart contracts between the contractors and mining companies will provide additional transparency and trust in the dealings.

Cybersecurity. The critical avenues within the mining industry that are prone to such attacks includes industrial automation and control system, operational technology, databases of financial transaction, centralized information management system and cyberespionage.

Adoption of blockchain technology can help in eliminating the usage of third-party software that relies on databases to store information such that all the transactions can be secure and encrypted.

Conclusion

Blockchain technology is a technology that offers immense value in some of the inherent processes within the mining industry by providing the benefits of immutability, transparency and a distributed database.

The specifics of the implementation of blockchain within the domain of each of the mentioned use cases would require site-specific consideration for a particular operation. However, the underlying concepts and utility remain similar in terms of advantages and value provided to the organization. Ultimately, the mining industry is poised to observe the adoption and benefits of the application of blockchain technology in the coming years. ■

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Geological domaining with unsupervised clustering and ensemble support vector classification

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Keywords: Machine learning, Ensemble learning, Geological domaining, Support vector classification, Geostatistics

A geological model accounting for uncertainties possesses important advantages for resource estimation. Machine learning algorithms (MLAs) employed on multivariate geochemical datasets open up ways to new methodologies for such geological models with ease in comparison to traditional geostatistical methods. This article proposes a two-step MLA with an ensemble implementation to define geological domains and their uncertainties based on geochemical data. The proposed workflow is applied hierarchically on a dataset from a porphyry copper deposit to perform binary classification that can be attributed to alteration domains.

Background

Estimation domains play an important role when building accurate resource estimation models. Information like alteration, mineralization and lithological aspects can inform the definition of these domains. However, such geological information is prone to errors, as decisions are made subjectively during the logging of drillhole samples. Instead, decisions made by computer algorithms based on multivariate geochemical data can be more consistent to define these estimation domains. To take advantage of such rich geochemical datasets, we propose a methodology based on MLA that offers promising solutions to geological domaining.

Methodology

The work consists of two steps: (1) a binary-unsupervised clustering approach to perform clustering on data containing geochemical information and (2) an ensemble learning method formed by support vector classification (SVC) to impose the spatial structure accounting uncertainty.

The main principle of the adopted unsupervised clustering approach [1] is that geochemical variables that can be employed to determine geological aspects like mineralization, lithology or alteration follow a log-normal behavior in a single domain. Determining the parameters of each log-normally distributed variable in each domain can make classification of each sample possible. The first step is to select an appropriate variable out of the geochemical dataset to characterize a specific geological aspect, such as alteration. This is done using the geological literature along with statistical exploratory data analysis. Secondly, parameters defining the log-normal distribution of each variable for each domain are determined by an optimization process. Finally, all the samples are assigned to a domain by a greedy algorithm to obtain the optimum fit to the expected distributions. This process can be repeated multiple times by assigning samples to domains using different subsets of samples and of variables.

The second step is to build the geological domain model

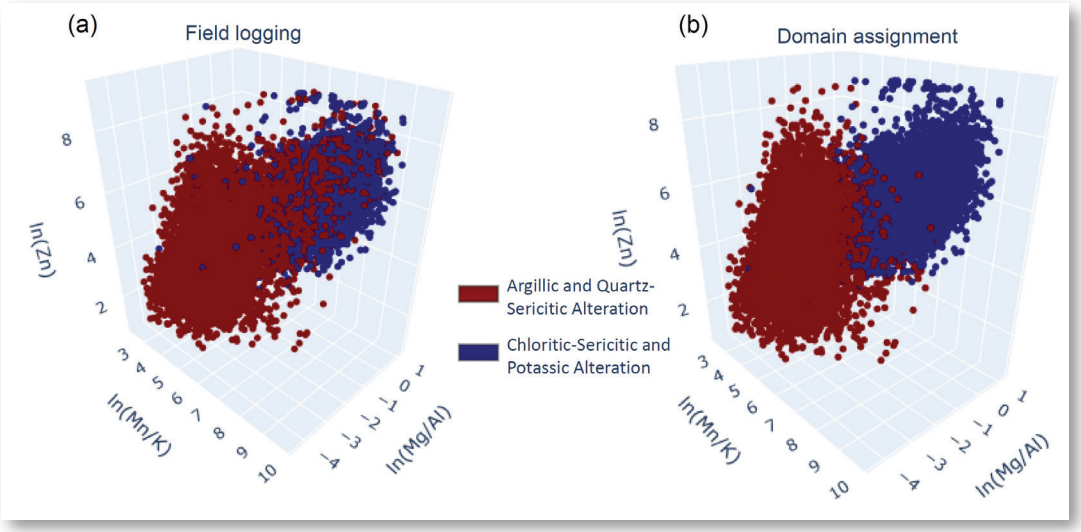

Fig. 1 Distribution of samples in trivariate space: (a) alteration logged and (b) the result of domain assignment.

accounting for uncertainties. To do this, SVC is used, where the input of each run is a subset of samples assigned to domains, through the previous step using different subsets of variables. All models obtained during this process are combined to build a final model accounting for uncertainty and providing a measure of reliability of the data, hence we coin the term ensemble SVC. Two important parameters of SVC controlling the complexity of the model and relevance of samples are tuned by k-fold cross-validation. This defines how boundaries of domains extend beyond the data. Finally, averaging all predictors on each point of target space gives the combined final predictor. The result can be considered a probabilistic model which provides the probability of finding each domain at every location.

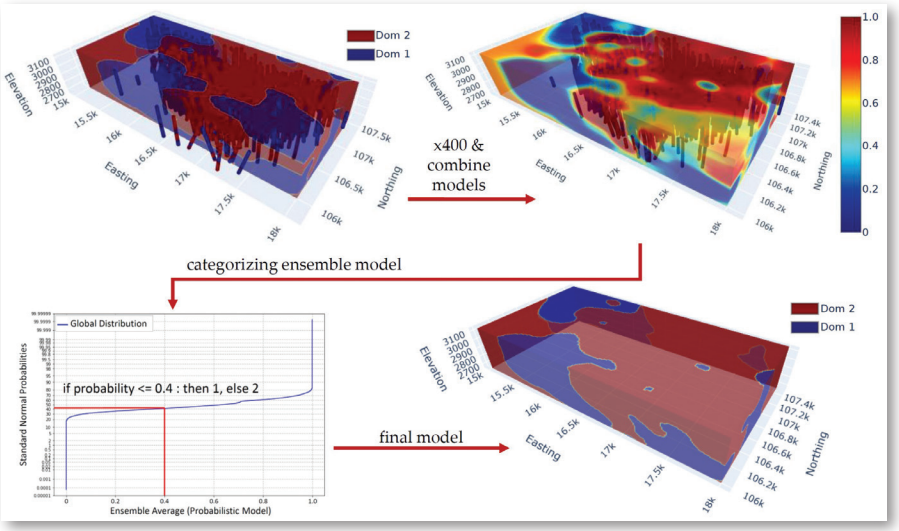

Fig. 2 Workflow showing the steps to build the ensemble model.

A binary approach was preferred to perform the workflow because of computational restrictions. The workflow can be applied hierarchically on data with more than two domains.

Case study

The hierarchical workflow was applied on a geochemical dataset of a porphyry copper deposit to obtain domains representing possible alterations: namely, chloritic-sericitic, potassic, quartz-sericitic and argillic alterations. Ratios of elements manganese/potassium (Mn/K) and magnesium/aluminum (Mg/Al), and the elements zinc (Zn), lead (Pb), yttrium (Y) and gallium (Ga) were found to be relevant to perform the unsupervised classification. Unsupervised classification was performed 20 times using three-variable subsets of the chosen six variables. Clustering of a single case and field logging (never used in training) of samples are shown in Fig. 1 for comparison.

Ensemble SVC was applied on the labeled subsampled data to obtain the extent of the domains with a probabilistic estimation. Subsampling was repeated 20 times for each subset of variables, leading to a total of 400 models. All predictors were averaged to build the final model, which was categorized into a binary model (Fig. 2).

The procedure was repeated within each of the obtained domains, to build four domains. In this case, four geochemical variables were used on each domain. While the final balanced accuracy was 91.3 percent for the first step of the hierarchical application, it decreased to 73 percent for the final model with four domains. The sequential indicator simulation program BlockSIS was employed on the labeled data to compare with Ensemble SVC. The accuracies of the binary model and model with four domains obtained by BlockSIS program were 92.5 and 69.4 percent, respectively.

Discussion

The proposed unsupervised clustering combined with ensemble SVC demonstrated an excellent performance, as compared to standard procedures to build estimation domains. In order to work, selected variables should have discriminant power to define the required domains. Departures from the optimum distributions during the samples assignment indicate potential mixtures of populations in the global data. While the hierarchical implementation of the methodology is easy and overcomes computational complexities, it also unveils the possibility of propagating errors as the level of hierarchical application increases. A more complex clustering algorithm for multiple domains can be the focus of future studies. While accuracies of models obtained by ensemble SVC and BlockSIS model were comparable, the former requires fewer modeling decisions and generates more continuous domains.

Conclusion

The proposed workflow stands as a robust alternative to the domaining approaches that use traditional simulation techniques. Ensemble models informed by consistently labeled samples can be helpful in guiding resource estimation models, especially in terms of uncertainties associated with the extent of geological domains.

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Respirable coal mine dust in the vicinity of a roof bolter: An inter-laboratory study to compare wet versus dry dust collection systems

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Keywords: Roof bolter, Respirable dust, Dust collection box, SEM–EDX, Silica

The resurgence of severe lung disease among U.S. coal miners has not only highlighted the need for improved dust controls, but also the need for an improved understanding of dust characteristics and monitoring strategies [1]. Following up on prior work by the National Institute of Occupational Safety and Health (NIOSH) to demonstrate a novel wet dust collection system on a roof bolter [2], the current study explores the effect of that system on dust characteristics and uses interlaboratory comparisons to comment on analytical methods. Results indicate the wet system did not appreciably affect the composition or size of respirable dust in the vicinity of the operating roof bolter. However, the system does appear to have substantial benefits for the operator. NIOSH has already shown it can reduce the respirable dust mass concentration to which the operator is exposed during dust-box cleanout [2,3], which is a frequent maintenance activity that can re-aerosolize dust, and new results here indicate the silica and silicates content in this dust may also be reduced, thereby reducing the overall hazard. Moreover, regarding analytical methods, excellent correlation was demonstrated between measurements of quartz mass, taken first by NIOSH and then by a university laboratory, using direct-on-filter Fourier transform infrared (FTIR) analysis. This method is the basis for envisioned "end of shift" silica monitoring (quartz is the predominant form of crystalline silica in coal mines) [4]. For particle-level analysis by scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX), there was more variability in results generated by two independent university laboratories.

Background

Among underground coal miners, roof bolter operators are generally considered to have some of the highest risks for hazardous respirable dust exposure. This is because bolting can generate large quantities of dust, which can be high in mineral content, including silica and other silicates. To reduce the potential for operator exposures during the bolting process, modern machines are equipped with dust collection systems, typically analogous to a vacuum with a dry dust box. However, inadvertent but potentially significant secondary exposures can occur during dust-box cleanout, when the contents of the box can be re-aerosolized. To mitigate this possibility, a novel dust collection system that essentially uses a wet dust box has been field tested twice by researchers at NIOSH in partnership with Blue Mountain Energy's Deserado underground coal mine [2,3]. In both tests, the wet dust box (versus a standard dry box) led to a reduction in the operator's respirable dust exposure.

While detailed dust characterization was not included in the original NIOSH study designs, there is increasing interest to understand the effect of dust controls and other factors on dust composition and particle sizes. Incidentally, dust samples from the first round of NIOSH field testing [2] had been preserved and were made available for the current study to explore dust characteristics using SEM-EDX. Because the samples had been collected in pairs (duplicates) and had already been analyzed by NIOSH using direct-on-filter FTIR analysis for quartz (silica) mass [4], this sample set also presented a valuable opportunity for intralaboratory comparisons.

Materials and methods

A total of 48 respirable dust samples (24 pairs of duplicates) were available for study. These represent dust collected in six standardized locations (Fig. 1) during each of four sampling events. Five locations (labeled 1-4 and 6 in Fig. 1) were sampled while the bolter was operating; the other location was on the vest of the operator and was only sampled during dust-box cleanout. The roof bolter was

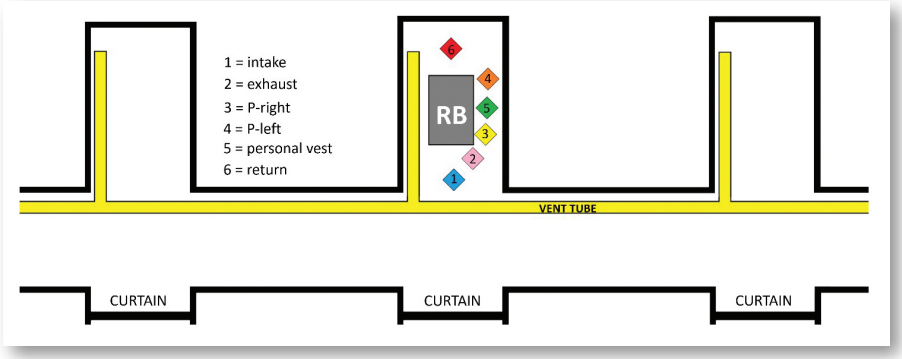

Fig. 1 Standardized sampling locations used by NIOSH to evaluate dust concentrations during the use of a wet dust collection box (versus a traditional dry box) on a roof bolter.

equipped with the wet dust collection system during two events, and with a standard dry system during the other two events. The samples were split (one from each pair) between two university laboratories at Virginia Tech (VT) and Michigan Technological University (MTU), respectively. Each laboratory performed SEM-EDX analysis using its own internal methodology on a subset of the received samples, and results were compared on the basis of relative number percentages of particles in primary constituent classes (carbonaceous, silica, silicates, carbonates and others). The VT laboratory also performed direct-on-filter FTIR analysis on the samples it received to compare quartz mass with earlier results from NIOSH.

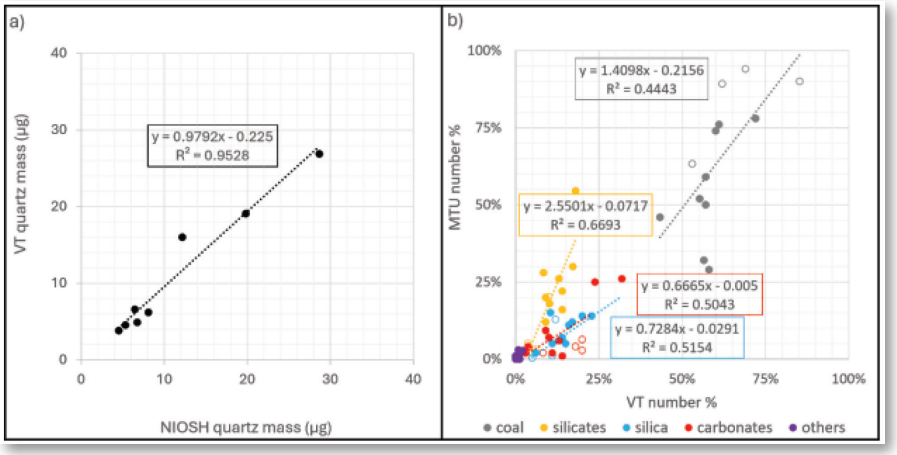

Fig. 2 Plots showing intralaboratory comparisons: (a) VT and NIOSH estimates of quartz mass by direct-on-filter FTIR. (b) MTU and VT estimates of relative abundance of dust constituents by SEM-EDX.

Results

While the roof bolter was operating, the SEM-EDX results showed variability in dust composition and particle sizes in the sampling locations around the roof bolter. In general, event-to-event variations were most pronounced and are likely due to factors that could change between events such as local air circulation patterns, specific roof rock geology, and the relative contribution of particles (including coal or carbonates from rock dust products) in the intake air entering the bolter area. Importantly, in the locations around the operating roof bolter, no consistent trends were discerned related to use of the wet versus dry dust collection system per se.

During dust-box cleanout, results from the operator's personal samples indicated the wet dust box reduced the relative silicate+silica content by 41 to 82 percent versus the dry box. The NIOSH study for which these samples were originally collected reported an average reduction in respirable dust mass concentration of 60 percent. Taken together, these results suggest use of the wet dust collection system can reduce both the level of the operator's exposure and the relative abundance of the most hazardous constituents.

Regarding the intralaboratory comparisons, Fig. 2 summarizes the results. Using the standardized direct-on-filter FTIR method [4], the VT and NIOSH laboratory results are in strong agreement (Fig. 2a). This is remarkable given the relatively low mass of the respirable dust samples included in this study, and the significant storage time (more than five years) and additional handling and transport required for analysis by two laboratories. There is much more scatter in the SEM-EDX-derived data from the VT and MTU laboratories (Fig. 2b), which is not surprising considering key differences between the methodologies employed by each. That said, the data do demonstrate fair agreement in terms of relative abundance of primary dust constituents. For example, both laboratories found that coal represented the majority of dust particles in most samples with the remainder of the particles being divided between other primary classes (silicates, silica and carbonates).

Conclusions

Dust controls are typically evaluated based on their ability to reduce mass concentration. However, there is increasing interest to better understand the possible effects on specific dust characteristics that might influence the hazard of exposure. Using preserved samples from a prior NIOSH study, the current work investigated the effects of a wet dust collection system on a roof bolter. Results demonstrate the added insights that can be gained by exploring dust characteristics in parallel with more common metrics. To enable comparability between dust characterization results across studies, standardized methods should be developed and used.

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Selected Abstracts

3D characterization of auriferous pyrite flotation samples for liberation and grain exposure analysis using micro X-ray computed tomography

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Keywords: Auriferous pyrite, Flotation, Micro X-ray computed tomography, Liberation analysis, Grain exposure, Image processing, Machine learning

The liberation and exposure of valuable mineral grains in ore particles are of significant importance in understanding the efficiency of flotation separations. A flotation feed sample from the Kensington concentrator was scanned by micro X-ray computed tomography (micro-XCT), to determine the liberation and exposure of auriferous pyrite grains. The analysis results suggest a satisfying extent of liberation for particle sizes smaller than 212 µm. Theoretical flotation recovery of pyrite for selected particle size fractions was predicted from the three-dimensional liberation and exposure analysis. The plant flotation tail was also characterized by micro-XCT to identify liberated and partially liberated pyrite particles that might not be collected into the concentrate. However, liberation analysis of the tail sample revealed that the majority of liberated pyrite was recovered in the plant flotation circuit. Trainable Weka, a machine learning segmentation approach, was compared with the Watershed thresholding segmentation for the 106 × 45 µm particle size fraction scanned at a voxel size of 1.85 µm. Improved segmentation of small particles was found using the machine learning method. ■

Collection on Application of Artificial Intelligence and Machine Learning in Mining

Machine learning for slope failure prediction based on inverse velocity and dimensionless inverse velocity

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Full-text paper:
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Keywords: Blasting, Slope failure, Mining, BlastVision, GroundProbe, Slope stability, Blasts

Slope instabilities in openpit mines pose a safety risk to workers and a financial burden on production. The direct impact of slope stability on safety and production makes slope failure predictions one of the important challenges in the mining industry. Predicting the precise time of slope failure has been the subject of much research in conjunction with the development of innovative monitoring technology designed to prevent sudden failures. This paper investigates the use of an autoregressive integrated moving average (ARIMA) model to predict the time of slope failure. Input data such as inverse velocity (IV) and dimensionless inverse velocity (DIV) from 20 slope failures were used to train the model to predict the failure time. For comparison purposes, the time of slope failure using the traditional inverse velocity method is also provided. We show that ARIMA provides 90 percent more accurate predictions than the TIV approach. ■

A wrap-up of the 2023 PCMIA/SME Pittsburgh Section

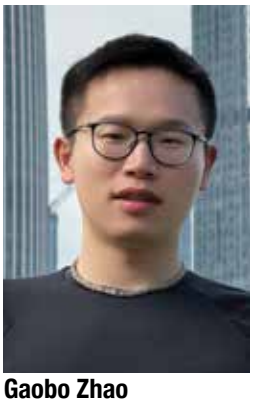
student short-presentation contest

by Hatice Esin Kaydim and Cengiz Kaydim, graduate research assistants, West Virginia University

We are delighted to share the results of the recently concluded 2023 Pittsburgh Coal Mining Institute of America (PCMIA) and SME Pittsburgh Section Short Presentation Contest. Our sincere gratitude goes out to the participating students from Penn State University (Penn State), Virginia Tech (VaTech) and West Virginia University (WVU), who contributed to the success of this event. After the first round of eliminations, six students competed against each other in a live session and answered the questions of jury members. Congratulations to the top three winners: Gaobo Zhao, Victor Famobuwa and Syabilla Cardosh, all of WVU. We also want to extend our thanks to our judges Cem Sarvan, Hua Jing and Micheal J. Brnich. Finally, special thanks to Mary Delrosso for her support to organize this contest.

The PCMIA/SME Pittsburgh Section jointly hold a student short-presentation contest annually to recognize successful research conducted in select regional universities: Penn State, University of Kentucky, WVU and VaTech. The contest provides an opportunity for students to showcase their work in a visible setting and to compete for monetary prizes based on the quality of their presentations as determined by a team of judges. Keep an eye out for upcoming announcements regarding registration and contest details for the 2024 contest. Call for submissions start in early September.

Winning presentations



Gaobo Zhao

First: Reconstruction of laminated shale cores/specimens by physics-informed image processing and its application. Author: Gaobo Zhao, WVU, Morgantown, WV. Abstract: Shale is distinguished from other rocks by its laminated and fissile nature, as it consists of many thin layers and easily splits into thin pieces along the bedding planes. A common approach in a geomechanical simulation of shale is to simplify its complex structure by representing bedding planes as continuous, straight and equidistant. This approach is acceptable for approximating the general behavior of shale and is numerically efficient, but it also limits our understanding of the true mechanical response of shale to mining-induced stress changes. This study proposes an end-to-end, physics-informed image-processing method to reconstruct laminated shale cores/specimens. Using this method, critical parameters such as the number, spacing, length and frequency of bedding planes were extracted.

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Freeport-McMoRan names Kathleen Quirk president and CEO, effective June 11

SME News Contents

Kathleen L. Quirk has been named president and chief executive officer of Freeport-McMoRan, effective at the annual meeting of shareholders on June 11, 2024. In a statement, the company said Quirk will assume full responsibility for executive management of the business, reporting to its board of directors. Richard C. Adkerson will remain chairman of the board of directors, supporting the leadership transition and Freeport's business on strategic matters of significance to the company.

Kathleen L. Quirk

Quirk joined Freeport in 1989 and had responsibility in a 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 in 2023. She is a graduate of Louisiana State University.

"For some time, the board has been engaged in a process to identify Richard (Adkerson's) successor. Kathleen has earned the respect of the board, the Freeport organization and external stakeholders through her track record of accomplishment,

(Continued on page 41)

Transforming copper production

through innovation with novel catalytic technology

by John L. Uhrie, vice president of metallurgy, and Nelson Mora, chief technology officer, Jetti Resources

Copper has recently been placed on the critical raw materials list by the U.S. Department of Energy. This is because technologies such as renewable electricity generation and transportation electrification are expected to continue to drive copper demand, with some estimating demand will double over the next 30 years.

Despite this projected surge in demand, mines are a nonrenewable resource. All mines age, and the discovery and development of new mines is notably lagging. One method to increase production as well as profitability is to convert previously uneconomic material to ore, often using new technology. Jetti Resources has a novel catalytic technology that releases copper from primary sulfide ores that could not previously be processed economically.

Approximately 75 percent of the world's copper is contained in the hypogene zone of porphyry ore bodies, primarily as the mineral chalcopyrite ($CuFeS_2$). The conventional method to produce copper from chalcopyrite and other primary sulfides involves bulk mining, fine grinding, flotation, dewatering, and finally smelting and electrolytic refining.

A lesser but still significant percentage of the world's copper is produced from the oxide and supergene zones of copper porphyry ore bodies. Here, chalcopyrite sitting above the water table is oxidized over geologic time and transported down gradient and concentrated into oxide minerals such as malachite ($Cu_2CO_3(OH)_2$), azurite ($Cu_3(CO_3)_2(OH)_2$) and chrysocolla ($Cu_2(H_2Si_2O_5)(OH)_4 \cdot nH_2O$) or the secondary sulfides of chalcocite (Cu_2S) or covellite (CuS).

All oxide and some of the secondary sulfide copper minerals are economically recovered using the proven industrial hydrometallurgical process of heap leaching. Heap leaching involves using bulk mining methods, but instead of conventional milling and smelting, these ores are stacked into large piles or heaps (with or without crushing) and irrigated with an acid-ferric solution to leach copper into solution. The now-aqueous copper can then be concentrated and recovered using conventional solvent extraction-electrowinning (SX-EW) techniques.

The leaching of oxide ores are simple acid-base reactions, but the leaching of sulfide ores requires oxidation-reduction chemistry (redox reactions). The oxidant is ferric iron (Fe^{3+}), which is reduced to ferrous iron (Fe^{2+}) by sulfide minerals such as chalcopyrite, chalcocite, covellite or pyrite (FeS_2). All these reactions require the flow of electrons, and the flow of electrons is defined as an electrical current. For example, in the first-stage leaching of chalcocite, the reaction occurs rapidly, and electrochemically, chalcocite behaves as a resistor, allowing the fast and efficient flow of electrons.

To date, the economical hydrometallurgical recovery of copper from chalcopyrite ores remains elusive and is the single greatest opportunity in the copper industry. This is because under heap-leaching conditions, chalcopyrite exhibits the electrochemical properties of a semiconductor and rapidly passivates. Chalcopyrite, electrochemically, is an n-type semiconductor, but upon commencement of leaching in acid-ferric solutions, an iron-depleted, copper-rich surface rapidly forms. This resulting surface may only be atoms thick but electrochemically is a p-type semiconductor. A p-type semiconductor (chalcopyrite) in contact with an n-type semiconductor (copper-rich surface) results in the formation of the classic p-n junction, or the electrochemical equivalent of a diode. Diodes are an electrical one-way gate that impedes the flow of electrons necessary to continue leach reactions and is the passivation layer often referred to when discussing the rate-limiting kinetic step in the hydrometallurgical leaching of chalcopyrite.

Jetti Resources is a technology company that was founded in 2014 with a vision to make the hydrometallurgical, heap-leach processing of chalcopyrite a reality. It has worked in cooperation with researchers from the University of British Columbia to develop a low-cost leach additive that can interrupt the chalcopyrite passivation layer and potentially double or even triple leach kinetics under conventional heap-leach conditions. This patented additive requires little to no environmental permitting, is fully compatible with existing heap-leach SX-EW processing, has extremely low capital intensity, is relatively inexpensive and is stable under acidic conditions. The catalyst adsorbs to the chalcopyrite surface and permits the flow of electrons through the passivation layer, thereby allowing the economic hydrometallurgical recovery of copper from low-grade chalcopyrite dominant ores.

The catalyst has been proven through column leaching using multiple ores. Jetti has partnered with copper producers in the southwestern United States to perform commercial-scale technology demonstrations. It is furthermore advancing test work encompassing ores from across the world covering 27 companies, including eight majors at 35 mines.

With this ever-expanding database, Jetti will be able to

(Continued on page 41)

Meet the M&E Chair, Don Dwyer;

general manager, Orla Mining and M&E 2024 Program Chair

by Emily Rose, mining geotechnical engineer, Barr Engineering

The 2024 Chair of the Mining & Exploration (M&E) Division is Don Dwyer. Dwyer has more than 20 years of experience leading teams at openpit and underground mines. He has been the general manager for the Orla Mining South Railroad Project in northeastern Nevada for just over a year and provides leadership as Orla permits a new surface gold mine in Elko county. He resides in Elko, NV, with his wife and is the proud parent of two children who both attend university in Arizona.

Dwyer appreciates opportunities to take on new challenges.

Dwyer grew up in St. Charles, MO, a suburb of St. Louis. Having never been exposed to mining, he became interested in mining engineering after attending the Jackling program hosted by the University of Missouri-Rolla (now Missouri University of Science and Technology) and the mining engineering department's presentation, and he decided to declare mining engineering as his major. While at university, he was heavily involved in the mining engineering department, the student chapter of SME and mine rescue. He also gained experience during university, working internships at underground mines in Arizona and Kentucky. He continues to stay involved in his alma mater through participation on the Mines and Metallurgy Academy Advisory Board.

Upon graduation with a B.S. in mining engineering, Dwyer began his career working in an openpit aggregate quarry just outside Birmingham, AL. He started as an entry-level mining engineer, gaining experience working on small projects around the quarry and plant and spending time assisting with maintenance. When the itch to get back underground hit, Dwyer transitioned from the aggregates world to an underground base-metals mine operated by Teck in northeastern Washington state. He worked as a mining engineer and became a front-line supervisor when the mine expanded. Dwyer had many great mentors at that mine and gained valuable experience from the miners on his crew.

A little more than 16 years ago, Dwyer and his family moved to Nevada to work in gold country. He took on a role as a mining engineer at Barrick's Goldstrike underground mine. Over his 11 years with Barrick, Dwyer held progressing leadership roles, which included operations superintendent of the Storm Mine, maintenance superintendent at the Cortez underground mine, and openpit manager at the Cortez Complex. Dwyer also had the opportunity to work a yearlong assignment on a Barrick project in Chile and Argentina. He appreciated the opportunities to take on new challenges and work with a great group of people. In 2018, Dwyer transitioned from Barrick to SSR's Marigold Mine as the mine manager and eventually took on the general manager role. The Marigold Mine is a surface heap-leach gold operation near Battle Mountain, NV. Before joining Orla in late 2022, Dwyer enjoyed his time at Marigold, where he had the honor of working with several great leaders and being part of an excellent culture.

Dwyer is proud to be a part of the mining industry. The opportunity to meet amazing people, build successful teams and perform transformational and challenging work is what makes mining an exciting career. He values the relationships and mentors from his career, including the network he has developed through SME over 25 years and counting.

As the M&E Division Chair for 2024, Dwyer is excited to continue serving the Division. He plans to continue the work Greg Sutton and Brad Dunn started, establishing a new scholarship for students attending trade schools. His primary goal is to find new ways to attract members and ensure the Division maintains its reputation for quality technical programs, supporting students through scholarships, and recognizing excellence in the industry through Division awards. Dwyer values being able to give back to SME as the organization has been an invaluable part of his career. ■

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 2024 is Don Dwyer.**

Environmental Division hosted a wide range of events at MINEXCHANGE 2024

by Julie Neilson, research professor, University of Arizona

The Environmental Division (ED) Executive Committee members were happy to see many of you at the MINEXCHANGE 2024 SME Annual Conference & Expo in Phoenix in February. The ED hosted 13 sessions covering many important topics. We are excited by the diverse group of industry and academic professionals who are addressing sustainability issues associated with mining. Many new ideas were presented at this year's conference. In addition, this issue of *Mining Engineering* has a special focus on mine reclamation. Be sure to read the article.

We would like to thank all of those who supported the ED silent auction. Proceeds from the auction support three ED scholarships ($2,000 each) every year. The ED scholarships are presented at the ED Luncheon during MINEXCHANGE. Over the next several months, we will introduce you to the recipients of the 2024 ED Scholarships on this Green News page. An additional $2,000 scholarship is awarded each year by Veolia Water Technologies.

The ED also hosted a student poster session. Winners received cash prizes to support their education or travel to future conferences. The first-place winner received $1,000, the second-place winner $500, and the third-place winner $250. In addition, each poster submission received a complimentary ticket to the ED Luncheon. The 2024 ED student poster winners will be presented in upcoming Green News editions, so stay tuned. ■

Green News **serves as a forum for the presentation and discussion of facts, ideas and opinions pertaining to the interests and technology of the Environmental 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 2024 is Annelia Tinklenberg.**

Fine Grind

(Continued from page 39)

accurately predict the impact that its catalyst technology has on the recovery of copper from different ore types.

Use of the technology continues to grow. Jetti and one of its partners have agreed to deploy the technology at a mine in Chile. The technology will be deployed on the existing leach stockpiles at the mine, targeting more than 20 million pounds of incremental copper cathode production per year after an initial ramp-up period. Use of the technology will enable the site to produce more copper while taking advantage of existing infrastructure, generating strong financial returns.

For more information on the science behind the Jetti copper leaching technology, read the peer-reviewed paper at www.sciencedirect.com/science/article/abs/pii/S135964542200492X?via%3Dihub. ■

Freeport-McMoRan

(Continued from page 38)

proven leadership and mission for value creation for all stakeholders. Through her 35-year career with the company, she has broad knowledge of Freeport's business and operations, its people and culture, and is highly qualified to lead Freeport as CEO," said Dusty McCoy, lead independent director.

"The board is grateful to Richard for his outstanding leadership as CEO and for his vision and execution to position our company so positively for the future," McCoy added. "During his 20-year tenure as CEO, Richard has established Freeport as a global leader in the copper industry, delivered on building value for stakeholders and built a strong organization and high-performance culture. Richard's ongoing commitment to support the company on global matters of strategic importance to Freeport and the copper industry broadly will continue to provide significant value."

"I am excited to lead this great company," Quirk said. "We have an exceptionally talented global team committed to our mission of providing copper and other metals essential to our lives and the global economy in a responsible and efficient manner. I look forward to continuing to enhance value for our stakeholders through strong execution of our plans, the pursuit of innovation and new technologies to improve efficiency and grow our business through the development of our large resource base to serve an expanding market for our products."

"Serving as CEO of Freeport for over 20 years has been an honor, and I am proud to be a member of the Freeport family. Our people are best in class, and together, we have made valuable, lasting positive impacts on our industry, our communities and society at large. I value my strong bond with our stakeholders — our employees, investors, industry executives, community partners and government officials — all of whom are critical to the success of our company and our industry," said Adkerson. "Kathleen's strong business and strategic acumen and increasing levels of responsibility over many years have demonstrated she has the skills to lead our company and continue Freeport's tradition of excellence. My passion for Freeport and our prospects for the future are stronger than ever, supported by great assets, great people and an outstanding board and leadership team." ■

$4K by 40 Challenge match offered through March

by Lorie Laessig, coordinator, SME Foundation

The $4K by 40 Challenge was designed to encourage philanthropic giving by young professionals to promote the mining industry and the outreach goals of the SME Foundation (SMEF). Member contributions are tracked, and those donating $4,000 or more cumulatively to the SMEF's programs by their 40th birthday are honored for their contributions and commitment to our industry.

The 2023 $4K by 40 Challenge Award recipients are Drew Mason and Matthew Ulizio. They are recognized for their generosity and support of the SMEF. We congratulate them for reaching their milestone this year.

Drew Mason

Brooks & Nelson match

To encourage more young members to donate, Brooks & Nelson LLC is donating a $6,000 $4K by 40 match through the end of March this year. All donations made by members under the age of 40 will be matched dollar for dollar.

In addition, Brooks & Nelson will make an additional $200 donation in honor of each person that signs up for monthly giving to reach their $4K by 40 goal. Thank you to Brooks & Nelson for your support of this program.

Brooks & Nelson, a woman-owned, global human resource management and recruiting consulting firm based in Golden, CO is a long-time supporter of SME and the SMEF.

All donors under the age of 40 are encouraged to set up a monthly, recurring gift based on the number of months left until they reach the age of 40. Donors have the flexibility to choose the allocation of which SMEF program they wish to support. Donations made will be jointly eligible for this challenge, the $1K Club and the John T. Boyd Challenge.

Visit www.smefoundation.org/4Kby40 for more information and to donate before the end of March. ■

SME Foundation unveils new donor pin for gifts of $500 or more

by Megan Martin, manager, SME Foundation

The SME Foundation (SMEF) is introducing a new initiative this year. For all individual SMEF contributions of $500 or more, donors will receive the new SMEF Donor Appreciation lapel pin to proudly wear to recognize your efforts in supporting the future of mining.

We invite you to consider making a gift of $500 in 2024 to get this limited edition pin. The easiest way to do this is to enroll in automatic recurring donations. Your consistent contributions will help support the SMEF programs and activities that are critical to our industry.

Every donation brings us one step closer to achieving our vision of "inspiring the next generation to provide for the needs of a mineral-rich future."

As you plan your annual charitable giving, consider making a tax-deductible donation to the SMEF. We are truly grateful for all of our members and their contributions to the industry. ■

WAYS TO GIVE

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- Visit smefoundation.org/donate

Contest

(Continued from page 38)

These parameters were subsequently used to generate the model of the laminated shale cores/specimens in Universal Distinct Element Code (UDEC). The resulting stress-strain behaviors and crack propagation in the three reconstructed shale specimens closely resemble laboratory observations. Our future work will involve upscaling to shale roof modeling, bridging the gap between shale's complex structure and geomechanical simulations by introducing the proposed physics-informed image processing approach for an accurate representation of bedding planes.

Profile: Gaobo Zhao received his bachelor's and master's degree from Henan Polytechnic University in 2017 and 2020, and attended WVU as a visiting scholar from January to May 2019. In August 2021, he joined WVU as a graduate research assistant and started studying for a Ph.D. As a Ph.D. candidate, he has authored or coauthored more than 40 technical publications and conference papers, as well as three book chapters. His work covers topics in geomechanics and ground control, encompassing longwall mining, surface subsidence and mitigation, overburden movements, pillar stability, rock mass behavior, and the innovative reconstruction of shale specimens/cores utilizing image processing and numerical modeling. For his work, he received numerous awards and scholarships, including the Syd S. and Felicia F. Peng Ground Control Mining Scholarship, WAAIME Scholarship, ICGCM Best Paper Award and Second Place Award of the 2022 PCMIA/SME Pittsburgh Section Short Presentation Contest.

Second: Biochar as a green adsorbent for rare earth elements extraction from aqueous solution. Authors: Victor Famobuwa, Hassan Amini, Oishi Sanyal, Shawn Grushecky and Deniz Talan, WVU, Morgantown, WV. Abstract: This study investigates an environmentally benign and low-cost biochar adsorption process for lanthanum recovery from aqueous solutions. The adsorption performance was systematically studied with biochars produced from Appalachian hardwood (AH), wood chip and chicken litter (WCC) and softwood (SW) after being subjected to pyrolysis temperatures of 675, 700 and 450 °C. Their effects on La (III) adsorption were evaluated in terms of pH, contact durations, and starting concentrations at ambient temperature. The findings indicated that the most favorable pH level for the adsorption process is pH 5, with an optimal contact time of 24 hours. AH had superior adsorption capabilities with La(III) adsorption capacity of 126.85 mg/g compared to WCC and SW. The adsorption kinetics was consistent with pseudo-second-order reaction, and the Langmuir isotherm was the most suitable fit for the system. Characterization studies including scanning electron microscopy, Fourier-transform infrared spectroscopy, Brunauer-Emmett-Teller analysis and zeta potential measurements were also conducted to examine the adsorption of lanthanum before and after the La (III) adsorption. Hence, biochar exhibits promising potential as an environmentally friendly substance for effectively adsorbing lanthanum from aqueous solutions.

Profile: Oluwaseun Victor Famobuwa is a master's graduate research assistant in the field of mining engineering at WVU. His research focuses on the utilization of environmentally friendly methods for the extraction of rare earth elements. He obtained his first degree from the Federal University of Technology in Nigeria, where he pursued a course of study in mining engineering during his undergraduate years. He has coauthored several publications in the field of mining and is in the process of submitting his first authored journal publications. His primary aspiration in life is to pursue a career as a metallurgist/process engineer with the intention of contributing to the advancement and development of his community.

Oluwaseun Victor Famobuwa

Third: Carbon mineralization and metal extraction from coal fly ash: A sustainable resource recovery. Authors: Syabilla Cardosh and Deniz Talan, WVU, Morgantown, WV. Abstract: Coal fly ash holds immense untapped opportunities for various elements vital to modern technologies. This study aims to develop recovery processes for multiple elements by combining process system analyses for optimized conditions. Experimental testing involves metal release, carbon mineralization to produce calcium carbonate, and metal recovery to produce critical minerals through various approaches while systematically exploring several operating conditions. As industries seek innovative solutions to meet resource demands while reducing environmental impact, carbon mineralization emerges as a transformative approach with considerable potential to reshape coal fly ash utilization and element recovery strategies. The study also offers waste minimization, resource sustainability, and environmental conservation.

Profile: Syabilla Cardosh is a graduate student at WVU, focusing on mining engineering with a specialization in mineral processing. She has actively participated in various research initiatives, collaborating with industry experts and academic mentors to address real-world challenges in the mining sector. Although she completed her undergraduate studies in chemical engineering, her commitment to excellence and her natural curiosity led her to explore the dynamic world of mining engineering and mineral processing, where she laid the foundation for her career in the field. With her academic background and practical experience, Cardosh aims to bridge the gap between chemical engineering principles and mining engineering applications, contributing to developing efficient, safe and environmentally conscious mineral-processing techniques. ■

Syabilla Cardosh

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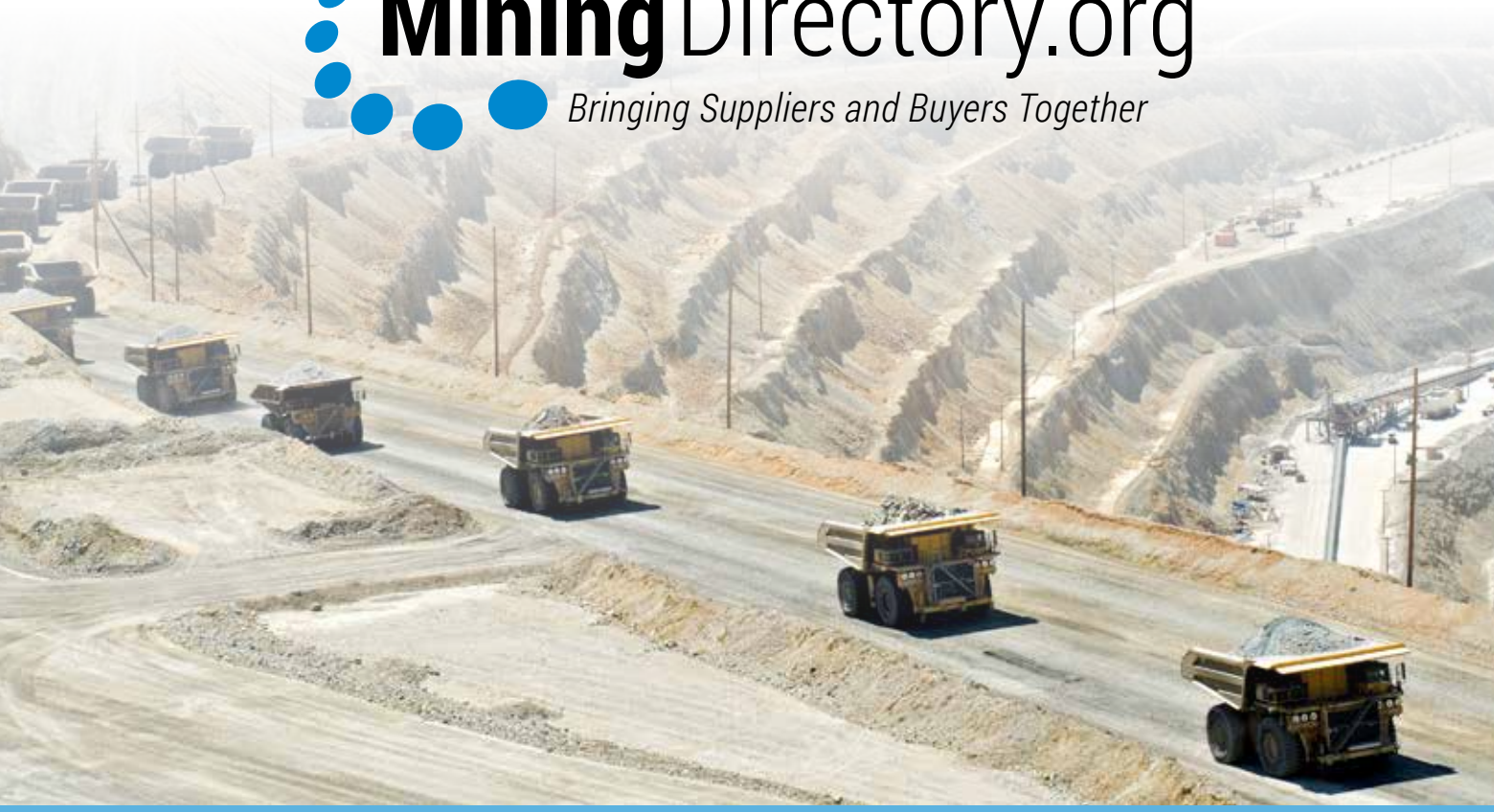

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Interest in nuclear energy rises in challenging times

William Gleason
Editor

The theme of the keynote session at the MINEXCHANGE 2024 SME Annual Conference & Expo was Energy is Everything. The overriding theme of the headlines at *Mining Engineering*'s website are often energy related, and whether they are about the minerals that will fuel the growing fleet of electric vehicles (EVs) or those that will provide fuel to power the grid for entire cities, the issue of power and mining's role in it are seemingly everywhere.

This magazine has devoted many pages and lots of ink to news around the critical minerals that many hope will hold the key to unlocking a carbon-free future. Lithium is one of the most discussed of these minerals, as David Hammond told me that when it comes to investors, "If are a junior mining company and don't have a project in the lithium space, you aren't on anybody's radar."

Hammond has more than 50 years of experience as a geologist, engineer and mineral economist. We talked at length about the recent downturn in critical mineral prices and the challenges of creating an economic forecast in these rapidly changing times. Hammond told me cooling sales of EVs in the United States and around the world is one of the primary reasons there has been less demand for the minerals like lithium and nickel which are essential to EV batteries. While the demand remains high overall for EVs the first wave of early adopters is probably done and there are more challenges in convincing the next wave to buy into EV technology. According the Hammond, the forecasted demand for EVs was likely larger than the reality.

We also talked about the role of nuclear energy, which has been somewhat lost in the buzz of a new energy future. While it is one of the cleanest and safest forms of energy, nuclear power also has a major public relations (PR) problem. For many people, their knowledge of nuclear energy includes Three Mile Island, the Chernobyl disaster and a three-eyed cartoon fish in the animated sitcom *The Simpsons*.

"I think nuclear suffers from the worst PR of any energy form," James Walker told me. He is a nuclear physicist and chief executive officer and board member with NANO Nuclear Energy, a company that is developing microreactor technology. "Nuclear energy is actually the safest form of energy. If you look at deaths per GWh, nuclear beats out wind, solar and every other form of energy. And it's orders of magnitude safer than fossil fuel power in terms of actual danger and deaths that are generated per GWh."

Jay Yu, founder of NANO Nuclear Energy called the current state of nuclear energy demand "almost of a perfect storm of rising interest in nuclear energy and technology."

And he is not alone. In December, the 28th United Nations Climate Change Conference (COP28) formally specified nuclear energy as one of the solutions to climate change in the First Global Stocktake of progress toward meeting the goals of the Paris Agreement.

"Advancements in nuclear technology, including the development of small modular reactors (SMRs) and the launch of such initiatives as the Nuclear Energy Agency's (NEA) Accelerating SMRs for Net Zero provide realistic pathways to providing the clean energy that countries need to meet this goal," Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency director-general William D. Magwood said.

Driven by climate and national security concerns, there is a renewed interest in these smaller nuclear reactors. *Bloomberg* recently reported on one such reactor off the Siberian coast. It is on a Russian ship that has been docked for four years. *Bloomberg* said it is the world's first floating nuclear power plant and it provides power to about 200,000 people.

The Bill Gates-backed TerraPower is also investing in nuclear. In August 2023, it announced that it had purchased land in Kemmerer, WY to build its Natrium Reactor Demonstration Project, an advanced nuclear reactor and energy storage system that will be the first commercial reactor to be operated in the state. Sited near a retiring coal facility, the Natrium demonstration plant is the only coal-to-nuclear project under development in the world.

While there are a lot of challenges ahead for the global energy transition, it seems that nuclear is making progress.

"The cost of renewable energy was more than expected and the economy of scale didn't really bring the costs down. Combine that with the inconsistency of renewable energy and it's clear there is a need for comprehensive baseload power," Walker said. "I wouldn't say renewable energy hasn't delivered, but the storage costs and the land usage costs were higher than expected …. In the end, reality was very unforgiving when it came down to it." ■

Tunneling & Underground Construction

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Artificial intellegence and machine learning are becoming more common in tunneling and underground construction. On page 12, LiLing Chen and coauthors discuss how automated tunnel inspection will provide information to serve different purposes and bring benefits to the users and asset owners at the Eglinton Crosstown West Extension project in Toronto, Canada. On page 19, Shane Yanagisawa and coauthors discuss the use of a digital geologist to identify and count cobbles on the RSC7 tunnel. Cover design by Ted Robertson.

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Fox Conference kicks off a new year

Wow! The George A. Fox Conference is the underground industry's premier event to kick off the year and what a way to start 2024. The program was packed with great speakers, inspiring topics, and we saw the largest attendance ever with the Moles Inc. annual awards dinner the following day. The Fox Conference, held annually in New York City, has expanded to include projects, participants and attendees from across the United States and the world who are directly involved in or support heavy civil and underground infrastructure projects.

In the United States and internationally, the underground industry is seeing rapid growth in the number of large and complex underground infrastructure-related projects that will challenge the industry, but I feel we are up for the challenge.

The recent large investments in infrastructure is a good thing that will improve our cities on all levels. The large infrastructure projects will continue to expand, improve and connect communities, improve quality of life and protect the environment. Underground projects are a great solution to address these needs and provide a long-term durable facility. It takes care, dedication, technology, leadership and investment.

Why is the Fox Conference the "go-to event" to kick off the year?

Dale Ericco from Railroad Construction Co. Inc. said, "As a member of the UCA I can't wait to start off the year attending the Fox Conference that recognizes George A. Fox for his accomplishments in tunneling and underground construction. It is truly enjoyable to meet and listen to the leaders in the industry from around the world who provide the insight and experience of the tunneling and underground construction."

Laura Mason, executive vice president, Capital Delivery, Amtrak,

Erika Moonin
2023-2024 UCA Chair

opened with the history of Amtrak and the transition Amtrak is making to be able to meet the unprecedented demands and challenges by updating and upgrading rail passenger service in the United States. It is this large investment in passenger rail that is necessitating Amtrak to look toward to a new approach. Amtrak is organizing itself and its contracts to streamline the way projects are implemented by grouping similar types of work. Amtrak is also implementing alternative delivery methods to include a delivery partner contract that is more common in other countries such as Australia. This is similar to a program manager but with incentives for achieving goals as measured by key performance indicators. In addition, Amtrak is investing in education of the workforce by building a training center.

I think it is encouraging that the industry is seeing more large infrastructure owners, including Amtrak, recognizing the need to meet the challenges and the need to implement new approaches and methods that are critical for success.

Luigi Rosa, AVP, Frederick Douglass Tunnel Program, Amtrak, gave an inspiring talk titled "I already see the light at the end of the tunnel." Rosa spoke about his past with experience in Italy, Oman and now New York on transportation improvements opening

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First construction contract awarded for extension of Second Ave. Subway in New York

New York's Metropolitan Transportation Authority (MTA) has awarded the first construction contract for the extension of the Second Avenue Subway from 96 Street to 125 Street in Harlem to C.A.C. Industries Inc., a family-owned heavy civil contractor based in New York City specializing in infrastructure projects. New York Gov. Kathy Hochul made the announcement on Jan. 22.

Spectrum News NY 1 reported that the initial $182 million award is for the first component of the Second Avenue Subway Phase 2 project, which will finally deliver subway service to residents of East Harlem, one of the most transit-dependent neighborhoods in New York City.

"We're moving full speed ahead to extend the Second Avenue Subway to East Harlem, expanding transit access for thousands of New Yorkers," Hochul said. "This critical milestone will put shovels in the ground for the next phase of this transformative project. East Harlem has dreamed of transit access for decades — and we're committed to getting the job done."

It is the first of four construction contracts for the new line, which will extend the train from 96 Street to 125 Street, serving more than 100,000 average daily riders and building three new ADA-accessible stations for the East Harlem community. The contract will relocate underground utilities from 105 Street to 110 Street on Second Avenue at the site of the future 106 Street Station, in order to facilitate the subsequent cut-and-cover construction of the station.

MTA chair and chief executive officer Janno Lieber said, "Phase 2 of the Second Avenue Subway will change lives and expand opportunities by bringing transit equity to the East Harlem community who have waited decades for this. The expansion of the Second Avenue Subway will get more than 100,000 daily riders to jobs, education and recreation not only in the city but throughout the region."

MTA construction and development president Jamie Torres-Springer said, "The MTA is implementing valuable lessons learned from past projects into

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Milestone reached on Toronto subway project

Engineering firm COWI announced that it has reached the halfway mark of the design of two new subway stations for the Ontario Line at King/Bathurst and Queen/Spadina in Toronto and will shortly move on to the construction documentation phase.

Scandinavian architecture firm, Arkitema, a part of COWI Group, has supported COWI's North American team with its in-depth knowledge of design excellence, metro station design and passenger experience. When designing the stations Arkitema has taken a holistic approach to create clean, sleek contemporary layouts with meticulous attention to detail, aesthetics and a welcoming atmosphere.

"This is an exciting project for our North American team," Thomas Dahlgren, president of COWI North America said. "With the Ontario Line, the balance has been to translate the project requirements into the quality that we prioritize over in Denmark: simple, rational and aesthetic solutions with inviting, open and friendly spaces, creating simple, intuitive pathways. Our goal was to create modern layouts with a strong focus on enhancing the passenger experience."

COWI was awarded the design and engineering contract for its first major subway project in Toronto, Canada in late 2021 by Ontario Transit Group, a joint venture between Ferrovial Construction and Vinci Construction. The team is responsible for the detailed design of two new underground stations — King/Bathurst and Queen/Spadina, located in downtown Toronto. The new stations will be situated within a 10-minute walking distance for around 50,000 local residents and will create vital connections between popular transport routes.

The new Ontario Line is a 15.6-km (9.7 miles) rapid transit line — the largest single expansion in Toronto's subway history which will connect Exhibition Place to the Eglinton Crosstown LRT at Don Mills Road and Eglinton Avenue East. It will include 15 fully accessible stations and more than 40 new connections to GO train lines and existing subway, streetcar, and bus lines. It will run along the existing rail corridor in Riverside and Leslieville. Expected to accommodate around 388,000 passengers per day, the line will relieve crowding on popular transport routes throughout the city and bring transit to underserviced neighborhoods. Construction is now underway.

Central to COWI's work on the project is safeguarding and future-proofing the city's heritage by seamlessly integrating the new stations into their urban surroundings while retaining the existing buildings historical attributes and character in the new station designs. ■

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DC Water awards $819 billion design-build contract for Potomac River Tunnel

A joint venture of CBNA, Halmar, COWI, and Hatch has secured a design-build contract for the construction of the Potomac River Tunnel (PRT).

The $819 million PRT contract represents a pivotal moment for DC Water, marking the largest-ever awarded contract by DC Water. The 8.8-km (5.5-mile) long tunnel will serve as a crucial mechanism to control combined sewer overflows (CSOs) into the Potomac River, significantly enhancing the water quality of this vital natural resource. This project is an integral component of the broader Clean Rivers Project, a $2.99 billion initiative aimed at improving water quality in the Anacostia and Potomac Rivers and Rock Creek while strengthening the sewer system's capacity.

"COWI will lead the design of the tunnel and adits, and provide geotechnical support for the entire project. We leverage our domestic and global personnel to bring experts in multiple disciplines," Steven Kramer, COWI senior project director, said. "Our team began working in late 2023 and has already delivered several key early lead items which has enabled the design and build team to begin construction. Working with CBNA-Halmar through the tender process and now the actual project has been very exciting and gratifying for our engineers. In a design and build project, it is always rewarding to see our design being implemented especially on such a critical project as the Potomac River Tunnel."

"At Hatch, we believe in partnerships that align with our core values of sustainable progress and community enhancement," said Bruce MacKay, Hatch's managing director for DC Water. "This collaboration exemplifies our dedication to pioneering designs that ensure a healthier, more sustainable future for the District of Columbia and its residents. Working with our partners, Hatch will be responsible for overall design management as well as the detailed design of underground works including support of excavation and concrete structures."

Traversing beneath and along the Georgetown waterfront, West Potomac Park and the National Mall, the 5.4-m (18-ft) diameter tunnel will extend to Hains Point, ultimately connecting to the existing Anacostia River Tunnel. Utilizing advanced tunnel boring machines, the construction will navigate various ground conditions, ranging from soft ground to rock. The surface and subsurface challenges will require precise engineering and the use of innovative construction techniques by the project partners. Commencing in 2024 and slated for completion in early 2030, the project's impact will be significant. Once operational, the PRT is projected to curtail CSOs to the Potomac River by an impressive 93 percent during typical rainfall years, solidifying its pivotal role in enhancing environmental sustainability for the region. ■

Funding for 10 major passenger rail projects announced in December by President Biden

President Joe Biden showcased $8.2 billion in funding for 10 major passenger rail projects across the United States on Dec. 8. The projects include work on high-speed, electric train routes that could one day link Nevada and California, as well as Los Angeles and San Francisco.

The administration said the 350.8-km (218-mile) train route linking Las Vegas, NV and Rancho Cucamonga, CA, about 65 km (40 miles) east of downtown Los Angeles, may one day serve more than 11 million passengers annually.

The administration hopes the investment through federal and state partnership programs will help to boost prospects for the long-discussed project, which supporters say could revitalize travel in the American West and critics argue is too costly.

Another electric rail line getting funding has been billed as the nation's first high-speed route and is eventually planned to traverse California's Central Valley and extend to San Francisco and on to Los Angeles, with trains reaching up to 354 km/h (220 mph).

The funding the president will highlight will not be nearly enough to cover the full costs of either project, but signals the Biden administration's commitment to spurring train travel in a nation that has long celebrated the spirit of fast cars and open highways.

"The bottom line is that, under President Biden, we're delivering world class passenger rail service that Americans ought to be able to expect," Transportation Secretary Pete Buttigieg said on a conference call with reporters.

Other train projects getting funding include upgrades to heavily traveled corridors in Virginia and North Carolina, with the eventual goal of linking Richmond and Raleigh by rail. Funding will also go to improvements to a rail bridge over the Potomac River to bolster passenger service in Washington and cover train corridor upgrades in western Pennsylvania and Maine, while expanding capacity at Chicago's Union Station, one of the nation's busiest rail hubs. ■

Team sets tunneling record for single TBM drive

The world tunneling record for the longest single tunnel boring machine (TBM) drive was set in England in December when STRABAG's tunneling specialists reached the 25.8-km (16-mile) mark on a tunnel drive for the Woodsmith Mine near Whitby, northeast of England.

The team is excavating a 37-km (23-mile) tunnel beneath the North York Moors National Park with a Herrenknecht TBM. The 1,775-t (1,956-st) machine with a diameter of 6 m (20 ft), named Stella-Rose, has been boring underground for around four and a half years.

The Woodsmith project will be the world's longest conveyor tunnel for a permanent mineral transport system (MTS) on behalf of Anglo American. When completed, the MTS will be used to transport ore from the world's largest polyhalite deposit from under the North York Moors National Park to Wilton, Teesside, for further processing. Polyhalite, a naturally occurring mineral that can be used as a fertilizer in organic farming, is extracted from the Woodsmith Mine via two 1.6-km (1-mile) shafts connected to the underground conveyor belt, a system which was chosen to minimize the environmental impact at the surface. With an internal diameter of 4.9 m (16 ft), the conveyor tunnel and transport system are designed to handle a throughput of up to 20 Mt/a (22 million stpy) of material.

Following completion of the overall project, Anglo American and STRABAG expect to have the record officially confirmed by Guinness World Records. About 450 people are directly employed on the Woodsmith project, with around 75 percent of them local to Teesside. STRABAG's preference for working with local construction partners and suppliers has also created many further jobs in the region.

"We are extremely proud of the team at the Woodsmith project for reaching this incredible milestone and passing the current world record set for a single bored tunnel drive. This is another example of our growing presence in the northeast of England and the UK, demonstrating our industry-leading expertise," managing director of STRABAG UK, Simon Wild said in a statement.

"We are delighted to achieve such an incredible milestone in the UK as part of our pioneering project. It is a demonstration of the fruits of teamwork with our partners. We are now focused on looking forward and setting a new world record every day. The Woodsmith tunnel is a fundamental part of our commitment to create a sustainable mine with minimal environmental impact," Andrew Johnson, Woodsmith project director for Anglo American said. ■

Coming Events

North American Tunneling Conference — **June 23-26, Nashville, TN**

More information: Meetings Department, SME, phone 800-763-3132, 303-948-4200, fax 303-979-4361, email sme@smenet.org

Second Ave. Subway: Phase 2 to expand the subway in East Harlem and beyond

(continued from page 4)

Phase 2 of the Second Avenue Subway, and this contract reflects our new approach by proactively relocating utilities upfront. Improving this process will help deliver this project more efficiently and provide residents of East Harlem with increased transportation options better, faster and cheaper than before."

U.S. Senate Majority Leader Charles Schumer said, "I fought tooth and nail to ensure that the Bipartisan infrastructure and jobs law made historic investments in transit, and because of that, the federal government committed to $3.4 billion for the Second Avenue Subway project this fall. I am proud to see that work on the project is advancing to the next contract. The Second Avenue Subway project will expand the subway in East Harlem and beyond, connecting thousands of riders to jobs, school, entertainment, friends, family and new opportunities."

U.S. Senator Kristen Gillibrand said, "This federal investment will make a real difference in the lives of East Harlem residents, and I'm very pleased that Phase 2 of the Second Avenue Subway project is moving forward. The expansion of the Second Avenue Subway line will ease commute times, reduce congestion, create local jobs and connect the community more seamlessly with the rest of the city. I'm proud to have worked to pass the Bipartisan Infrastructure Law that provided the funding to make projects like this possible, and I'll keep fighting for resources for New York's straphangers."

In July, the MTA also unveiled new conceptual renderings of the proposed stations for the extension, providing future riders with a first-ever glimpse into the potential station interior and exterior designs. The draft renderings are subject to further design development and are available from MTA.

Revenue from congestion pricing will support $15 billion in funding for critical projects in the MTA's current capital program, which includes Second Avenue Subway Phase 2.

The second phase of the project will extend train service from 96 Street north to 125 Street and then west on 125 Street to Park Avenue, approximately 1.5 miles in total. There will be two new stations at 106 Street and 116 Street on Second Ave, and a direct passenger connection with the existing 125 Street subway station on the Lexington Avenue subway line. Phase 2 will also feature an entrance at Park Avenue to allow convenient transfers to the Metro-North Railroad 125 Street Station.

Each station will have above-ground ancillary buildings that house ventilation, mechanical and electrical equipment, as well as space for possible ground-floor retail and community uses. The expansion will serve an additional 100,000 daily riders and provide three new ADA-accessible stations — raising the bar for customer comfort and convenience. Increased multimodal transit connectivity at the 125 Street station at Park Avenue with connections to the Metro-North trains and the M60 Select Bus Service to LaGuardia Airport, will allow for convenient transfers to other subway and commuter rail lines, facilitating smoother, faster transportation across the city and metropolitan region.

Phase 1 of the project extended the line from 63 Street to 96 Street and was New York City's largest expansion of the subway system in 50 years. Service opened on Jan. 1, 2017, with additional stations at 72 Street and 86 Street. Since its completion, the Second Avenue Subway has carried more than 130 million passengers in total, including more than 200,000 passengers on a typical prepandemic day. ■

Chair column: It's a great time to be in the industry

(continued from page 4)

up opportunities for people in the communities to connect and work in places they would not be able to if not connected by rail. He emphasized the importance of the team. I could not agree more — on large complex mega projects — it is about the specific people and working together as a cohesive team focused on the same objectives. That is one of the things that has attracted me to this industry — large complex projects that are successful because of the amazing people that come together and work to overcome these challenges.

There were presentations on other major projects and technical aspects of construction. We heard from Joe Sopko, Keller North America about solid techniques on ground freezing for tunnels and adits and the last session in true tradition fashion was the U.S. Tunneling Industry Update by Jim Rush of Benjamin Media. He recapped the completed projects and reviewed the long list of active and upcoming underground projects for the still jam-packed room.

"The 2024 Fox Conference provided an excellent balance between technical issues and project updates with a nationwide perspective," said Randall Divito of Hatch.

Thank you to the conference chair Victor Paterno of Skanska, the conference committee, and the speakers and attendees for making the conference a success.

A few takeaways from the conference — through many of the presentations that align to the UCA's strategic plan and goals:

- Alternative delivery methods — advancing technology and the industry as whole.
- Connecting communities — bringing opportunities for more people.
- Building a workforce — dedicating time and resources for training centers and investing in the local community skills development.

Link to strategic goal

The UCA has many activities to connect and keep the dialogue going for owners, contractors, designers and suppliers. If you are an owner you may want to join the Owners Forum virtual meetings held during the year. The Down for That program is holding tunnel tours for young professionals. If you or someone you know is considering the underground industry as a career choice, attend one of the upcoming tours and/or check out the resources on the Down for That website. The next big event is the North American Tunneling Conference, in Nashville, TN June 23-26.

It truly is a great time to be in the underground construction industry. We see some big changes in our future and are up for the challenge. Here's to a great start to 2024 and may we all continue to collaborate and work together as we build infrastructure and leave a legacy. ■

National Grid submits plans to upgrade electricity infrastructure

London-based National Grid has submitted plans to upgrade electricity infrastructure between Grain and Tilbury, England. The applications follows a consultation last October with local Gravesend and Tilbury residents.

As part of its plans, National Grid Electricity Transmission announced that it proposes to build a new cable tunnel underneath the Thames, which will deliver cleaner electricity to the area. The existing Thames Cable Tunnel between Tilbury and Gravesend is more than 50 years old and is coming to the end of its useful life. The proposed new tunnel will replace it and help to reinforce the local network.

Planning applications have now been submitted under the Town and Country Planning Act to both Thurrock and Gravesham Councils.

Two new "headhouses" will also be built at either end of the tunnel at Gravesend and Tilbury.

These headhouses are buildings that are needed to connect the tunnel and act as access points for National Grid workers.

National Grid is also planning the later refurbishment of the existing overhead line between Tilbury, Kingsnorth and the Isle of Grain, although this phase of works is not planned until 2028 and does not form part of this consultation.

The Grain to Tilbury proposals form part of The Great Grid Upgrade, the largest overhaul of the grid in generations, with new infrastructure across England and Wales helping the UK to meet its net-zero ambitions, reduce its reliance on fossil fuels and contribute to lower energy bills over the long term.

"The Grain to Tilbury project is essential to upgrade the energy network in Kent and Essex to ensure that we can continue to carry more clean energy to homes and businesses, and help the country reach net zero by 2050," said Lee Driscoll, lead project manager. "We are pleased to have now submitted our planning applications and look forward to delivering this important upgrade following their approval." ■

Amtrak awards contract for Frederick Douglass

Amtrak announced that it has selected a Kiewit/J.F. Shea joint venture to build the brand new, state-of-the-art passenger rail tunnel that will serve electrified Amtrak and MARC commuter trains for the Frederick Douglass Tunnel Program in Baltimore, MD.

"We are one step closer to unlocking the biggest passenger rail bottleneck on the Northeast Corridor between Washington, D.C. and New Jersey," said Amtrak executive vice president of capital delivery, Laura Mason. "This would not be possible without historic funding through the Infrastructure Investment & Jobs Act, as well as continued support from the Biden-Harris administration, FRA and our funding partners at the Maryland Department of Transportation Maryland Transit Administration (MDOT MTA)."

The Frederick Douglass Tunnel will replace Amtrak's existing B&P Tunnel, which opened 150 years ago during the Ulysses S. Grant Administration. Over the years, Amtrak has made significant investments to keep the B&P Tunnel safe and operational. However, several age-related issues, including excessive water infiltration and a sinking floor, have required continuous upkeep.

The overall program is scheduled for completion in 2035 and will be delivered through three major construction contracts, which include:

- Replacing five roadway and rail bridges; building new rail infrastructure (interlockings, tracks, catenary/power, etc.); and constructing a new ADA-accessible West Baltimore MARC Station.
- Building the Frederick Douglass Tunnel (both tubes).
- "Fitting out" the new tunnel with tracks, rail systems and ventilation facilities.

This generational investment is the centerpiece of Amtrak's Frederick Douglass Tunnel Program, which will modernize and transform an approximately 16-km (10-mile) section of the Northeast Corridor (NEC). The new tunnel is named in honor of civil rights leader and abolitionist Frederick Douglass, a Maryland native.

"The new Frederick Douglass Tunnel will generate fresh opportunities for Marylanders and help secure our transportation future," said Maryland Gov. Wes Moore. "This project marks an important step forward in our work to build strong pathways to work, wages, and wealth for all — while investing in critical infrastructure throughout the state. I'm grateful for the partnership of the Biden-Harris Administration and all of the stakeholders who have come together to make this vision a reality."

Located just south of Baltimore Penn Station, the new tunnel will serve electrified passenger trains with two parallel, single-track tunnel tubes, each approximately 3.2 km (2 miles) long. It will also support much faster travel speeds than the existing tunnel, where trains are currently limited to maximum speeds of 30 mph due to the tight curves.

Collectively, these investments will improve travel times for more than 12 million annual Amtrak and MARC passengers who rely on the NEC. When the Frederick Douglass Tunnel opens, it will be the first new passenger rail tunnel built on the NEC since 1986, and the first in Maryland since 1934.

The third and final construction contract to fit out the Frederick Douglass Tunnel with tracks, rail systems and more will be announced at a future date, with an anticipated award in 2025/2026. Amtrak will also soon select a Delivery Partner to coordinate and support the successful execution of the Program.

Construction of the new tunnel is being delivered through the innovative Construction Manager At-Risk (CMAR) delivery method, which improves project delivery time and allows design, preconstruction and other work to proceed simultaneously. ■

Herrenknecht presents TBM for Vienna

Wiener Linien, the operator of the Vienna subway, a joint venture between STRABAG and PORR is building the extension of subway line 2 from Vienna City Hall to the south. The Austrian tunnel construction specialists ordered an earth pressure balance (EPB) Shield tunnel boring machine (TBM) from Herrenknecht for this project.

"The Herrenknecht EPB Shield is the optimal machine type for the predominantly clayey geology that we expect according to the preliminary investigations," said Ralph Lickert, project manager at Herrenknecht.

The Herrenknecht EPB Shield for the Austrian capital has a diameter of 6.84 m (22.3 ft), a length of around 120 m (393 ft) and weighs a total of around 1.1 kt (1,200 st). The drive will start at the future Matzleinsdorfer Platz station, from where the machine will drive 2.1 km (1.3 miles) of tunnel northward to below Augustinplatz. The machine will then be pulled back through the bored tunnel, which is lined with precast concrete segments, in order to drive the parallel tube from Matzleinsdorfer Platz.

With the expansion of the metro network, the city of Vienna is responding to a rising population. More than 2 million people are expected to live in the capital by 2030. According to the city, the investment in the line extensions will create and secure around 30,000 jobs. Construction companies worldwide have already bored more than 3,000 km (1,800 miles) of tunnels for high-performance metro systems in more than 1,300 projects using Herrenknecht's mechanized tunneling technology. Current flagship projects include the major Grand Paris Express and Sydney Metro projects with 22 and 15 Herrenknecht machines, respectively. ■

Applying automation and machine learning for tunnel inspections

The Eglinton Crosstown West Extension (ECWE) is a proposed rapid transit line in the greater Toronto area that extends the current Eglinton Crosstown Line (ECLRT) further west from Mount Dennis Station to Renforth-Eglinton Station. The extension will stretch approximately 9.2 km (5.7 miles) from Mount Dennis to Renforth Drive, incorporating seven new stations and interchanges with the Mississauga Transitway at Renforth Gate. The project is split into four different contracts with the advance tunnel contract 1 (ATC1) currently under construction. The ATC1 will consist of an approximately 6.3 km (4 mile) long twin-bored tunnel of 5.75 m (18.8 ft) internal diameter with nine cross passages running from Renforth to the Scarlett area, as shown in Fig. 1.

Arup has been appointed as the technical adviser to Metrolinx and Ontario Infrastructure and Lands Corp., collectively, the contracting authority (CA) and is providing design compliance review and site construction oversight services to the CA. With support from the CA on implementation of digital initiatives for the project, Arup has proposed, among other digital works developed for the project, to develop and implement an automated tunnel inspection system for the ATC1, which is currently in the first phase of development for a pilot run. The current phase of work is to develop the tool to undertake photogrammetric survey of the tunnel and the development of a virtual model of the tunnel to allow users to view, review and compare defects.

This article will provide an overview of the survey methodology and benefits at different stages of the project, as well as the development of the inspection tool and potential future expansion of this to bring additional values to the asset owner over the long-term asset life.

FIGURE 1

Eglinton Crosstown West Extension Project.

LiLing Chen, Yung Loo, Fabio Panella, Tristan Joubert, Michael Devriendt, Nasir Qureshi and Ahmad Ali

LiLing Chen, Fabio Panella (members UCA), Yung Loo, Michael Devriendt and Tristan Joubert are senior tunnel engineering, senior data scientist, senior tunnel engineer, associate director and electrical engineer with Arup and Nasir Qureshi is director at Metrolinx, email li-ling.chen@arup.com

Project background

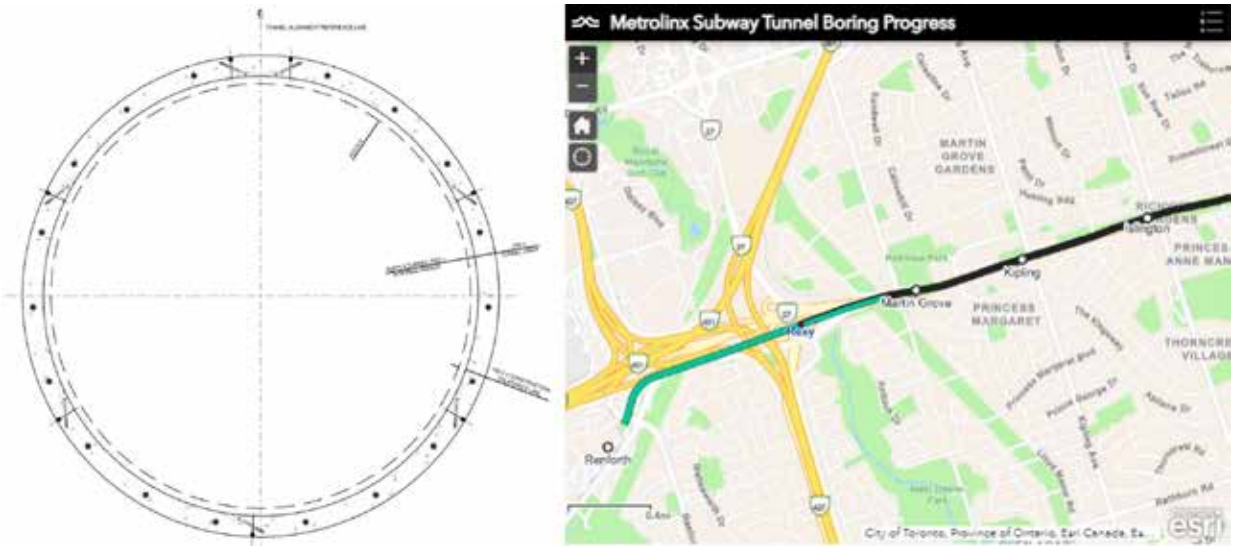
The tunnel to be constructed under the ECWE ATC1 contract consists of a twin-bored tunnel approximately 6.3 km (4 miles) long running between Renforth Gateway and Scarlett Road. The tunnels are 5.75 m (18.8 ft) internal diameter with 275 mm thick precast concrete segments. The ATC1 contract was awarded to Westend Connectors (WEC) and design and construction for the ATC1 contract started in May 2021. Both tunnel boring machine (TBM) tunnels are progressing and were 39.8 percent and 28.6 percent complete as of end of November 2022. The tunnels are expected to break through in 2024. Typical tunnel cross-section and tunneling progress are shown in Fig. 2.

Automated tunnel inspection system

At different stages of the project, the automated tunnel inspection is intended to provide information to serve different purposes and bring benefits to the users and asset owners. The automated tunnel inspection system that will be used for the survey consists of a camera array system for automated capture of high-resolution imagery at speed, and a web-based platform for visualization and interrogation of the inspections.

FIGURE 2

Typical tunnel cross section (left) and tunnel progress (right).



Construction stage. As part of the technical advisory services to the CA, Arup is providing construction oversight to the ongoing construction works for the ATC1 contract. Site inspectors carry out daily tunnel walks and undertake visual site inspections. Site observation notes on defects and photos are taken by the site inspectors and are then manually logged in a deficiency log afterward for tracking and site record. Locations and defect descriptions largely depend on inspector's notes and further review of the photos afterward when logging into the deficiency log. The survey taken by the automated tunnel inspection tool would supplement the current manual tunnel inspection process to allow:

- Virtual tunnel environment for review of defects observed visually on site.
- Dashboard platform providing a centralized location for summary of defects and user-friendly features for defect reviews.
- Identification of additional defects missed by the manual visual inspection.
- Supplement the visual inspection to provide an overall tunnel conditions baseline at tunnel breakthrough.

Project handover. Prior to handover of the tunnel asset to the CA, Project Co. is to ensure all defects are repaired and accepted by the CA. The tunnel inspection tool can be used at this stage to:

- Provide the common digital platform for relevant parties and stakeholders to review inspection data and make decisions on repair and acceptance.
- Validate the condition of the as-built tunnel against the design intent and required specifications.
- Provide a baseline of condition in the tunnel for future record, audit and comparison.

Operation and maintenance

Following tunnel commissioning and fit-out, the historic collected data from construction and hand-over will provide the baseline for comparisons over time against upcoming general and targeted inspections. This will provide rich visual data across the lifetime of the asset's operation and maintenance. The tunnel inspection tool can be used at this stage to:

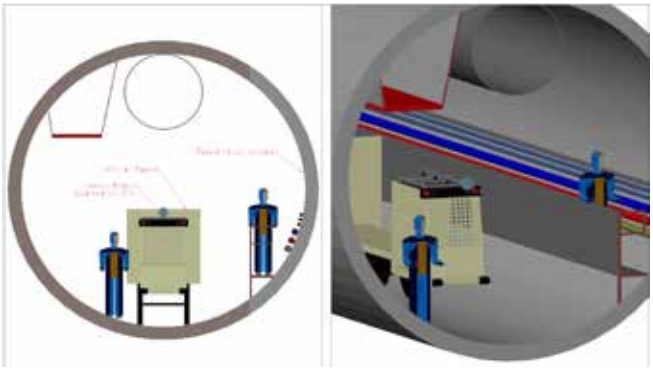
- Provide a digital repository of visual data of the tunnel condition over time.
- Enable the asset manager and tunnel inspector to effectively identify and record issues in the tunnel.
- Enable quick and repeatable data capture of the tunnel to be collected consistently over time.
- Enable the asset manager to be proactive rather than reactive in identifying potential emerging issues based on historic objective and consistent survey data collected. It should be noted that the civil asset condition often impacts on other tunnel systems, for example groundwater ingress/leakage affecting track and monitoring and evaluation systems.

Methodolgy

With the support from the CA on extending digital initiatives, ECWE ATC1 will be one of the first tunnel projects in Toronto to envision implementing automated tunnel inspections. The development for ECWE uses Arup's Loupe 360 tunnel inspection service and digital platform engine (https://www.arup.com/services/tools/loupe-360). This builds on technology and knowledge developed with public and private sector asset owners

FIGURE 3

Sketch of hardware frame setup.



predominantly in the U.K., where the technological, commercial, health and safety benefits of automated tunnel inspections are being demonstrated.

The development of the automated tunnel inspection system is carried out in several phases to meet project-specific requirements. It consists of an initial stage of proof-of-concept for the pilot run on tunnel inspection survey; further development with the CA on additional project-specific requirements including incorporation of machine learning for the construction and handover phase for tunnel baselining; and the final phase explores program-wide asset management requirements implementation for tunnel maintenance and management.

The current phase of the work is at the initial proof-of-concept stage. The automated tunnel inspections system consists of a physical hardware system and a web-based digital platform to view and interrogate the captured data to meet project needs.

An industry shift change. The combined hardware and software setup provides a step-change approach to how tunnel inspection is conventionally undertaken and automated. It moves forward all aspects of the approach:

1. A change from manual inspection to automated inspection. This speeds up the data capture process and removes personnel from the tunnel creating improvements in health, safety and welfare, enabling engineers to focus on less manual intensive and prioritized tasks based on the visual outputs.
2. Use of data-rich computer vision data and analytics to support decision-making. 360-imagery provides a fully comprehensive view of the tunnel, enabling objective analysis and baselining over time for comparison. This removes the reliance on inspector specific subjectivity and descriptive differences, which can always be compared back to the underpinning data.
3. Digitalization of assets, documentation and analysis. Representation of the asset and the inspection records within the digital platform enables easy and user-friendly access to a wide user base (on a secure access-controlled basis), and enables reporting and review of the tunnel environment to be a lot more accessible than within the conventional approach that relies on traditional documentation and reporting. As more surveys, layers and data-sets become available, these can be iteratively built on within the platform and deeper analytic insights can be found through overlapping data analysis.
4. Machine learning. Using machine learning to automatically detect defects and inventorying of tunnel furniture enables a data set of tunnel health metrics to be quickly developed across the tunnel, especially over long kilometer extents of repeat tunnel structures. The automatic insights to flag up and identify issues enable a first-pass assessment of the distribution and relative severity of deficiencies. The machine-learning approach enables a move from preventative to predictive maintenance regimes, which ultimately leads to better-informed understanding of the tunnel condition and the ability to intervene, plan and monitor the ongoing health of the asset.

Hardware design. The physical hardware system is comprised of a camera-array system and a frame support onto the tunnel multipurpose service vehicle (MSV). The camera array system comprises multiple GoPro cameras that are clustered together on a 3D-printed mount, specifically designed to ensure 360-degree field-of-view coverage of the tunnel, and benefits from using low-cost commercially accessible and upgradable hardware.

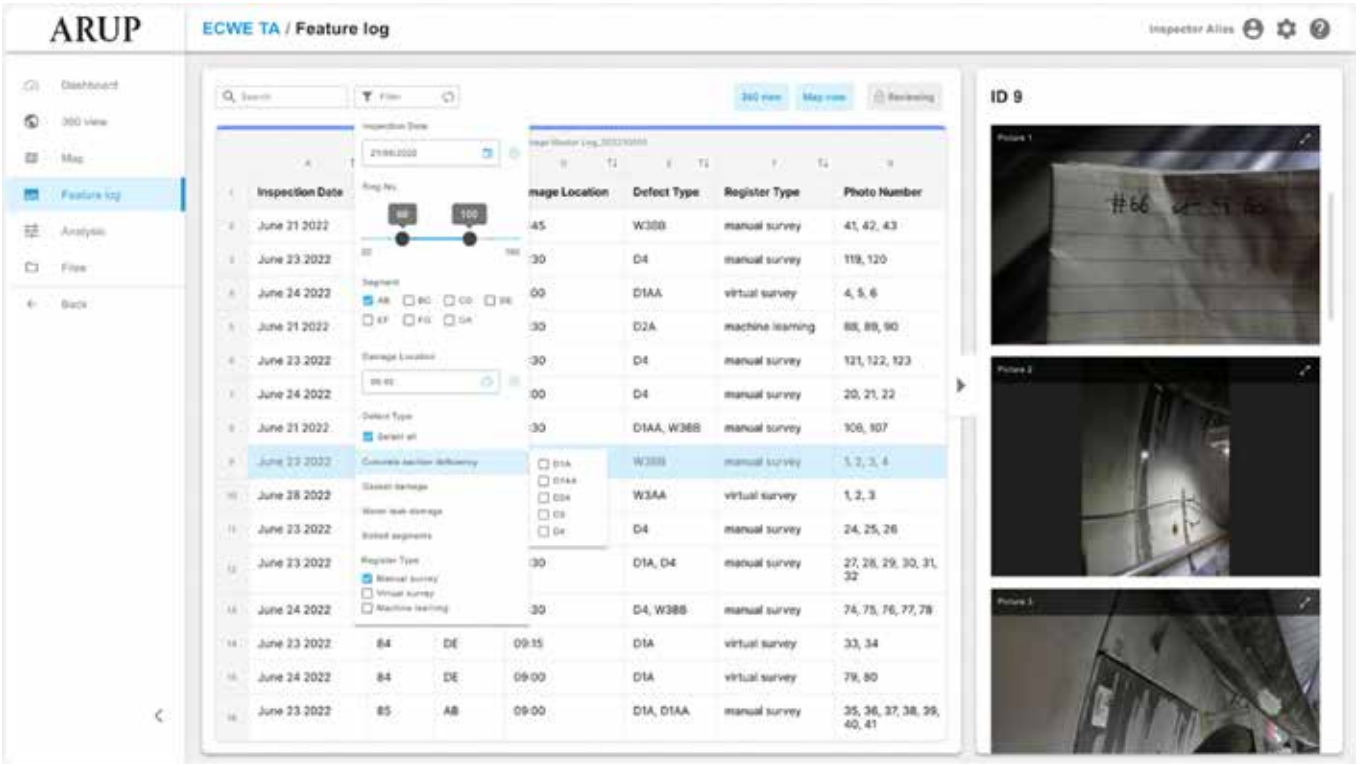
The cameras and mount are affixed onto the MSV by attachment onto an aluminum frame designed modular system to ensure stability and centering within the tunnel. The setup is also powered by an on-board battery and independent memory storage. The build is modular in design to allow future-proofing for future technology sensor development and additions, including: live geospatial location tracking, thermal vision and sound recordings, and aiding the inspection process. Should the in-tunnel communications network allow, live transmission of visuals and data storage in the cloud is possible in the future (Fig. 3).

The frame system is designed to be compatible with the equipment available on site considering various site constraints. The frame is needed to meet the requirements of the inspection, adhere to best practice design standards, and ensure compatibility and improvement to the site survey teams workload and conditions. The development of the frame system was coordinated among different parties, including the CA, Project Co., Arup's U.K. team, the project site team, and the project tunneling team in the North Americas. The tunnel is currently under excavation using the TBM.

Some of the main site constraints that are taken into consideration in development of the frame include:

FIG. 4

Software platform deficiencies log.



- Utilization of existing equipment used by Project Co. for frame attachments.
- Space limitation imposed by temporary systems within the tunnel, including ventilation duct, conveyor belt system and temporary sidewalk for camera array mounting.
- Lightweight for ease of lifting and handling during set up.
- Limitation on type of power supply for the inspection system within tunnels.

One of main considerations in development of the frame is to not have any, or to minimize any disruptions to the tunneling works and make use of the existing equipment currently in service in the tunneling activities on site. The teams collaborated on the project-specific frame design development, types of equipment and the vehicles currently in use for the tunnel construction, and concerns about using the different equipment for attachment were reviewed with Project Co. inputs. The MSVs currently in use on transportation of the tunnel segments or workers within the tunnel were identified as the most suitable method for the frame attachment and for carrying out the survey within the tunnel. A 3D-virtual model of the MSV was developed based on the specification provided by Project Co. and on-site imagery captures as well as on-site measurement verifications. Overall size of the frame was then designed to fit.

The hardware frame is designed in such a manner that adjustments can be made to ensure the equipment is always in the optimal position, i.e., tunnel center point and cantilevered over rails with sufficient clearance from temporary systems within the tunnel. Positioning the frame and subsequent equipment above the MSV drivers cabin is important for several factors: improved image quality, reduced impact to site survey team working conditions, and avoiding existing equipment within the tunnel.

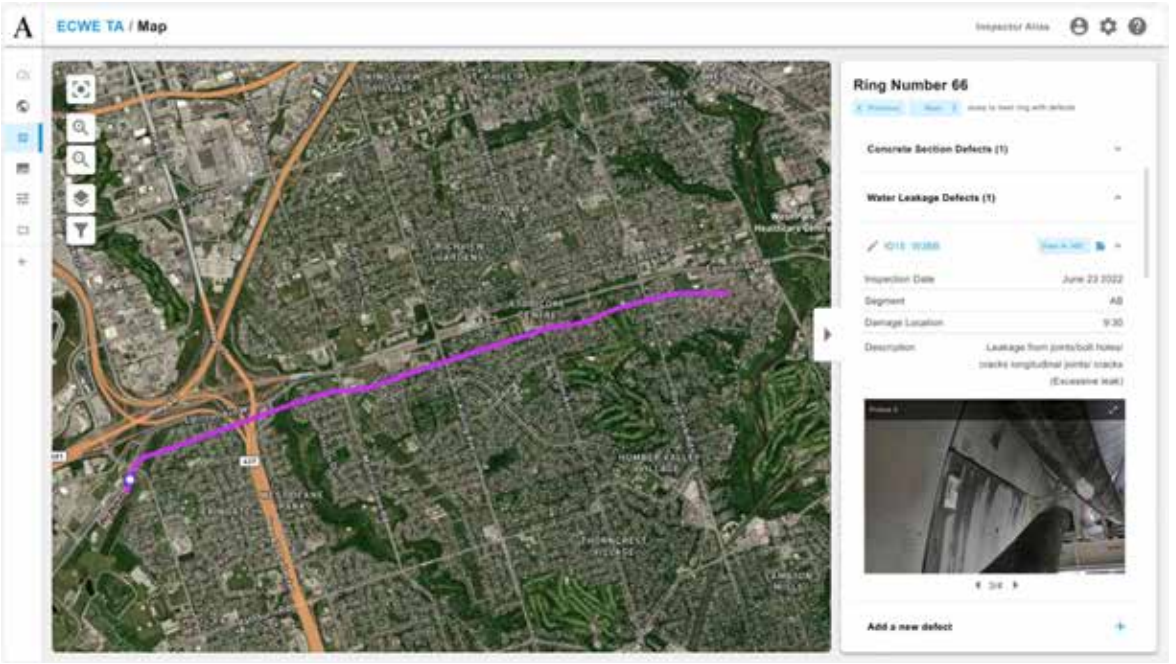
The use of aluminum material minimizes the total weight of the frame, thus allowing the frame to be easily mounted and detached from the MSV for site surveys and equipment maintenance. A combination of adjustable feet, an antislip rubber-mat and ratchet straps improve the overall friction between the frame and MSV; ensuring the frame remains in position during normal survey conditions and no permanent modifcation is required to the MSV.

As the existing MSV's power supply was intended for its own operation powering, external power for the tunnel inspection tool is required for the camera array system. With coordination with Project Co., an on-board battery attached to the MSV will be used.

Software platform. To visualize the captured imagery and to enable the tunnel engineer to analyze and interrogate the data in an effective manner, a user-friendly web platform has been developed to serve as a virtual survey environment. This enables the user to review the full data outside of the tunnel environment and

FIG. 5

Software platform mapping pane.



inspect the relevant parts of the tunnel in more detail as required. The platform is built within Arup's Loupe 360 tunnel inspection platform, with expanded functionality to take into account specific needs and requirements for ECWE. The platform comprises development and integration of various tools and features:

- Overview management dashboard: This provides an overview of tunnel information, 360-degree visuals summaries, tunnel health metrics and mapping layers.
- 360-degree viewer: High resolution imagery viewer with manipulation toolsets including side-by-side comparison mode, geospatial localization tab, and asset information tabs.
- Mapping pane: 2D map including tunnel alignment layers, and map styles e.g., street maps and satellite imagery.
- Deficiencies log: Upload functionality for integration of daily inspection deficiencies logs and point-and-shoot images database. Integration of inspections database with 360-degree viewer and geospatial querying.
- Machine learning: Automatic detection of selected defects and tunnel features.

Specific nuances of these toolsets have been developed through user interviews and workshops with the ECWE teams to ensure functional usability and prioritization of the feature development pipeline (Figs. 4 and 5).

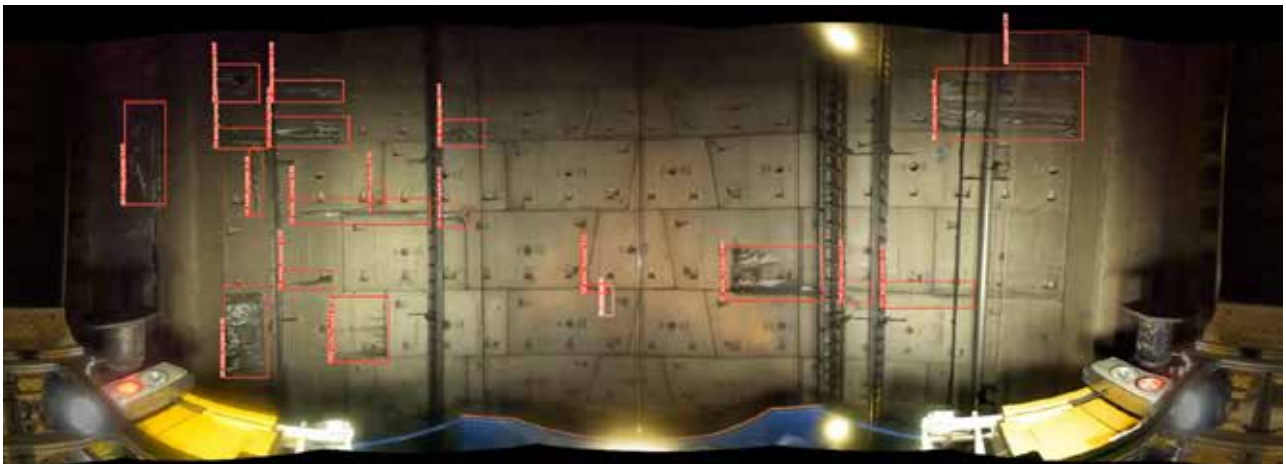
Machine learning (ML). The application of ML for transport civil engineering asset management purposes is seeing increasing uptake and interest, especially in light of the productivity and quality benefits demonstrated by early adopters and the success that ML application to other industries and sectors has shown. The development of ML within the automated tunnel inspection tool is focused around automatic defect detection and change detection. This will ultimately aid the engineer in identifying issues in the tunnel, understanding spatial and temporal changes in the tunnel, and making better-informed decisions on clear visual data.

Since the early 2010s, with the publication of ImageNet (Russakovsky, et al., 2015) and thanks to increasing computational power, deep learning (DL) has attracted more research as well as industry applications. Both ML and DL are algorithms that allow computers to learn directly from data without being explicitly programmed. However, DL is a subset of ML. The core of DL algorithms is the convolution operation (DL algorithms are also called convolutional neural networks (CNNs)). The main three properties of a CNN are parameter sharing, sparse interaction and equivariant representation (Goodfellow, Bengio and Courville, 2016). Thanks to these property CNNs, which are different from ML algorithms, one can learn from unstructured data such as documents, images and text. DL is being applied to the image-defect-detection problem on this project. This section describes the automation of visual inspection of tunnels with DL-based image understanding tasks.

By applying DL to ECWE's asset inspection, this will aid in demonstrating that accurate defect and inventory detection in tunnel environments can be effectively

FIGURE 6

Example of DL defect detection on an equirectangular image.



automated with DL approaches and enables ECWE to develop predictive-analytic capabilities in their inspection regimes that can aid in proactive inspection and maintenance plans. The authors highlight the importance of the data-collection design phase to maximize the detection output. Finally, we describe our approach to map images and defects in the tunnel's local coordinate system.

The process to deliver an ML-based application for ECWE from ideation to deployment is described in the next section.

Problem statement. The ATC1 construction work requires the tunnels to be progressively inspected and surveyed to ensure that construction progress matches the design intent. Traditionally, the record of deficiencies and tunnel condition are manually noted, recorded and compared. With kilometers of repeat tunnel structures being inspected and visual changes being observed on a daily basis, automation and use of computer vision technology to aid these traditional processes is becoming more possible and accessible with the development in new ML-based technology computer vision stacks. Identification and understanding of the specific asset owner's needs and cost-benefits needs to be accounted for as well. The primary objective of the ML aspects of the automated tunnel inspection tool is image understanding of the tunnel environments with the aim of detecting structural defects like cracks and water ingress. Among the multiple ML approaches to perform this task (including image classification, object detection and image segmentation) object detection is the approach of choice for this application as sufficient geometric information can be identified (bounding box class, location and dimensions — see Fig. 6) and it is inexpensive in terms of data labelling and required computational power.

Data collection. To be sure that the ML algorithm performs as expected it is important to train the ML model on images representative of the dataset used in production. Well validated datasets and pretrained algorithms that achieve high-quality results do not widely exist for concrete tunnel linings and low light tunnel environments. Arup has built up a dataset of labelled data in these tunnel environments and builds off of this to develop and train models applicable for the ECWE environment. As the base imagery collected is panoramic imagery, much of the training data set includes panoramic images as well, to match the format of the data collected. As more data from the ECWE in-tunnel surveys are collected over time, this will serve to increase the pool of data for the ML training to be developed across to improve the accuracy and precision of predictions.

The training is supported by a process of manual labeling for object detection purposes that consists in defining the coordinate of the bounding box containing the feature of interest and the respective label. Although this is a highly repetitive and time-consuming process, labeling accuracy is important, especially on new data sets, and it is important that a significant portion is labeled and reviewed by engineers familiar with identifying and recognizing these defects.

Defects tracking for condition monitoring. For the next step, the panoramic video, collected with the hardware, will then feed to the object detection algorithm for defect and fire equipment detection and counting. The algorithm will analyze each frame of the video as an independent image. This means that there is no correlation between two detections of the same object when it appears in two consecutive frames. This could negatively affect the defect/inventory counting from overlapping frames. To overcome this limitation, combination of YOLOv5 algorithm with the DeepSort algorithm will be considered. DeepSort (Wwojke, Bewulus, 2017) combines the Kalman filter (estimating the velocity and motion) and appearance descriptors per each bounding box to track uniquely identified objects.

Finally, for defect and inventory mapping it is essential to identify the camera position in the tunnel coordinate system. Considering the linear nature of tunnels, thus the

FIGURE 7

Example of DL-based condition monitoring visualization in Loupe 360.

impossibility to have any loop closure, a bespoke pipeline will be considered to be implemented for in-tunnel mapping. It will be based on the detection of distinctive natural features of the tunnel lining, for example segment joints, and tracking their position to the center of the equirectangular image of the tunnel. This way, the number of rings inspected can be counted. This would be the same approach used by engineers to locate themselves when performing a traditional visual inspection.

Figure 7 is a screenshot of an example of final deep learning-based condition monitoring. Detected objects are mapped in the tunnel's local coordinate system giving the possibility to identify, with an easy to understand red-amber-green visualization, the areas that require more attention.

Future development and conclusion

The strength of the system grows with collection of repeat data over time. DL algorithms for automated defects and inventory detection represent a fast and repeatable approach to automate visual inspection of large infrastructure. As additional surveys are undertaken, additional training will be able to be integrated to improve even more the detection performance. Future works will implement ML for the tunnel inspection system and automate data labelling from the deficiencies log that is provided at the handover of the new infrastructure to the asset owner, and future asset inspection logs and reports generation.

In the progression from coarse to fine inference, image semantic segmentation represents the last evolution of DL approaches, providing a per pixel classification. This approach would benefit especially the detection of cracks giving the possibility to define length, width and orientation of the detected cracks. Even though extensive research is available on the topic (Panella, Lipani and Bohm, 2022), extensive training datasets for tunnel lining inspections are still missing. Future effort can be made to create an engineer-validated dataset for semantic segmentation of cracks and other defects at a per pixel classification level, and attuned to specific deficiency categories and monitoring and prediction of its change over time.

The development of the automated tunnel inspection system for ECWE is at an early stage on ATC1. Following the pilot trials in early 2023, collection of the on-site data and integration into the software platform, it is anticipated that further iterative development will enable the system to be embedded into business-as-usual processes for inception during the TBM drive progression, through handover, and onto the operational period. Adoption of new technology and systems requires changes in human processes and operations, so embedding technology adoption change needs to be accompanied with processes that enable this to happen. As other drives and Metrolinx assets will operate similar systems, scaling the innovation to other assets would benefit consistency of approach across assets. As the projects progress, inte- gration with ECWE's future operational and maintenance asset management systems, sensors and processes may also be possible, which can help build up a richer picture of the tunnel's health, building up different data sets across the structure that will be useful for operators, maintainers and cross-discipline teams. ■

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Using the digital geologist to count cobbles at the RSC7 tunnel

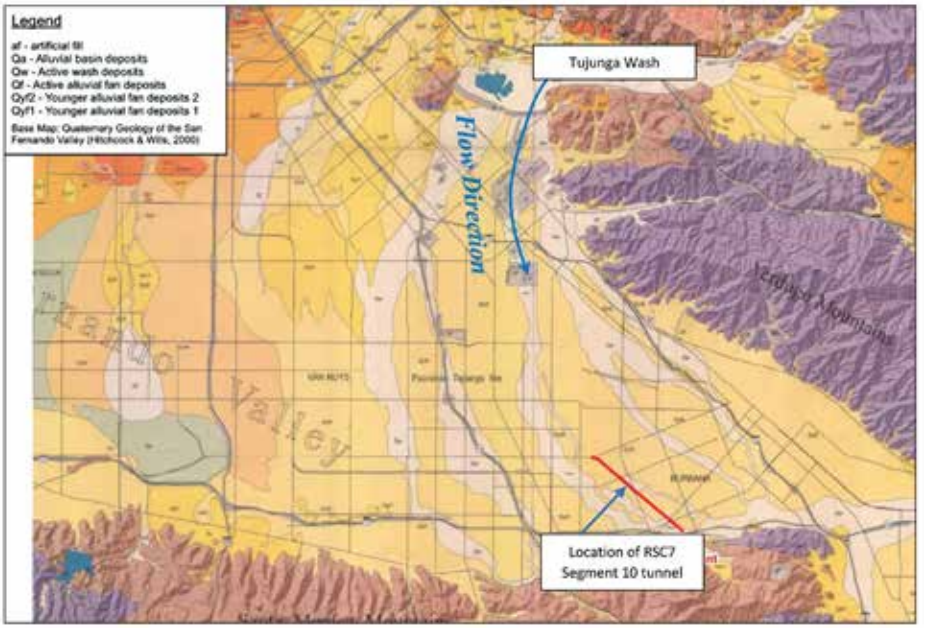
Cobbles are an important consideration when reviewing any geotechnical baseline report (GBR) for a soft ground earth pressure balance (EPB) tunnel boring machine (TBM) tunnel. How many times have you read a GBR that says, "For Reach Y, Cobbles are anticipated to be X percent of the total excavated volume of material?" Engineers use this language to better define the ground and set a baseline. Contractors review this language closely when they are bidding on the work or when they are wondering whether the ground presents a differing site condition.

Defining the cobble quantity is one thing, counting cobble is another. A field determination of the cobble content can be done by weighing the muck cars and then separating out the cobbles using a bar screen. The cobbles are then weighed and the cobble percentage by weight of muck is calculated. Conveyor belt scales are not accurate enough when one is trying to measure cobbles to an accuracy of one percent. If the baseline given is by volume, then the cobbles are weighed, and the volume calculated based on a sample cobble specific gravity determined laboratory test. Sorting out and weighing cobbles on a continuous basis is not practical or economical.

Face mapping by a registered engineering geologist can be done, but not continuously, and the interpretation and mapping can be subject to dispute. The geologist must be ready to go in the cutterhead when the TBM stops for cutterhead inspection. Sometimes the exposed face is unstable and the TBM must advance ahead a few more rings in hopes of better ground. If the entry is being done under compressed air, the geologist must go in and out through a compressed air lock with the rest of the crew. Clearly, a better way is required to quantify cobbles.

FIGURE 1

Location of the RSC7 tunnel in the San Fernando Valley.



The project and the problem

The Los Angeles Department of Water and Power (LADWP) contracted with Frontier-Kemper Constructors, Inc. (FKCI) to complete the River Supply Conduit Improvement Upper Reach –Unit 7 (RSC7) Project. Tunnel Segment 10 of the project was excavated by a 4.12 m (13.51 ft) diameter earth pressure balance tunnel boring machine (EPB TBM) advancing 3,584 m (11,754 ft) or 2,602 tunnel liner rings 1.37 m (4.5 ft) wide. The TBM holed through on March 15, 2022, 597 calendar days after launching on July 26, 2020, and 236 days behind the baseline schedule completion date.

The tunnel traverses the Tujunga Alluvial Fan (Fig. 1) and encounters a combination of wash deposits and alluvial fan deposits. These deposits are labeled in the contract documents as young alluvium. The young alluvium is described as sand with relatively large percentages of gravel with some silt. Within the fan deposits are storm channels or channel lag deposits that are known to contain coarse gravel, cobbles and boulders. These channels, as is the main channel of the Tujunga Wash, are oriented generally parallel to the tunnel drive.

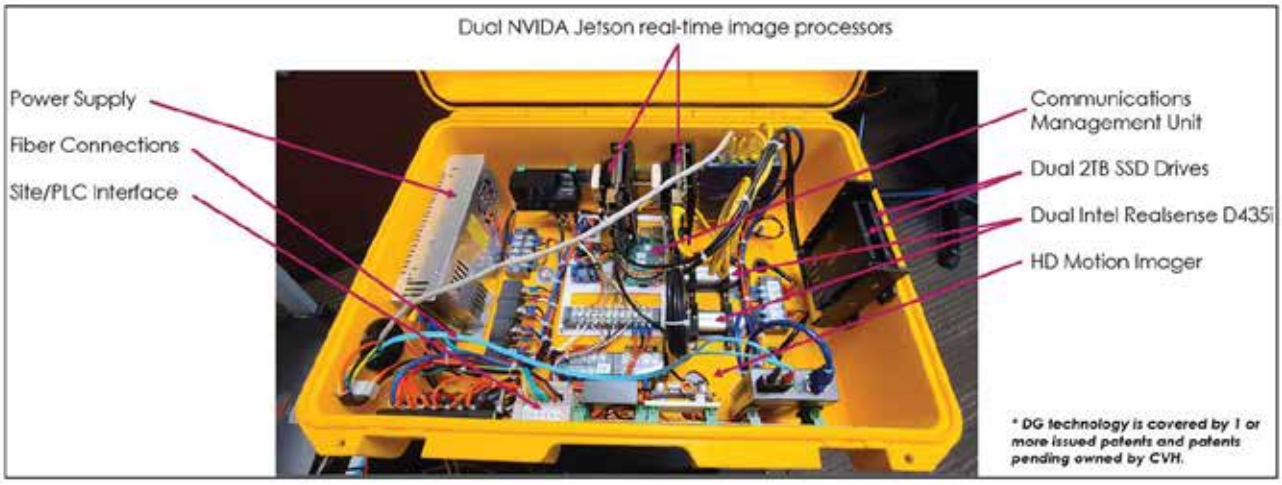
During the tunnel drive, FKCI thought that the tunnel alignment could be following an old storm channel of the Tujunga Wash infilled with cobbles and

Shane Yanagisawa, Dan Preston, Don Deere and Robert Marshall

Shane Yanagisawa (member UCA) is principal, Osprey Engineers LLC, Dan Preston is chief executive officer, Claro Via Holdings LLC, Don Deere is principal, Deere & Ault Consulting Engineers and Robert Marshall is vice president of operations and project manager, Frontier-Kemper Constructors Inc. email shane.yanagisawa@gmail.com .

FIGURE 2

The guts of the Digital Geologist 2.0.



large gravel. As a result of these geologic conditions, FKCI believed that the 76 to 305 mm (3 to 12 in.) cobbles encountered were substantially more than the seven percent by weight of excavated materials baseline given in the Geotechnical Baseline Report (GBR) and constituted a differing site condition. FKCI began documenting the number of cobbles by having a certified engineering geologist map the face and assess the percentages of cobbles. Mappings were done at 10 locations starting at Station 89+87 and ending at Station 49+85, a span of 4,002 ft. These mappings yielded an average cobble content by weight of 22 percent. A claim was submitted to the owner alleging a differing site condition (DSC) based on the number of cobbles mapped but the claim was denied.

Developing a technical solution to count cobbles

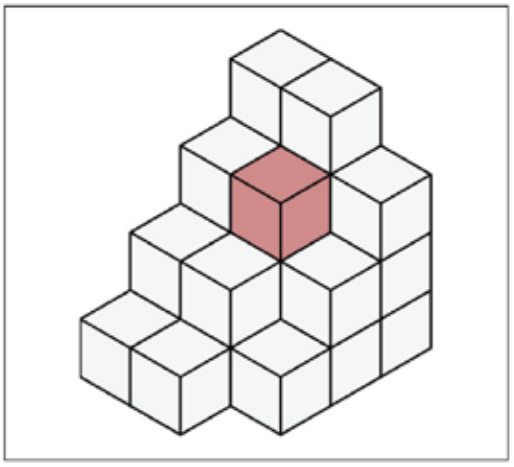
FKCI engaged CVH to adapt and install a system that could classify and count coarse gravels and cobbles by direct three-dimensional measurement as they moved up the conveyor belt immediately after discharge from the TBM screw auger.

The goals of the digital geologist were to:

- Capture 100 percent of the mined materials with a direct measurement system and a high definition (HD) image.
- Using the direct measurement data collected, generate a three-dimensional light coded depth map using state-of-the-art technology developed by Intel.
- Provide a reliable method to count cobbles and large gravel.
- Convert the cobble and gravel volumes to weights.
- Calculate percent by weight of cobbles as a percent of weight of the mined materials by ring advance.

FIGURE 3

Voxel object.



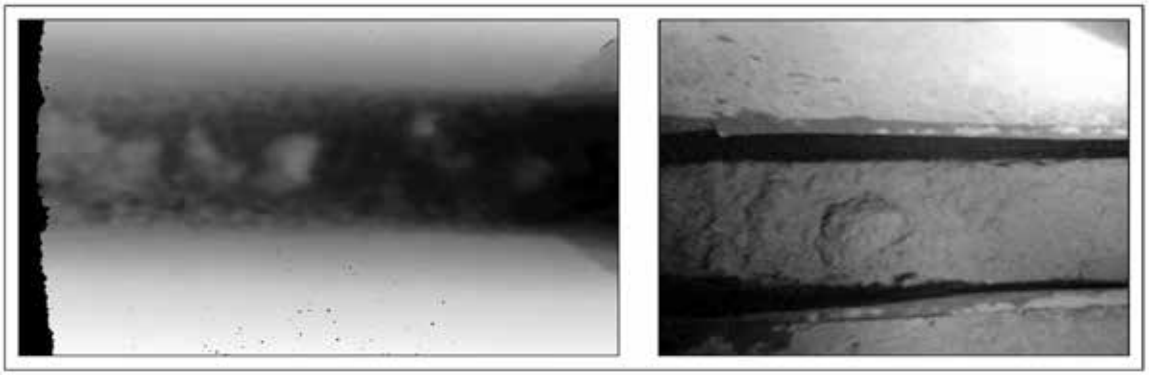
Digital Geologist 2.0 (DG 2.0) was assembled from commercial off-the-shelf technologies to be a data-generation and data-logging system configured to operate as a real-time "digital sieve." The underlying technology was based on hardware and software developed by Intel and sold as Realsense D435i. DG 2.0 was based on a class 1 laser projector and two global shutter-infrared imagers in a stereo solution offering high-quality, millimeter-accurate depth measurements for a variety of applications. The DG 2.0 also had a single high-definition imager for validation. These images could be used by personnel to validate output data produced by the Realsense imagers.

The Realsense D435i imagers scan an object and transform it into voxels. Voxel is analgous to a pixel. While a pixel represents a picture element, a voxel represents a volume element, a value on a grid in three-dimensional space.

The height of each voxel against the baseline depth or height map yields a column 1 mm by 1 mm. When

FIGURE 4

Image created from voxels at left and a high-definition pixel image at right.



multiplied by height it equals the volume of the column in cubic millimeters (Fig. 3). When filtered by rules and integrated across the image a three-dimensional polygon(s) emerge with volume in cubic millimeter. In Fig. 4, the images are an example taken by the DG 2.0 at RSC7. On the left is a light encoded three-dimensional rasterized image of the high definition (HD) image on the right. The left image is a visual representation of a 3-D point cloud in a 2-D image. The voxels are 1 mm square boxes color coded to a shade of gray that represents elevation; or simply stated, it is a 3-D image presented in a 2-D coded format. The blur in the image is a function of resolution of the voxels 1 mm square.

The Realsense 435i generally operates as a direct measurement system where the geometry of parallax in the stereoscopic imagers generate a distance forming a height map as represented by a point cloud in the form of a light-coded, rasterized image. The right image in Fig. 4 is the visual image typical in conditioned soil/muck.

The imagers were set to scan and capture 100 percent of the materials discharged from the TBM screw auger onto the conveyor belt. Frame rates were set high to ensure that subsequent analysis would be accurate. The images had to be stitched together so that no material was missed or counted multiple times. The images were broken into "slices" that represented a portion of the material as the belt moved across the imager's field of vision. The counting algorithm flagged material that had been measured in previous frames. Rather than erroneously adding the value to the volume total, the overlapping portion of these slices were averaged to limit the effect of any noise in the bulk volume data.

There were three embedded controllers located in the DG 2.0 housing configured for the data collection and logging needs, external communications, web interface, and real-time analysis and reporting. There was also an interface to the TBM programmable logic controllers (PLC) for signaling from the PLC. An analog 4-20 ma signal transmitted belt speed information and a fiber connection for data collection, movement and storage.

Measuring a cobble

The hardware used to assemble the DG 2.0 can be bought by anyone. The key technologies developed by ClaroVia are the patented algorithms used to reliably sift through the massive amounts of data generated by the stereoscopic sensors. The sensors produced numerical data that was input into a huge matrix and manipulated by algorithms after the data was uploaded from the jobsite to CVH's offices. The algorithms accounted for noise in the data, scanned the belt and located and classified the cobbles by size. During post-processing, the DG 2.0 was able to take raw imaging data and rerun the data with different filters to classify the rock in different ways. The operation of the DG 2.0 is described below in nontechnical terms.

One of the challenges was the presence of conditioned ground (Fig. 5) defined as ground to which a soil conditioner has been added during the TBM excavation process to produce a more plastic mass of material. The ground conditioner was made of water, foaming agent and air. The conditioned ground was opaque, and the instruments selected were not configured to image below the surface. Any cobble or large gravel masked by the conditioner was not counted.

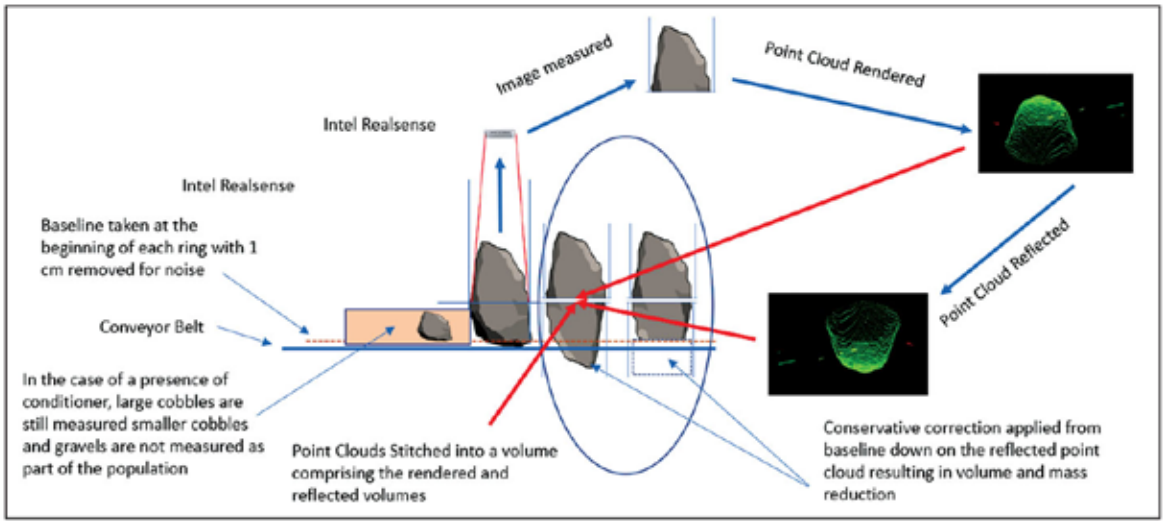
Prior to starting a TBM advance cycle, the empty

FIGURE 5

Conditioned ground with cobbles whizzing by on the TBM conveyor belt.

FIGURE 6

Cobble volume determination by the REFLECTION method.



running belt was scanned to determine belt position relative to the stereo scanner resulting in a baseline measurement of +1 mm. The conveyor surface was assumed in later calculations to be 10 mm (0.4 in.) above the measured surface to account for any bounce in the running belt. The bounce was determined to be nearly zero, but the 10 mm (0.4 in.) cutoff was kept as an added measure of conservatism and became the baseline in the calculations.

When a cobble passed under the DG 2.0, the profile of the muck was determined by direct measurement and differenced from the baseline taken at the start of the advance. The minimum threshold for a 76 mm (3-in.) cobble was set at 78 mm (3.07 in). The DG 2.0 can be configured to make volumetric determinations based on one of three configurations:

- Cylindrical.
- Spherical.
- Reflection.

DG 2.0 was configured to implement the most conservative configuration, which is the reflection method shown in Fig. 6. Measurements made above the muck are reflected and inverted. When the baseline is subtracted, any material projecting below the baseline is eliminated. Any part of the cobble below the conditioned muck outside the reflected volume did not contribute to the volume determination.

If there was no muck masking the cobble, the reflection line was made at the last part of the cobble visible to the scanner. Again, the cobble 3D-image was inverted about the reflection line and the part projecting below the baseline was cut off. Cobbles tended to lay with the widest, heaviest part of the cobble on the conveyor belt surface and the reflection method would not count this part of the cobble if it was below the muck line.

Commissioning the digital geologist from rings 1450 to 1573

The DG 2.0 was mobilized, calibrated and tested from rings 1,450 to 1,573. During the commissioning period between rings 1,450 and 1,573, an extensive validation exercise was done using known-object dimensions on the belt.

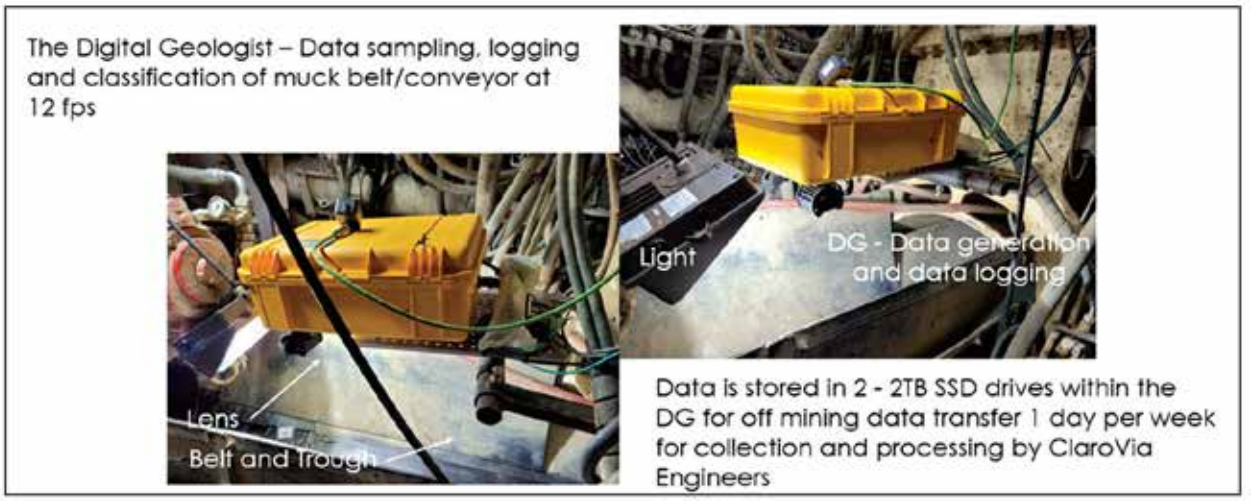
The DG 2.0 was mounted directly over the conveyor belt about 60 cm (2 ft) behind the TBM screw auger discharge and used multiple three-dimensional direct measurement systems for volumetric determination (Fig. 7). The direct measurements were taken at 12 frames per second to classify cobbles over 76 mm (3 in.) and large gravel more than 38 mm (1.5 in.). The scanned cobble volume was calculated. A density derived from lab data of cobble samples was then applied to the cobbles to compute a weight.

Since the cobbles and boulders were baselined in the GBR as the percent weight of excavated material, the total weight of muck removed from the tunnel also had to be known. The contract specifications required that FKCI keep and maintain a mass balance sheet that tracked the weight of material excavated for each ring. FKCI tracked the weight of all the tunnel muck discharged from the beginning of tunneling activities. The total weight from each 1.4 m (4.5 ft) advance of the TBM was measured by a remote reading below-the-hook load cell on the shaft crane that measured the weight of every muck car. Adjustments were made for the amounts of water, bentonite and soil conditioner added to arrive at weight for each tunnel liner ring advance.

A human technician using images from the high-definition camera spot checked the objects analyzed by the DG 2.0. After reducing and analyzing the first 50-ring excavation cycles, we identified challenges that impaired some of the data. The challenges identified and resolved included:

FIGURE 7

Digital Geologist 2.0 mounted over conveyor directly behind screw auger discharge.



Belt speed. The reported belt speed from the TBM was not its actual speed. The reported speed was actually the belt set by the TBM PLC and sent to the conveyor belt drive. As the belt loaded and moved materials, the belt speed shifted up to 0.5 m/sec, which resulted in either an over-sampling or under-sampling. This issue was solved by analyzing the data to determine belt speed to ensure sliced and stitched belt images represent a 100 percent sampling without over- or under-sampling.

Image data corruption. Relying on miners to clean the imager lenses between rings was only a partial solution. The DG 2.0 was located close to the screw discharge and mud would often splash on the lenses during TBM advance. Specks of mud on the imager lenses would result in false readings of depth on some voxels gathered by the 3-D imagers. Post processing could average the adjoined voxels to detect any unexpected jumps in volume for adjoining voxels, if these were detected, the voxel was flagged, and these anomalies were eliminated and corrected. Sometimes the imager lenses were covered by too much mud to render a usable image. Although enough data was collected to meet statistical requirements, the mud problem persisted to the end of the project.

Low voltage supply. Blocks of data missing, or incomplete data, were correlated to error logs generated by the image processor. These errors were identified as "under volt and over temperature" shutdowns and each event required a 15-minute auto restart. Some low-voltage events were correlated to welding repairs done on the TBM during a maintenance period. An uninterrupted power supply was installed ahead of the DG 2.0 to eliminate damage from low-voltage events.

Raw data. The data collected and transferred was a constant and time-consuming element of the post processing. Two network-attached servers were installed; one located on site and one at CVH. Ultimately, the stored raw data was in the range of 20 terabytes of data for 1,028 rings or 19 gigabytes of data per ring. This data was transferred to the CVH lab for analysis. The data included image data, raw-depth images, baseline belt data, differenced images from the baseline, high-definition images and meta data.

Constrained processor resources. Up to 36 hours of processing on a desktop computer were required to analyze all the stereoscopic images for a single TBM liner ring advance of 1.4 m (4.5 ft) due to the immensity and complexity of the image data. Even though the results of the analyses were good, running multiple analyses to ensure repeatability took another one to two weeks per ring cycle per run. A dedicated data processing machine was built that analyzed and reduced the data processing to three to four hours for each TBM ring advance.

Digital geologist in full operation

The DG 2.0 was in full operation for the last 1,412 m (4,633 ft) conversion of the tunnel from Stations 58+04 to 11+71 (ring 1,574 to 2,602). Station 11+71 and ring 2,602 are at the terminal end of the tunnel. Following the data collection phase, post-processing analysis was conducted according to ANSI/ASQ methods Z1.4 and Z1.9. (Please note that in this discussion the words "strata" and "stratum" are used in a statistical sense, not a geological one.) Initially, a random sampling methodology was planned. The muck from all the 1,028 TBM ring advances would be scanned, and a random sampling would be used for analysis. Statistical theory says that with a population of 1,028 rings, 379 samples were required to have a confidence interval of +4 percent. Computer-image processing was a slow and expensive process so not all viable data was processed.

However, the data collection was impacted by several

FIGURE 8

Layer of cobbles and coarse gravel in the tunnel face.

events that rendered a portion of the data unusable. Because the DG 2.0 was close to the discharge of the screw auger, mud would occasionally splash on the digital imager lenses that were not immediately cleaned. There was a low-voltage event that caused the DG 2.0 to shut down. Sometimes the number of images taken was insufficient.

CVH was able to objectively shift analytical methods from random sampling across the population to a stratified random sampling. This was done by applying objective filtering to form the data strata. The strata were collectively and mutually exclusive in that every element in the population was assigned to one and only one strata. The data from these 1,028 rings was divided into five strata:

Strata 1 - Unusable data 311 rings or 30.25 percent
a. 269 ring data with obstructed measurements (e.g., mud on lens).
b. 42 ring data with low voltage – over temperature shutdowns.
Strata 2 - Insufficient data – 138 rings or 13.4 percent with less than 10,000 images per ring available to process.
Strata 3, 4, 5 - Viable data – 579 rings or 56.3 percent random samples including:
Strata 3 - Viable data with < 7 percent high-density materials by weight.
Strata 4 - Viable data with > 7 percent high-density materials by weight.
Strata 5 - Viable data with >> 7 percent high-density materials by weight.

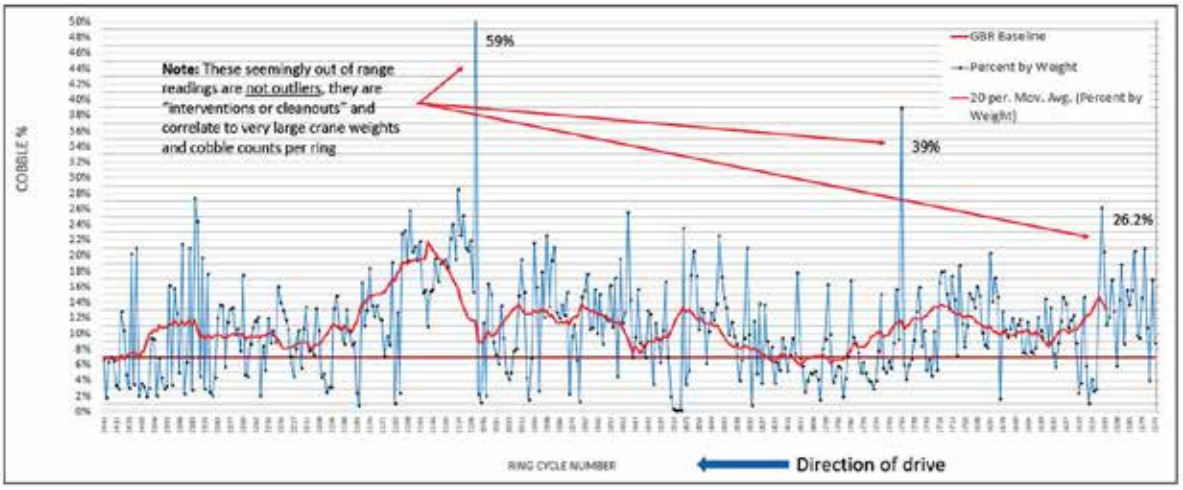
The data processed for 416 rings (out of 579 viable rings) represented a sample size of 40.3 percent. Data processing was stopped after 416 rings as the criterium for a 4 percent confidence factor was met. The remaining 165 rings could still be analyzed if necessary. The 416 ring datasets were selected at random and no cherry picking of data was done.

Data analysis results

Upon completion of the analysis, the results determined that the population of data yielded an arithmetic mean of cobbles greater than 78 mm (3.07 in) by weight of the excavated materials calculated to be 11 percent, with a confidence of 95 percent, and a confidence interval of 3.71 percent. What this means is that any ring not analyzed within the total population of 1,028 rings will have a 95 percent confidence that cobble volumes will be at the arithmetic mean of 11 percent with a confidence interval of 3.71 percent around the arithmetic

FIGURE 9

Percentage of cobbles by weight sorted by liner ring number.



mean (or +- 1.86 percent margin of error (which is half the interval). For example, if a typical ring had a dry soil weight of 32,658 kg (72,000 lbs), we would have a 95 percent confidence the weight of cobbles in excess of 78 mm (3.07 in.) would weigh 32,658 kg x 0.11 = 3,592 kg + 1.86 percent (or + 67 kg). This yields an uncertainty of 133 kg represented as a range of 3,525 to 3,630 kg or 10.8 percent to 11.2 percent. The populations represented by these numbers are in the strata of 3, 4 and 5. Strata 5 included the sample population of interventions and clean outs but also some very heavy rings during normal TBM advance.

In addition to cobble volumes greater than 76 mm (3 in.), the DG 2.0 was able to quantify large gravel visible above the conditioner, or in the absence of conditioner. The mean value of the large gravel 38 to 76 mm (1½ to 3 in) by weight of the excavated materials was 2 percent of the excavated material detected at the same 95 percent confidence and confidence interval of 3.71 percent around the mean. Only large gravel visible on the conveyor belt was counted. The majority of gravels in this size range were probably not visible and not counted as a result of being buried in the muck.

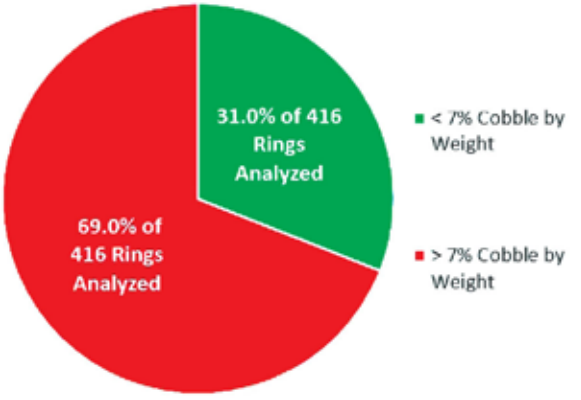
Figure 9 shows the calculated percentages of cobble for individual ring cycles. Only the 416 valid data points are shown. The data is shown with the TBM drive from right to left. The heavy dark line is the 20-ring moving average. The horizontal line represents the cobbles and boulders 7 percent by weight guideline from the GBR. Within the analyzed datasets of the 1028 ring cycles, there was observed a low of 0.2 percent and a high of 52 percent weight of cobble to weight of the mined materials within the ring cycle. Outliers and all suspect values were evaluated. The three large peaks identified above are real and coincide with interventions and they also coincide with extreme muck-car ring weights. The graph clearly shows the high variability of the cobble content.

The arithmetic mean of 11 percent does not adequately describe the ground. As was shown in CVH's report, there was a wide range of cobble percentages in the data with a maximum of 52 percent and a minimum of 0.2 percent. This information would not have been available but for the DG 2.0.

Because the DG 2.0 measured every visible cobble in the 416 ring dataset, we can also classify the cobbles by size. Figure 11 shows the percent of cobbles by excavated weight sorted into categories based on the frequency of detection by ring. For example,

FIGURE 10

Percentage of cobbles by weight exceeding GBR 7 percent.



the green bar on the far left says that there were six sample rings where the cobble weight was between one and three percent of the excavated weight.

The green bars on left show there were 129 sample rings where the cobbles were seven percent or less of the excavated materials by weight. The red bars show 287 rings with cobble weight greater than seven percent. The largest occurrences shown were for 209 rings where the cobbles were between eight and 16 percent by weight. A significant number, 70 rings or 17 percent of the total were in the 17 to 25 percent range.

Figure 12 shows the volumes of the large gravel and cobbles sorted by size counted during the excavation of 416 rings. The large gravel is not included in the 557 m^3 (19,242 cf) total shown in the table. The size distribution of the cobbles is the normal distribution one would expect to find in an active stream bed. The quantity of

FIGURE 11

Frequency of cobbles sorted by percent of cobbles by weight of excavated ground.

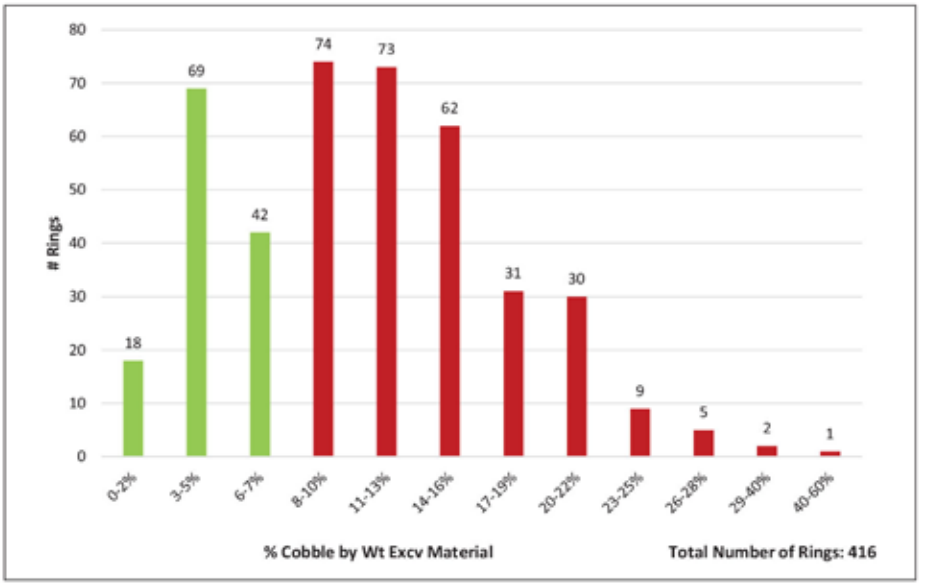
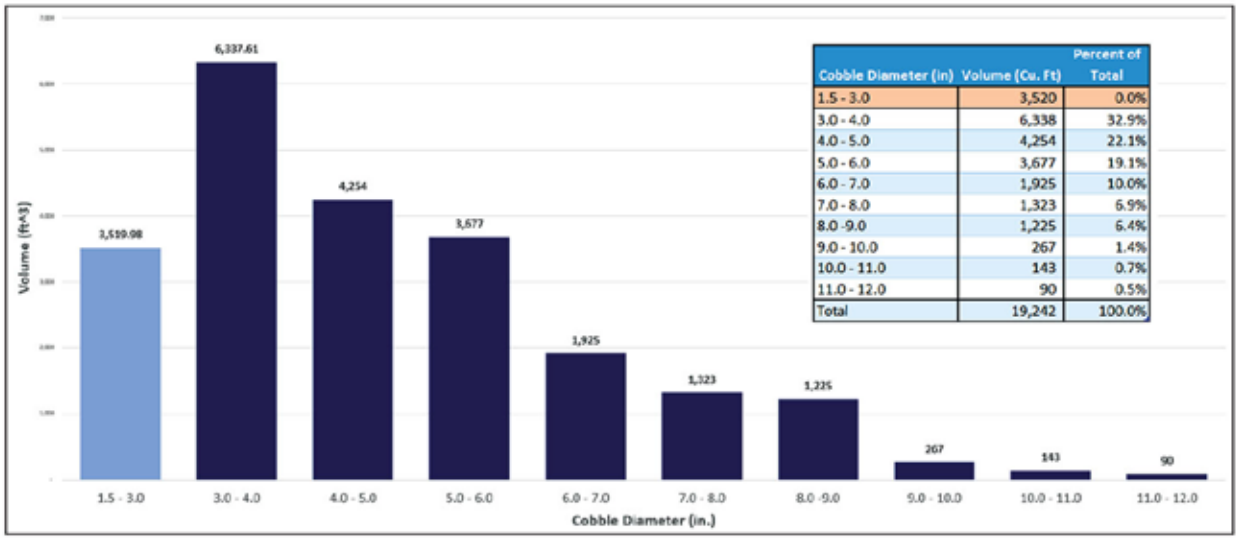


FIGURE 12

Large gravel and cobbles by volume for 416 rings sampled.



Cobble Diameter (in)	Volume (Cu. Ft)	Percent of Total
1.5 - 3.0	3,520	0.0%
3.0 - 4.0	6,338	32.9%
4.0 - 5.0	4,254	22.1%
5.0 - 6.0	3,677	19.1%
6.0 - 7.0	1,925	10.0%
7.0 - 8.0	1,323	6.9%
8.0 -9.0	1,225	6.4%
9.0 - 10.0	267	1.4%
10.0 - 11.0	143	0.7%
11.0 - 12.0	90	0.5%
Total	19,242	100.0%

large gravel is low because the DG 2.0 can only count the visible large gravel. Most of the gravel is hidden under the conditioned muck. The amount of gravel exceeds what was indicated by the contract geotechnical documents. If we make a projection for the large gravel that follows the charted size distribution for the cobbles, the amount of large gravel would be about 2.5 times what is shown or about 5 percent by weight of excavated materials.

The dimensional accuracy of the measurements was + 1 mm and the reflection method of volume assessment was conservative. Any part of a cobble from 0 to 10 mm above the conveyor belt was not included in the volume calculation. Larger dimensions of the cobbles hidden by the muck were not counted. This may explain why the DG 2.0 averaged 11 percent cobbles by weight of excavated material while the geological mapping averaged 22 percent over the span of 10 face mappings. Another explanation is that there were more cobbles in the area assessed by face mapping.

The DG 2.0 also counted large amounts of gravel in the 38 to 76 mm (1.5 to 3 in.) range although only the visible gravel was counted. The first 10 mm (0.4 in.) above the belt was excluded, therefore the counts for gravel are very conservative.

No reliable correlation between cobble count and muck-car weight

Since we weighed all the muck cars with good accuracy, we wondered if there was a correlation between muck-car weight and cobble count. We did not find a reliable correlation. Variations in the surrounding soils matrix density overshadowed the cobble density. Actual soil densities at the TBM reception shaft varied from 1,842 to 2,210 kg/m^3 (115 to 138 pcf) with an overall density of 1,986 kg/m^3 (124 pcf). Consider the chart in Fig. 13 that shows theoretical bulk densities for the excavated soil as the percentage of cobbles by weight is varied. For the calculations, an initial density of 2,210, 1,986 and 1,602 kg/m^3 (138, 124, and 100 pcf) were used. For reference, compact dense-clean sand has a density of about 1,602 kg/m^3 (100 pcf) and wet concrete typically has a density of 2,322 kg/m^3 (145 pcf).

The graph shows that bulk-soil densities did not vary much with cobbles variations that would clearly constitute as DSC if they occurred. Using the average density of 1,986 kg/m^3 (124 pcf), a 10 percent variation in cobble count by weight only results in a 48 kg/m^3 (3 pcf) change in overall bulk density. Even a lighter soil such as clean sand shows only a 64 kg/m^3 (4 pcf) change with a 10 percent change in cobble count.

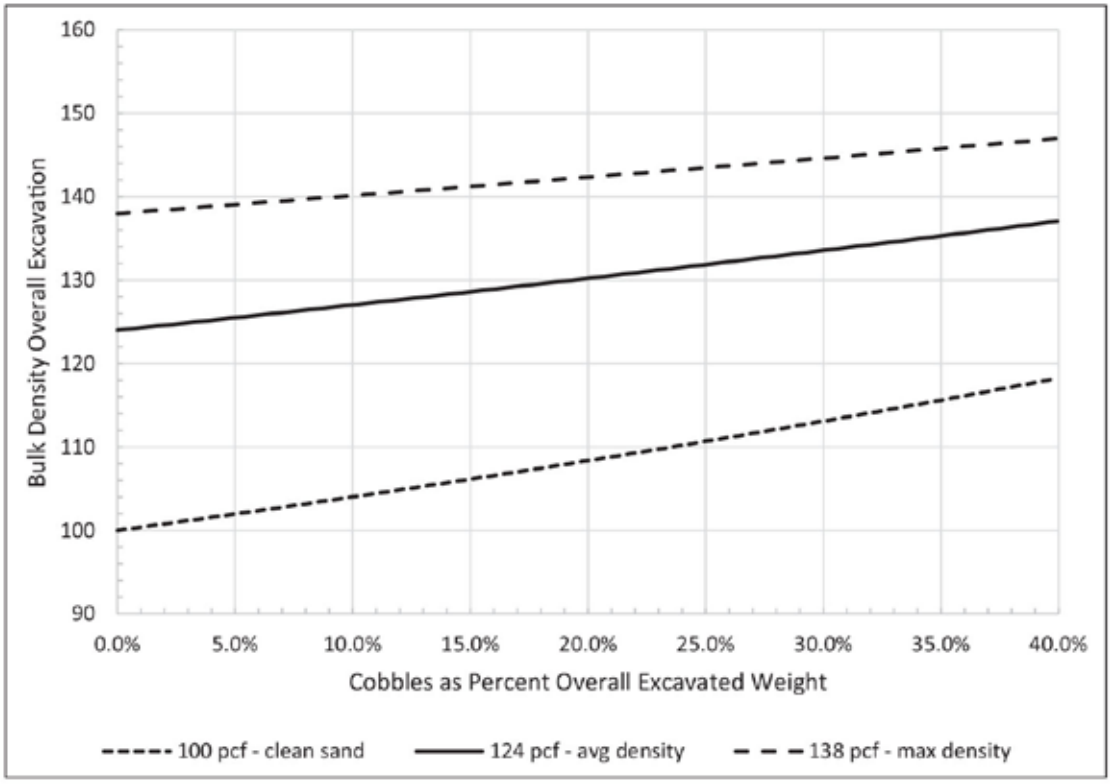
Face mappings showed that soil matrix was always in different layers, never a completely uniform face. The face often showed sand layers interlaced with extremely dense layers of cobbles, large gravel and sand. The point is that variability in geology resulted in swings in bulk density that were not necessarily related to cobble density. The cobbles must be tracked by screening, face mapping or electronic means such as the digital geologist.

Conclusion

Looking ahead to the future FKCI and CVH intend to use this technology on future EPB projects with improved technology and gain industry acceptance for its use. The RSC7 tunnel was an ideal candidate for counting cobbles using the DG 2.0 optical technology. The ground was largely absent of plastic fines that would produce a tunnel muck that could blanket the cobbles and make them uncountable to optical technology. Clay soil was nearly nonexistent, so the DG 2.0 didn't have to worry about distinguishing cobbles from clay balls. For the most part, the cobbles stood out clearly on the conveyor belt. For the next project CVH is looking into adding a millimeter wavelength to assist in measuring cobbles obscured by the presence of soil conditioners.

FIGURE 13

Percent cobbles by weight versus bulk density of excavated ground.



On the next project, the authors recomment a rigorous test validation program be conducted early in the drive in order to verify the precentage of cobbles digitally measured versuse a physical field sieve analysis of the muck. This program will also establish how conservative the reflection method used to establish volumes of cobbles is compared to the actual cobbles encountered.

Future projects will have all data analysis and reduction done in real-time onboard the digital geologist eliminating the need for post-processing and providing more immediate feedback to site management. The digital geologist should be introduced to the owner and construction manager up front with protocols to establish acceptance early in the project.

GBRs would do better to specify the cobbles in terms of volume rather than as a percentage of the excavated weight. This would be a more direct measurement that would eliminate the step of calculating the weight of all the material excavated from the material. In ground known to have cobbles and boulders, Hunt (2017) recommends the use of boulder volume ratio methods that screen larger samples than possible with conventional borings to determine cobble and boulder volumes. As stated by Hunt (2004), a focused, boulder-sensitive subsurface investigation and proper baselining are essential information to communicate risks to the contractor and allow better tunnel risk mitigation.

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Hitchcock, C.S., and Wills, C.J., 2000, Quaternary Geology of the San Fernando Valley, Los Angeles County, California, Map Sheet MS-050, California Division of Mines and Geology.

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Hunt S.W., 2004. Risk Management for Microtunneled Sewers, Proceedings of Collection Systems 2004: Innovative Approaches to Collection Systems Management, Water and Environment Federation, Alexandria, VA, Paper 9D, F2004.6, 15p.

TUNNEL NAME	OWNER	LOCATION	STATE	BID YEAR	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	STATUS
Potomac River CSO Tunnel	DC Water and Sewer Authority	Washington	DC	2023	CSO	24,000	18	Awarded - under final design
Minneapolis Central City Parallel Tunnel	City of Minneapolis	Minneapolis	MN	2023	CSO	4,200	10-19	Final planning
I-70 Floyd Hill Highway Tunnel	Colorado Dept. of Transportation	Denver	CO	2023	Highway	15,840	60 x 25	Under design
Alameda Street Wet Weather Conveyance	SFPUC	San Francisco	CA	2023	CSO	4,000	12	Under design
The Portal Downtown Extension (DTX)	TJPA	San Francisco	CA	2023	Transit	3,400	TBD	SOQ's submitted; RFP mid 2024
CA High Speed Rail (Northern Section)	CA High Speed Rail Authority	Fresno	CA	2024	Transit	TBD	TBD	Design 1Q 2024
CA High Speed Rail (Southern Section)	CA High Speed Rail Authority	Bakersfield	CA	2024	Transit	TBD	TBD	Design 1Q 2024
West Santa Ana Line	LACMTA	Los Angeles	CA	2023	Transit	TBD	20	Under design
Ontario Airport Tunnel	San Bernardino Co. Trans. Authority	San Bernardino	CA	2023	Transit	22,000	24	Under procurement
Gateway Tunnel Project	Gateway Development Commission	Newark/ NYC	NJ/NY	2023	Rail	2 x 14,600	25.17	Under final design and construction
Gateway Hudson River Ground Stabilization	Gateway Development Commission	Newark/NYC	NJ/NY	2023	N/A	1,200	110	Awarded - under final design
Gateway Palisades Tunnel	Gateway Development Commission	Newark	NJ	2024	Rail	2 x 5,100	25.17	Under procurement
Gateway Manhattan Tunnel	Gateway Development Commission	New York	NY	2024	Rail	2 x 700	varies	Under procurement
Gateway Hudson River Tunnel	Gateway Development Commission	Hoboken/ NYC	NJ/NY	2025	Rail	2 x 7,400	25.17	Under final design
Gateway Systems and Fit Out	Gateway Development Commission	Secaucus to NYC	NJ/NY	2025	Rail	2 x 22,000	varies	Under final design
Gateway NJ Surface Alignment	Gateway Development Commission	Secaucus to North Bergen	NJ	2025	Rail	2 x 7,400	N/A	Under design
Gateway Existing Tunnel Rehabilitation	Gateway Development Commission	Union City/ NYC	NJ/NY	2036	Rail	2 x 13,000	varies	Final design completed
2nd Ave. Phase 2	NYS-MTA	New York	NY	2023	Subway	16,000	20	Bidding mid-2024
2nd Ave Phase 3	NYS-MTA	New York	NY	2024-2029	Transit	89,600	20	Procurement in 2025
Amtrak Fredrick Douglass Tunnel	Amtrak	Baltimore	MD	2023	Rail	40,000	32	Construction contract awarded
Alum Creek Relief Tunnel Phase 1 Phase 2	City of Columbus	Columbus	OH	 2023 2024	Sewer	 30,000 21,000	 18 14	 Under design Under design
Ontario Line North Extenstion	Metro Linx	Toronto	ON	2023	Subway	29,500	20	RFP in 2023
West Vaughn Sewage Servicing Project	York Region	Toronto	ON	2023	Sewer	36,000	10	RFQ shortlist completed
Yonge North Subway Extension	Metro Linx	Toronto	ON	2023	Transit	40,000	20	RFQ Pending
Blue Line Extension	Societe de transport de Montreal	Montreal	QC	2023	Transit	19,000	33	Under design

TUNNEL NAME	OWNER	LOCATION	STATE	BID YEAR	TUNNEL USE	LENGTH (FEET)	WIDTH (FEET)	STATUS
REM-S Project	Societe de transport de Montreal	Montreal	QC	2023	Transit	23,000	33	Under design
Southerly Storage Tunnel	NEORSD	Cleveland	OH	2023	CSO	18,000	23	Under design
DELCORA Wastewater Tunnel	DELCORA	Chester	PA	2023	CSO	45,500	13	Proposals received
Enbridge Line 5 Tunnel	Enbridge	Traverse City	MI	2023	Oil	23,760	12	Proposals received
Mill Creek Trunk Improvements	City of Nashville	Nashville	TN	2023	CSO	13,800	10	Under design
Green Line LRT	City of Calgary	Calgary	AB	2023	Transit	9,000	40	RFP submitted
Nose Hill Project	City of Calgary	Calgary	AB	2023	CSO	10,800	10	Under design
Kensico-Eastview Connection Tunnel	NYC-DEP	New York	NY	2024	Water	11,000	27	Under design
Silver Line Extenstion	Boston Transit Authority	Boston	MA	2023	Transit	8,400	22	Under design
Stanley Park Water Supply Tunnel	City of Vancouver	Vancouver	BC	2023	Water	5,000	15	Bidding
ALCOSAN CSO Ohio River Allegheny River Monongahela River	Allegheny Co. Sanitary Authority	Pittsburgh	PA	 2025 2028 2030	 CSO CSO CSO	 26,000 33,000 28,000	 14 - 18 18 18	 Under design RFQ 2024/25 RFQ 2024/25
Germantown Winghocking Relief	City of Philadelphia Water	Philadelphia	PA	2025	CSO	28,000	20	Under design
Project Connect Subway Program	City of Austin	Austin	TX	2025	Transit	8,500	20	Design delayed
West Seattle to Ballard Extension	Sound Transit	Seattle	WA	2025	Transit	10,500	20	Under design
Northside Interceptor Tunnel	City of Akron	Akron	OH	2023	CSO	6,600	16.5	Bidding
Taylor Massey Tunnel	City of Toronto	Toronto	ON	2025	CSO	20,000	15	Under study
Quebec City - Levis Tunnel	Quebec Trans. Ministry	Quebec	QC	2025	Transit	27,230	60	Under study
Del Mar Bluffs Tunnel	SANDAG	San Diego	CA	2025	Rail	TBD	TBD	Under study
Fraser River Tunnel	BC Ministry of Transportation	Vancouver	BC	2025	Highway	3,000	TBD	RFP expected
Queensway Tunnel	Region of Peel	Toronto	ON	2025	Sewer	18,000	9	RFP Ongoing
Stormwater Control Program	Harris Co. Flood Control District	Houston	TX	2026	CSO	52,800	25-40	Under study
LA Metro Sepulvada Pass Corridor	Los Angeles MTA	Los Angeles	CA	2026	Transit	55,000	TBD	Under design
D2 Subway - 2nd Light Rail Alignment	Dallas Area Rapid Transit	Dallas	TX	2026	Transit	7,230	22	Delayed
Flushing Bay CSO Tunnel	NYC-DEP	New York	NY	2026	CSO	16,500	22	Under study
Cross Harbor Freight Tunnel	PANYNJ	New York	NY	TBD	Rail	25,000	30	Under study
Superconducting Maglev Project -	TNEM/BWRR	Washington	DC	TBD	Rail	146,500	43	Under design

UCA participates in 2024 ASCE Legislative Fly-In

Each spring, the American Society of Civil Engineers (ASCE) conducts its Legislative Fly-In in Washington, D.C., providing member societies such as UCA, the opportunity to connect with Members of Congress or their senior legislative staff to advance policy priorities.

The UCA has taken part in this program for the past five years as an opportunity to promote the value of tunneling and underground construction projects to decision-makers in the nation's capital and will do so again this year.

"We begin by thanking our representatives for their support of infrastructure spending and the major bills that have been passed into law in the past few years," said Bob Goodfellow, Past Chair of UCA and president of Aldea Services Inc. Goodfellow has represented UCA on previous Legislative Fly-Ins and will participate in this year's trip along with Joe Clare, vice president and national practice lead for tunnels and underground construction for Shannon & Wilson.

Goodfellow said that the UCA contingent will focus on building support from legislators for two major tunneling projects; the Seattle Sound transit program from Ballard to West Seattle, WA and the Amtrak Frederick Douglass Tunnel in Baltimore, MD.

"Securing the funding stream for these critical projects is an important topic of discussion," said Goodfellow, who will be armed with support material created by UCA members. "We pass along our Tunnel Watchlist and our Five Myths of Tunneling handouts to the representatives and staff. This again is part of our educational effort highlighting the value of infrastructure and specifically underground infrastructure."

The Tunnel Watchlist was created in 2021 to highlight future tunneling projects that will provide significant benefit to the United States and the communities in which they will be constructed. Many of these projects include tunnels that improve water quality or transportation and these are projects are often in need of funding or additional support.

"Building awareness of the significant benefits to society and the economy of funding infrastructure and building awareness that underground infrastructure is the least invasive and least disruptive form of construction is one of the top goals (of the Legislative Fly-In)," said Goodfellow. "The second objective is to educate policy makers that there is a cost benefit to going underground."

As civil engineers, Goodfellow said that the whims of planning and funding often have a massive impact on infrastructure projects so it is important to advocate for necessary funding.

"It is empowering for all of us to know more about those planning and funding processes. In many ways it is the opposite of our training in logic and mathematics, but this also can be a strength by giving the elected official a forgotten perspective from those of us directly employed and dependent on these projects that they push and pull off the board for other social and monetary reasons," said Goodfellow. ■

Mayers named chief operating officer at Schnabel

Schnabel Engineering has announced the appointment of Chad Mayers, P.E., to chief operating officer (COO), a new role within the engineering firm. Mayers assumes this role after serving as president of one of Schnabel's business units for the past four years. He has been with the firm since 2004.

According to Walt Rabe, chief executive officer of Schnabel, "I can't be more excited that Chad Mayers has assumed the role of chief operating officer. Chad has proven himself in roles of increasing responsibility since beginning his career at Schnabel nearly 20 years ago. His focus on the unity of the entire company has him wired for success in his new role."

While the addition of a COO is a huge step for Schnabel and its operating structure, Mayers has stressed that he is committed to maintaining a culture and environment that support and encourage the firm's staff to continue to thrive. Said Mayers, "In the coming years, I plan to prioritize recruiting, retaining and training Schnabel's most valuable asset, its people, while focusing on accountability, stewardship and cross-functional collaboration. This will ensure that our systems, tools, and organizational structure are best-suited for operational excellence."

Throughout his 20-year career at Schnabel, Mayers' leadership positions have ranged from branch leader of the Sterling, VA and Rockville, MD offices to executive vice president and then president of Schnabel's geoprofessional business unit. He has also led Schnabel's International Pursuit Team, delivering consequential projects throughout the world.

Mayers holds a bachelor of science in civil and environmental engineering from Virginia Tech, and earned his master of engineering in geotechnical engineering from the University of Maryland. He is registered as a professional engineer in Washington, D.C., Virginia, and Maryland, and is a member of the American Society of Civil Engineers (ASCE), American Council of Engineering Companies (ACEC), and Society of American Military Engineers (SAME).

Mayers was named one of ENR Mid-Atlantic's Top Young Professionals in 2020. ■

International tunneling awards are presented

The 9th edition of the ITA Tunnelling and Underground Space Awards took place in Mumbai, India.

Since 2015, the international competition seeks and rewards remarkable achievements in tunneling and underground industry. Organized by the International Tunnelling and Underground Space Association (ITA), the event both showcases the most ambitious underground projects all over the world as well as latest innovations, techniques and methods in tunneling.

Through seven categories, the ITA Tunnelling Awards identifies and rewards major disruptive innovation and groundbreaking projects.

Major Project of the Year (more than €500 million)

EOLE, the Paris East-West Express Rail Link, expands the current E line of the RER (Regional Express Network) by 55 km (34 miles), connecting the existing St. Lazare Station — second busiest station in Europe with more than 450,000 passengers/day, in the heart of Paris — to the western metropolitan region. Operation is set to begin mid-2024, on time for the Paris Olympic Games.

Project of the Year (between €50 million and €500 million)

Comprehensive Project of Shenzhen Binhai Avenue (Headquarters Base Section) Coastal Wide Underground Space — The Binhai Avenue Tunnel, with a total length about 1,560 m (5,100 ft), is laid flat and shallowly buried on the main and auxiliary tracks, with in situ sinking and stacking layout. The south and north auxiliary roads of the subsidence-style tunnel are arranged in staggered layers and the "two-in and two-out" special ramps are set up respectively in combination with the development of the Super Headquarters base to connect the Super Headquarters underground road network system, forming an underground three-level road system of "underground express road + underground ring road + plot garage" to ensure the large-scale traffic demand of the Super Headquarters base and create an efficient underground transportation System.

Project of the Year incl. Renovation (up to €50 million)

Mount Royal Tunnel — Double Arch Replacement & Rehabilitation for the REM Project — A section of the REM goes through the 5-km (3.1-mile) long existing Mount Royal Tunnel which was completed in 1917 and connects the downtown area with the north side of Montreal.

The project addresses the concerns from detailed inspections and strength assessments concluding that the South Section (92 m or 300 ft) was not in an acceptable condition after 100 years of deterioration caused by infiltration of chloride-laden groundwater. Another 290 m (950 ft) length of the tunnel, named North Section, felt to be in an adequate condition to be remedied using observational rehabilitation methods.

Technical Innovation of the Year

Building Blocks in a Foundation Pit — Prefabrication and Assembly Construction Technology for Metro Stations — A new construction method for underground metro stations, using precast concrete structural components and assembling them like "building blocks" on-site in a foundation pit, to quickly assemble into tunnel structures, minimizing on-site construction activities.

Beyond Engineering

Permanent Sprayed Concrete Linings on Mumbai Metro Line 3 Sahar Road crossover cavern — The Sahar Road Crossover Cavern is a stepped-profile cavern on the Mumbai Metro Line 3 project, and comprises six different cross sections, symmetrical about the middle of the cavern.

Product/Equipment Innovation of the Year

Hard Rock Shield + Earth Pressure + Slurry three-mode TBM — The section of Luogang station — Shuixi station of Phase 2, Line 7, Guangzhou Rail Transit is 1,086.5 m (3,564 ft) long in total, with 19.73 m (64.7 ft) buried depth, 600 m (1,970 ft) minimum radius of curve, and 28 percent maximum gradient, with tunnel outer diameter of 6 m and inner diameter of 5.4 m (17.7 ft). The engineering geology in the section is complex and variable. The TBM mainly tunnels through granite residual soil, boulder, upper-soft and lower-hard rocks, and full-section hard rocks, with high strength of rock stratum (up to 140 MPa), and relatively developed boulder (66.7 percent). During the construction, the shield continuously tunnels through important buildings and structures such as the airport high-pressure oil pipeline, tram line 1 and existing operating subway tunnels.

Young Tunneller of the Year

Cláudio Cabral Dias is a Portuguese tunnel engineer currently based in Madrid and working at Ayesa as a principal tunnel engineer. He is 34 years old and has more than 10 years of international tunneling experience, having lived and worked in Portugal, Brazil, the UK and Spain.

In September 2014, he joined CH2M (now Jacobs) as a tunnel design engineer in London and started working on the Ipswich Cable Diversion Works, the National Grid Tunnels, and the Tottenham Court Road London Underground Station Upgrade. In May 2015, he was seconded to Crossrail as a field tunnel engineer for the Fisher Street crossover tunnels and caverns site. He then worked as a CAT 3 reviewer for the Purple Line of Los Angeles Metro.

Lastly, he worked on the detailed design of Hinkley Point C Marine Works as lead 3D modeler and as package manager for cast in situ lining. In May 2018, he was hired by TYPSA as a senior tunnel engineer for the High Speed 2 project, London contracts, to work for a Design JV of TYPSA, ARUP and STRABAG. ■

UCA Teach the Professors program looks to expand

The Teach the Professors program is aimed at providing education and curriculum in the growing field of civil underground engineering to professors/instructors who teach junior-level structural, geotechnical and construction courses. Civil underground involves the design and construction of tunnels, shafts, deep excavations and underground infrastructure. The American Society of Civil Engineers (ASCE) and UCA technical committees have identified the shortage of trained civil engineers to be a major threat to this growing infrastructure sector.

Ten civil engineering professors/instructors will be selected to attend the North American Tunneling Conference in Nashville, TN June 23-26, 2024 to both learn about civil underground and to participate in a curriculum workshop during the conference. Participating professors/instructors will then implement appropriate lessons, homework problems, and/or presentations in a junior level course (introduction to geotechnical engineering, structural engineering, construction engineering) during academic year 2024-25. The curriculum is intended to teach existing topics required in these junior-level subjects using civil underground examples and concepts. No experience in civil underground is needed. A passion for teaching civil engineering undergraduates is required.

Each participating professor/instructor will be paid a $1,500 honorarium for participation in the program plus all travel expenses for the conference. Eligible professors/instructors are those who will teach structural, geotechnical or construction engineering to junior-level civil engineering students during academic year 2024-25. Only applicants teaching at a U.S. institution are eligible. To apply, please gather the following information and submit your application.

- Brief description of why the applicant would like to or should participate.
- A summary of the applicant's teaching experience and teaching approach.
- A summary of the junior-level course the applicant will implement curriculum elements in during the 2024-25 academic year.
- A curriculum vitae.

To apply, visit https://natconference.com/lecturers-program/

Applications are due March 15, 2024. Decisions will be made by March 31. ■

Scholarship application deadline approaching

One of the top priorities of the Underground Construction Association (UCA) is to support the continued success and growth of the tunneling and underground construction fields.

In recent years, the industry has struggled with attracting young engineers to the field. In an effort to educate the prospective engineers the UCA offers a number of scholarships each year including the North American Tunneling (NAT) Conference attendance scholarhip, Cutting Edge Conference attendance scholarship, RETC Conference attendance scholarship and academic scholarships.

The application deadline for the NAT Conference attendance scholarship is April 15.

The scholarship for conference attendance provides selected students with an opportunity to attend where they can experience first-hand the challenges, opportunities and rewards of a career in the field of tunneling and underground construction. The scholarship is sponsored and awarded by the UCA and RETC.

The conference participating scholarship includes:

- Conference registration.
- A one-year student membership to UCA of SME.
- An invitation to the networking event and the scholarship orientation.
- Valuable opportunities to network with industry experts and potential employers.
- Up to $1,000 travel reimbursement to the conference (these funds are intended to cover travel costs associated with the conference and recipients will need to provide an expense account following the conference).

For more information visit: https://ucascholarships.secure-platform.com/a ■

Tunneling & Underground Construction
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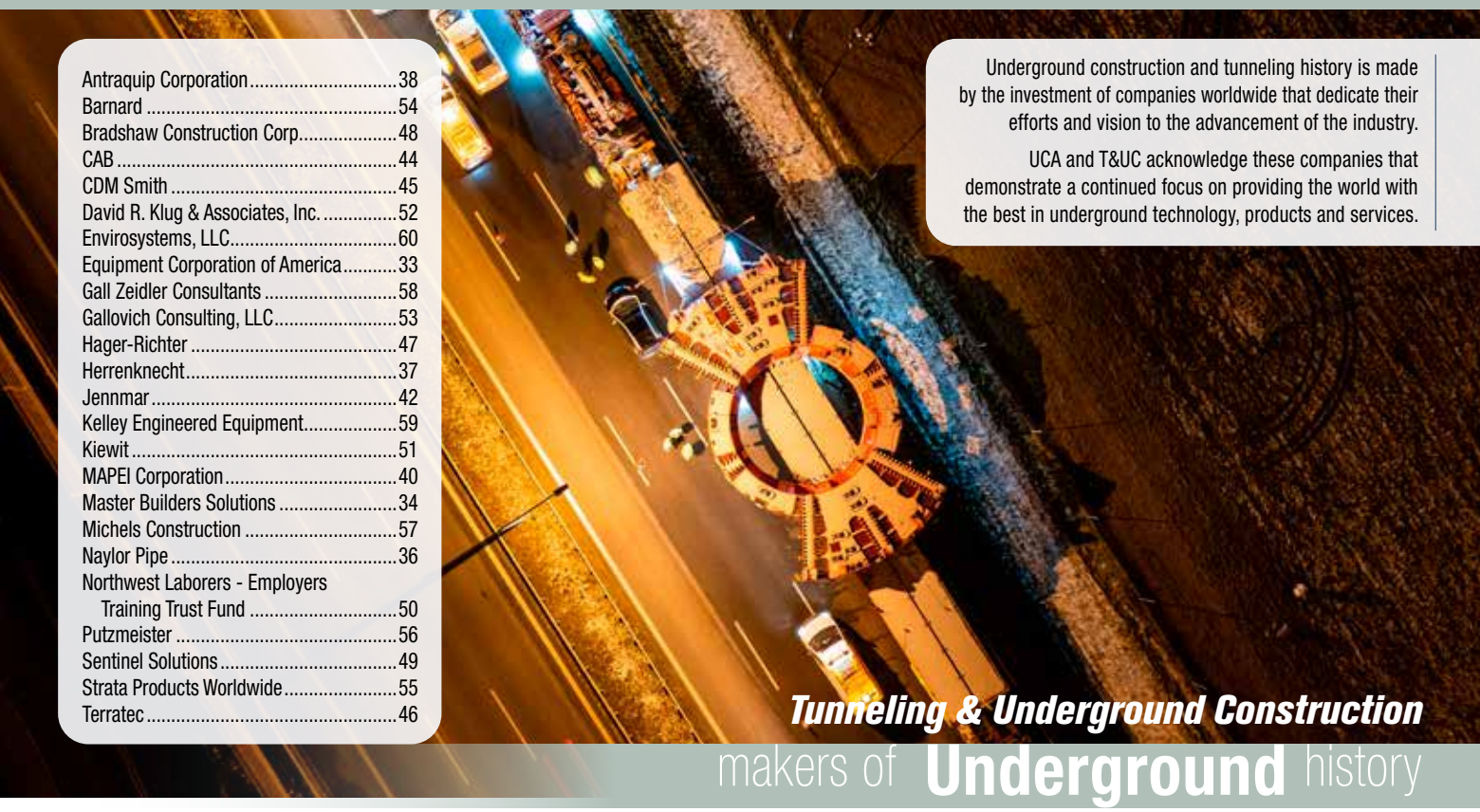
Business Profiles

A special advertiser-sponsored advertorial section

March 2024

Underground construction and tunneling history is made by the investment of companies worldwide that dedicate their efforts and vision to the advancement of the industry.

UCA and T&UC acknowledge these companies that demonstrate a continued focus on providing the world with the best in underground technology, products and services.



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Master Builders Solutions continues to break new ground in addressing the needs of tunneling professionals and the needs of the industry for carbon reduction. Our Underground Construction team brings a total solutions approach to your projects, providing an added resource to help meet your challenges underground. Our solution-based systems enhance the efficiency and performance of the TBM operations and offer performance-based ground support solutions, from novel soil conditioning technologies to innovative anchoring systems; no matter the tunneling method. Throughout the life of your project, our team of specialists work with all relevant stakeholders to help maximize your production rates and to ensure the most successful product and system selection, including sustainability tools and resources, such as EPDs.

The MasterRoc® product line offers a wide range of solutions for TBM excavation in soft ground and hard rock, with high-performance products including soil conditioners, polymers and anti-clay agents. Our full line of greases and sealants help to maximize efficiency for every excavation method and soil type. Sprayed concrete, Rock Bolt Anchoring systems, Injection and water management systems are also widely considered, selected and used for ground support and enhancement in Tunneling and Mining applications. Master Builders Solutions offers customers innovative product solutions and experienced technical resources to tailor cost-effective solutions to specific project needs. These solutions dramatically improve working environments, production, safety and sustainability.

The Master Builders Solutions product line is designed to be a single source for all your underground construction needs. In addition to the wide range of products and systems, our globally connected team assists our customers in selecting the right systems and combinations, allowing for successful operations, coupled with the highest safety standards. Master Builders Solutions, a world leader in reliable products specifically designed to address the requirements of tunneling projects worldwide with a focus on reducing global warming potential (GWP). Utilizing our global expertise, we are steadfastly focused on the needs of tunneling professionals.

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Naylor Spiral Buttweld pipe features two welds along the spiral seam. This creates a pipe structure in which the weld is as strong or stronger than the parent metal.

The Naylor manufacturing process creates a pipe that maintains an accurate diameter throughout its length. The uniformity of the pipe ends speed connection, whether mechanically coupled or welded.

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Every length of Naylor Pipe is inspected and where required hydrostatically tested to applicable ASTM specifications. The pipe is available in lighter weights than other pipe making it possible

to save money, not only on initial cost, but also in transportation, handling and installation. By sizing the diameter of the pipe to the exact requirements, with exact lengths and factory-sized ends, the greatest economies can be realized.

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PIONEERING UNDERGROUND TOGETHER

With the experience of more than 6,200 projects, Herrenknecht is a technology and market leader in the area of mechanized tunnelling technology. Herrenknecht is the only company worldwide to deliver cutting-edge tunnel boring machines for all ground conditions and in all diameters – ranging from 0.10 to 19 meters. The product range includes tailor-made machines for traffic, supply and disposal tunnels, technologies for pipeline installation as well as drilling equipment for vertical and inclined shafts and deep drilling rigs.

The Herrenknecht Group achieved a total output of 1,232 million euros in 2022. The independent family-run business employs around 5,000 people worldwide, including around 200 trainees. With around 70 subsidiaries and associated companies working in related fields in Germany and abroad, Herrenknecht is able to provide a comprehensive range of services close to the project site and the customer, quickly and in a targeted way. Under the umbrella of the Herrenknecht Group, a team of innovative specialists offers integrated tunnelling solutions with project-specific equipment and service packages upon request: separation plants, belt conveyor systems, navigation systems, rolling stock systems as well as segment moulds and even turnkey segment production plants.

As a reliable project partner, Herrenknecht supports its customers with an extensive range of services from the beginning of the project to breakthrough. From the initial project idea through manufacturing, transport, assembly, tunnelling support and spare parts service to disassembly, Herrenknecht accompanies the process at the customer's side. Even personnel solutions for the temporary supplementing of jobsite crews are provided if required. With competent service specialists and more than 45 years of experience in the tunnelling industry, the company regularly supports around 300 jobsites worldwide and offers customized service packages tailored to individual project requirements.

Road, metro, and railway tunnels for efficient traffic network. By the middle of this century, the world´s population is expected to reach nine billion, and two thirds of these people will live in large conurbations. To keep people and goods on the move, the way ahead for new efficient infrastructures is leading underground. With state-of-the-art technologies, efficient infrastructures are created exactly where they are needed, even in cramped and complex jobsite conditions. Herrenknecht technology pushes the boundaries of feasibility and creates new tunnelling standards worldwide. Herrenknecht technology extends existing transport networks and creates new connections in urban and rural areas – under mountains or deep beneath water.

Innovative solutions for underground supply and disposal systems. As the world's population grows the need for underground supply tunnels is also increasing; in emerging and developing countries as well as in modern metropolises. That is why more than 850 Herrenknecht Utility Tunnelling Machines are in operation around the world constructing or laying water and wastewater systems, gas and oil pipelines, as well as conduits for electricity and telecommunications. Here, trenchless tunnelling technology offers a range of advantages compared to conventional construction procedures: transport, business and the environment remain mostly undisturbed when Micromachines, HDD rigs or shaft sinking equipment are being used. Innovations such as Direct Pipe® set new standards in the semi-trenchless installation. The new technology E-Power Pipe® allows the secure and quick installation of underground cable protection pipes with smaller diameters and long advance lengths. Innovative HDD tools simplify pipeline construction operations at key sections. The Herrenknecht product portfolio is completed by a broad range of equipment for the areas of mining (construction of underground infrastructures around raw material deposits) and exploration (oil, gas and geothermal energy).

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Tunnelling Systems

ANTRAQUIP CORPORATION – your reliable, innovative partner

Antraquip Corporation continues to solidify its position as a leading designer, manufacturer and supplier of roadheaders, hydraulic rock cutting attachments, shaft sinkers, specialty tracked machines with a variety of boom options as well as ground support solutions for NATM tunnels.

Within Antraquip's rock cutting attachment product line, Antraquip has introduced diamond and carbide saw attachments for excavators ranging from 1 to 60 tons.Additionally, Antraquip has designed and manufactures the world's most powerful rock cutting attachment with 400 kW+ cutting power for excavators in the 80+ ton weight class. By continuing to invest heavily into research and development Antraquip strives to be able to cut hard rock which has previously not been possible with mechanized excavation methods.

As to roadheaders, Antraquip offers not only standard roadheaders in the 12 – 85 t on class but is proud to offer project oriented engineering solutions whenever requested and necessary. Some of the recent projects have included AQM roadheaders equipped with customized drilling attachments, fully automated remote control systems and automated guidance systems.

Within its ground control program, Antraquip specializes in any support product needed for NATM as well as drill and blast tunnels like lattice girders, steel ribs, specialized rock bolts, spiles, wire mesh and arch canopy systems (barrel vault system or arch pipe system).

In addition to offering project consultations, innovative cutting and support solutions, Antraquip recognizes the importance of after sales service. This commitment to offering the best service and technical support is carried out by highly proficient and experienced service engineers and technicians, all reinforced with large spare part inventories at hand. Innovation, reliability and experience offered by Antraquip makes them a reliable partner for any tunneling project.

Antraquip's main goal is: SAFETY, SAFETY and again SAFETY! Antraquip continues to strive to offer innovative products to make any job safer, faster and increase the bottom line for any contractor and owner.

Antraquip is well represented all over the world, but takes pride in paying detailed attention to any local tunneling challenge small or large.

IN THE FUTURE, THE WORLD WILL NEED MORE AND MORE TUNNELS – AND ANTRAQUIP INTENDS TO BE AN IMPORTANT, RELIABLE PARTNER FOR ANY UNDERGROUND PROJECT!

AQ6 Hydraulic Cutting Attachment

AQC180 on CAT336

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MAPEI Corporation

MAPEI's Underground Technology Team (UTT) provides the construction market with a range of products dedicated to underground construction work. MAPEI's UTT group and the products it represents were created to meet the expectations of these challenging environments. From the project specification to the admixtures for shotcrete and concrete to the final protective coatings, MAPEI's UTT group and technology are there "for the whole job," said Cristina Onate, PhD, UTT Business Development Manager — Tunneling.

The UTT group is a successful division of MAPEI Group, which has provided proven construction system solutions for more than 80 years. Established in 1937, MAPEI Group is a global corporation, based in Milan, Italy, and with 91 subsidiaries that include 84 plants in 35 nations. MAPEI is the world-leading manufacturer of mortars, grouts and adhesives, as well as complementary products for installing floor and wall coverings. MAPEI manufactures chemical products for building, including waterproofing products, admixtures for concrete and repair products, and decorative and protective exterior coatings — as well as the UTT product line.

MAPEI's UTT products were used to help a tunnel boring machine dig the Anacostia River Tunnel, which extends for 2.37 miles from Robert F. Kennedy Stadium in northeast Washington, D.C., to Poplar Point in southeast D.C.

"The UTT group started in earnest in the U.S. in 2015," stated James Pinkley, Country Manager UTT – North America. "But the business has grown substantially since then." In the underground industry, speed is essential – not only of the products themselves, but also of the evolution of technology. MAPEI reinvests a considerable percentage of its annual profits back into research and development to maintain a leading technological advantage. MAPEI's commitment to R&D ensures that the UTT line comprises the most innovative and technologically advanced products available. In addition to the latest in cutting-edge products, the UTT team is trained in their use, with decades of experience in the underground marketplace.

The UTT product line is divided into six categories: Mechanized Tunneling; Injections for Heavy Civil and Mining Applications; Waterproofing & Water Membranes; Shotcrete Products; Renovation, maintenance and repair; and Coatings for underground construction. No matter the division or the product line, MAPEI is known for quality products and for providing system solutions. As Pinkley stated, "The distinguishing point for UTT is our field support, and our applied technology in the field. Simply put, we don't just sell a product, but rather we go into the field and help our customers use our products – on their jobsite, with their conditions, personnel and equipment. MAPEI UTT services a project from the very beginning to the very end like no one else in the industry does," he said. "UTT also has the agility to adjust to the customers' needs when necessary per the demands of changing geological settings"

For more information, contact MAPEI's UTT group at www.utt.mapei.com.

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Underground works have unique characteristics that can be different in every project. This is why the MAPEI UTT team stands side by side with the professionals in the tunneling and mining industries, offering not only quality and environmentally friendly products, but also consistent technical services. **For every product, there's a team at your service.**

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We are a diversified manufacturer and services provider for above and below ground infrastructure that sets standards in terms of quality and safety for our stakeholders. Our mission is total customer support and satisfaction.

Our portfolio of brands is rebuilding America's infrastructure. We understand the ever-changing and demanding conditions above and below ground. That's why we've built the richest portfolio of diverse and complementary brands. From engineering to resin manufacturing, rolled-steel and drill-steel manufacturing, custom steel fabrication, precision wear parts, tools and bits, chemical roof support and sealing products, staffing solutions, transportation, and more - we ensure the customer has support at every stage of their projects. Visit our diverse portfolio of brands at www.jennmar.com.

JENNMAR continues to grow, but our focus will always be on the customer. This commitment to our clients is exemplified through the recent acquisition of DSI Tunneling in Louisville, KY. DSI Tunneling, a long-time competitor with a rich history in providing mining and tunneling products, has now been rebranded as JENNMAR Specialty of Louisville. This marks a significant expansion in our offerings to the civil and tunneling markets across the US and Canada.

This strategic acquisition follows a century-long legacy for the Louisville Operation in the manufacturing and supply of mining and tunneling support products. This operation expands our footprint and manufacturing capacity to support the tunneling industry across North America and beyond. DSI Tunneling brings not just an additional operational facility but also a wealth of industry expertise, technical sales staff, and structural and geotechnical engineers.

Our commitment remains strong to our customers and is guided by three words: SAFETY, SERVICE, and INNOVATION. It's who we are.

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JENNMAR has been the innovative leader in ground control for the mining industry for more than forty years. Over the past decade, our growth has led us to structural support in tunneling and civil construction projects, implementing the same vigor and detailed processes. Because we understand the ever changing and demanding conditions above and below ground we have built the richest portfolio of diverse and complementary brands.

JENNMAR sets the bar in every industry we serve and as we continue to grow, our focus will always be on the customer. Our products are made in the U.S.A. and backed by experienced engineers and technicians who are with you every step of the way, from initial consultation to qualified instruction and on-going technical support. We support and are dedicated to rebuilding infrastructure worldwide.

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CDM Smith is a leader in underground space and tunnel engineering. Working collaboratively with our clients, we employ our extensive global tunnel design and construction experience to develop holistic and optimal solutions for a wide range of projects.

Tunneling Expertise

With our experience encompassing soft ground, mixed face, and rock tunnels and excavations, CDM Smith offers a unique perspective and skillset that addresses the specific needs of each project. Our capabilities are comprehensive and include:

- Tunnel engineering
- Geotechnical engineering
- Geotechnical data & baseline reports
- Lining & structural engineering
- Numerical analysis
- Ground improvement & ground freezing design
- Deep excavations & ground support design
- Groundwater modelling & control
- Soil and rock testing

To support our clients, we offer comprehensive consulting, engineering, and construction support services.

Market Sector Experience

Tunneling and ground engineering is unique – it crosses market sector boundaries. CDM Smith's global tunneling assignments are executed within all market sectors, including:

- Transportation
- Environment
- Water/wastewater
- Mining

Award-Winning Projects

UCA Project of the Year Award (2022), projects between $50 to $500M, Bergen Point Southwest Outfall Replacement

MEED Project Award (2020), International Project of the Year, Ismaïlia Tunnels under Suez Canal

ACEC Engineering Excellence Award (2018), New York Harbor Water Siphon

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Terratec

Incorporated in 1990, TERRATEC is a world renowned designer & manufacturer of Tunnel Boring Machines, encompassing all ground conditions and diameters – ranging from 0.60 to over 16 metres – as well as TBM back-up equipment, Raise Boring Machines and other custom-engineered products for the tunnelling and mining industries. TERRATEC's success is based on the experience and excellence of its global engineering team. TERRATEC is also fully managed by engineers enabling quick and efficient solutions that meet customer expectations.

TERRATEC products are well-known in the industry as Robust, Durable and Safe, basic principles that must prevail in the design of any equipment made to work in the extreme conditions encountered underground. As a provider of Total Tunnelling Solutions, TERRATEC's scope of work extends to custom engineering, as well as the operation and maintenance of tunnel boring equipment and the supply of ancillary equipment.

TERRATEC's capacity to provide a wide range of services means that it is not only an equipment supplier but a qualified and experienced partner in the execution of tunnelling works.

As a result, it is becoming more and more common for TERRATEC to supply a Total Tunnelling Solution package consisting of the TBM/s, other main equipment in the tunnel (Trains, Conveyors, Segment Moulds and Ventilation), spares and consumables for the equipment and a team of TERRATEC field personnel who can assist in the operation and maintenance of the supplied equipment throughout the duration of the project.

TERRATEC offers full range of equipment from pipe jacking machine to open TBM, soft ground to very hard rock machine. TERRATEC's continuing success on global projects is a result of tailor-made robust TBM design, prompt onsite assistance, readily available stock of TBM spares and highly-skilled specialised TBM support throughout tunnelling operations.

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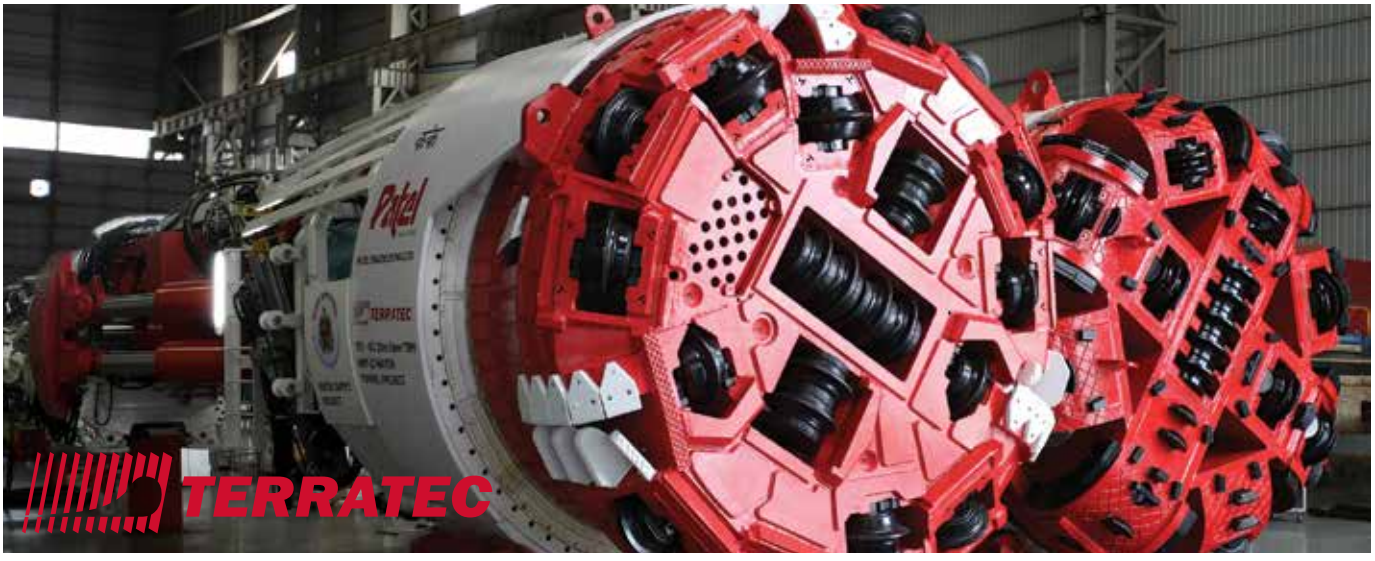

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HAGER-RICHTER GEOSCIENCE, INC. (HRGS) is an established small business that specializes in surface and borehole geophysical services for engineering and environmental applications (NAICS 541360). The firm has been in business since 1984, has grown to be one of the largest full service geophysical specialty firms in the eastern United States, and has earned a national reputation for quality geophysical services. HRGS specializes in surface and borehole geophysical services for the support of small and large-scale tunneling projects throughout the eastern US and beyond. HRGS has fully staffed and equipped offices in New Hampshire and New Jersey, and the firm owns the equipment it normally uses so that it does not rely on the rental schedules of others, allowing rapid response to projects throughout the United States. HRGS works exceptionally well as a member of a team providing specialty geophysical services that complement the expertise of clients and other project team members.

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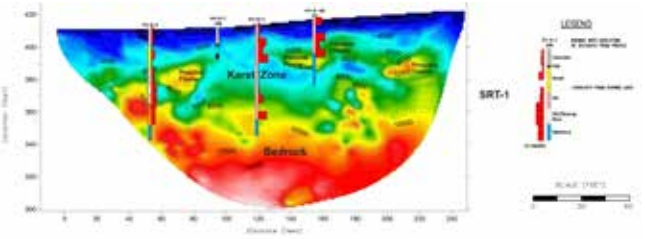

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Bradshaw Offers Innovative Tunnel Engineering and Construction Technology

Bradshaw Construction Corporation strives to apply the most appropriate tunneling technology to each project based on its purpose, subsurface conditions and surface restrictions. The company's management team is proud of its ability to construct any type of tunnel in any soil condition both above and below the water table. From small hand mined, wood-box and liner plate tunnels to large NATM shotcrete-lined tunnels; from small pilot tube guided auger bores to large rib-and-board shield and tunnel boring machine (TBM) tunnels; from conventional pipe jacking to slurry microtunneling (MTBM) to earth pressure balance (EPB) TBM tunnels; and from hand mined drill and blast to rock tunnel boring machines (TBMs), Bradshaw Construction has a solution.

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Sentinel Solutions

UCA 2022 Project of the Year Award

The Underground Construction Association (UCA) awarded the Bergen Point Southwest Outfall Replacement project in Suffolk County, NY with the 2022 Project of the Year Award at the North American Tunneling Conference award ceremony in June of 2022 ($50-$500 million). This award is presented to an individual or group "that has shown insight and understanding of underground construction in a significant project, which may include practices, developing concepts, theories, or technologies to overcome unusual problems within a project, resulting in little to no outstanding issues." – **CDM Smith**

"This 2.6-mile-long outfall replacement tunnel. The project team overcame slurry challenges created by the sandy and clay soils along the alignment". – **UCA Awards Video**

"Sentinel provided exceptional soil control as well as cost saving measures during the Bergen Point Outfall Tunnel Project. Their centrifuge equipment, engineering and analytical process was a tremendous benefit to the projects schedule and overall success." – **Jim Gray, Wastewater Division Manager – Posillico Inc. from team OHLA USA/Posillico/SELI Overseas USA**

"Our capabilities relative to drilling fluid engineering, solids control and the dewatering of spent fluids was an excellent match to the Bergen Point project. The team on the ground was very receptive to our suggestions and we were able increase production while simultaneously reduced disposal costs to virtually nothing." – **Chuck Skillman, Operations Manager – Sentinel Solutions "Got Muck…Call Chuck!"**

Sentinel Solutions
www.sentinel-solutions.com
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Northwest Laborers-Employers Training Trust – Safety and Hazard Awareness for Tunnels (SHAFT) program

The Safety and Hazard Awareness for Tunnels (SHAFT) program, developed by the Northwest Laborers-Employers Training Trust with input from a team of industry experts and stakeholders, is comprised of a blend of classroom discussion and interactive use of materials and mockups.

The curriculum offers comprehensive safety training for both new and experienced tunnel professionals; classes focus on tunnel safety, rail, and utilities.

The training facility, located in Elma, Washington, features a TBM mockup, rail, and access to 1,400' of 12' diameter tunnel – providing students with a unique educational experience.

Northwest Laborers-Employers Training Trust
+1 (800) 240-9112 www.nwlett.org

Kiewit

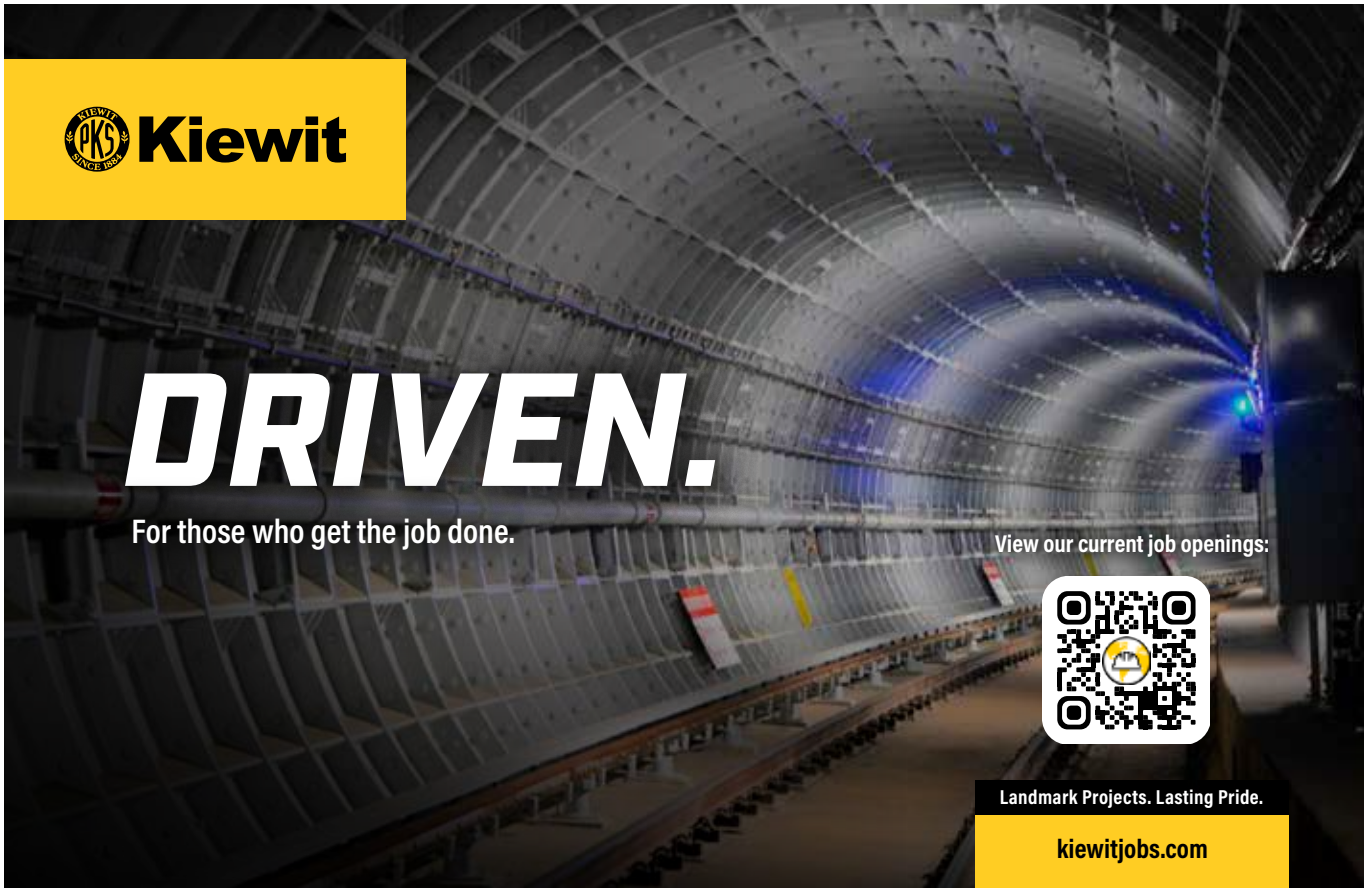
As a construction, mining, and engineering leader, Kiewit is a FORTUNE 500 company consistently ranking in the ENR's Top 10 Contractors. Kiewit is owned by active employees, creating a level of motivation that keeps the company on top. Kiewit, through its operating companies, brings a wealth of diverse resources and track record for delivering the highest quality results – on budget and on schedule. Our size and experience provides the stability, predictability, and knowhow our clients and partners expect – and the flexibility and overall best value they deserve.

Kiewit has built some of the most complex tunneling and underground projects for more than 75 years. We self-perform soft ground and hard rock TBM tunneling, along with conventional tunneling techniques such as SEM and Drill and Blast, and trenchless technologies such as MTBM and HDD. As one of North America's largest and most respected construction and engineering organizations, Kiewit's underground capabilities offer clients unique advantages to navigating complex, challenging projects from engineering and design, through construction.

We're hiring. Go to kiewitjobs.com to learn more.

Kiewit

Kiewit Infrastructure Co.
1550 Mike Fahey St.
Omaha, NE 68102
kiewit.com



David R. Klug & Associates, Inc.

Since 1996, David R. Klug & Associates, Inc. has provided international and national manufacturer's representative services to the underground heavy civil and mine construction industries. The company specializes in the sale and coordination of specialty products, equipment and services for soft ground, conventional and NATM/SEM tunneling practices. Expertise is offered in the supply of various componentry used in the manufacture of one pass precast segmental tunnel linings inclusive of EPDM gaskets, plastic and steel connectors, grout lifting assemblies and precision steel segment casting moulds plus final lining forming systems for C-I-P final lining applications. Through their distribution company, Klug Construction Systems, LLC offers Nittetsu ultrafine cement, GFRP rock bolts and soft-eyes, steel and synthetic fiber reinforcement, prefabricated welded wire fabric and rebar reinforcing panels, and specialty grout systems for various tunnel backfill grout requirements for highway, rail, subway, water and CSO tunnel construction applications.

David R. Klug & Associates, Inc.
1994 Lumber Ave.
Wheeling, WV 26003
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80TH ANNIVERSARY

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BARNARD

Whether we're tunneling through the mountains of northern British Columbia or below the streets of downtown San Francisco, our people arrive at projects determined to do the best for their communities and be the best in the industry. We self-perform heavy civil and underground construction including TBM tunneling, drill and blast, and sequential excavation methods. Our work also encompasses power transmission, dams and reservoirs, pipelines, and environmental construction. We have built our reputation on skill, innovation, reliability, safety, and our ability to complete projects on budget and ahead of schedule.

This work has been conducted under a wide range of contracts, including one of the first Progressive Design-Build tunnel projects in the US, the Silicon Valley Clean Water Gravity Pipeline Project in Redwood City, California. On the Lake Mead Low Lake Level Pumping Station Project, a CMAR contract for Southern Nevada Water Authority, our project team was onboard from the Early Contractor Involvement phase and through construction. Our teams stick with projects from start to finish, serving on a bid team and then heading into design or directly to the field to construct the project they've bid. We live where we work and know our projects personally. We build for People.

For more information, please visit our website, www.barnard-inc.com.

Strata Tunneling brings Communications, Tracking and IoT networking to Tunneling Operations

A reliable communication and networking system tailored specifically to the needs of the underground environment improves coordination and helps make operations more responsive and adaptive to sudden changes in production or safety.

Data can now be collected from many networked devices, including communication apparatus, atmospheric monitoring sensors, machinery, automated systems, conveyors, proximity detection sensors, dust detectors, and more. This data can be aggregated and leveraged to reveal real-time insights and possible inefficiencies in production, and disclose potential safety issues that may be developing.

"Improving the data collected within operations influences several production factors when it comes to reporting, alerting, and workflows," said Rob Albinger, General Manager of StrataCONNECT, Strata Worldwide. "This data collection can play a vital role in ensuring optimal safety for workers in the working environments."

Strata's StrataCONNECT suite of networking solutions is a customizable variety of wired and wireless technologies that combine functionality, redundancy, and economics to produce seamless underground connectivity.
In today's operations, it is important to have high bandwidth which carries large amounts of data continuously, and being connected to devices for monitoring, detection, and warning alerts greatly improves workplace safety.

StrataCONNECT DigitalBRIDGE Plus+
A combined fiber & leaky feeder backbone for high-speed Ethernet data transmission in addition to push-to-talk radio. DigitalBRIDGE Plus+ provides Power-over-Ethernet (PoE) access for IoT field devices, cameras, Wi-Fi access points, tag readers, gas detectors and more, throughout the tunnel and TBM using leaky feeder cable. It supports live video feeds, VoIP calling, remote monitoring and control, and real-time connectivity to emergency refuge chambers.

The StrataCONNECT IoT Gateway
Leverages existing infrastructures such as DigitalBRIDGE Plus+ leaky feeder, fiber and Ethernet to establish a wireless coverage area of up to 2000 meters. This technology supports open standard Wi-Fi, Bluetooth® and LoRa®

- Dual 802.11b/g/n 2.4 GHz Wi-Fi® radios
- 2x 1 Gbps Ethernet ports
- 802.3bt PoE in & Passive PoE Out
- 1Gbps SFP
- RS485/Modbus
- GNSS
- GPIO
- 900 MHz wireless mesh

StrataCONNECT Wireless is a completely wireless and battery-powered mesh network for tracking, communication, and atmospheric monitoring.
Personnel carry a handheld texting device that doubles as a location tracker. Tracking tags can be used for asset tracking, and a variety of third-party equipment such as gas detectors, environmental monitoring sensors, proximity detection systems, fan and pump control panels, belt control boxes, cap lamps, and more can be integrated to connect to the central server and user interface. With this technology operators can remotely monitor and control the devices, sending command and control functions while accessing data readings.
Strata's wireless network provides a real-time awareness of underground operations and working conditions.

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www.strataworldwide.com/tunneling

STRATA WORLDWIDE

Putzmeister

PUTZMEISTER – your partner for underground projects

Putzmeister is a worldwide leader in the development and manufacturing of concrete pumping equipment. Applying this knowledge in concrete pumping, Putzmeister has been designing, developing and producing concrete spraying equipment for mines and tunnels for the past 30 years.

What distinguishes Putzmeister's spraying equipment from others is knowledge and control over the main elements, in both design and production. The concrete pump, spraying arm, chassis and control software are developed and produced internally by Putzmeister. With a global vision for the product, Putzmeister creates machines that are perfectly synchronized and aligned with the harsh working conditions and unique needs associated with this industry.

The experience acquired over the years, along with ongoing investments in research and development, has made Putzmeister a leading company in this field of application. While the underground construction industry advances, Putzmeister will continue to offer state-of-the-art equipment while exploring product range expansion in this field.

With an extensive network of after sales service technicians, Putzmeister provides rapid assistance to ensure efficient solutions in any situation, whether it be for commissioning, break down repairs or inspections. Putzmeister also offers a reliable supply of genuine Putzmeister parts and accessories in over 120 countries.

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Michels is one of the largest, most diversified energy and infrastructure contractors in North America. By combining the collective strengths of the Michels Family of Companies, Michels delivers a team of hard-working people, sophisticated equipment fleet and unparalleled experience. Michels supports tunneling and underground construction projects with creative, safe solutions from pre-construction to completion.

Shafts & ERS: Safe access is a critical aspect of many tunneling and underground construction projects. Michels designs and builds shafts to the specific size and depth you need to supply crews, material and equipment to your work area. Look to us for value engineered secant shafts, drop shafts, and temporary and permanent earth retention systems (ERS).

Tunneling: Setting the bar for rapid performance, environmental protection, and safety in energy and infrastructure tunnel construction, Michels Trenchless, Inc. is one of North America's largest microtunnel, Direct Pipe, auger boring and tunnel contractors.

We Do That … & More
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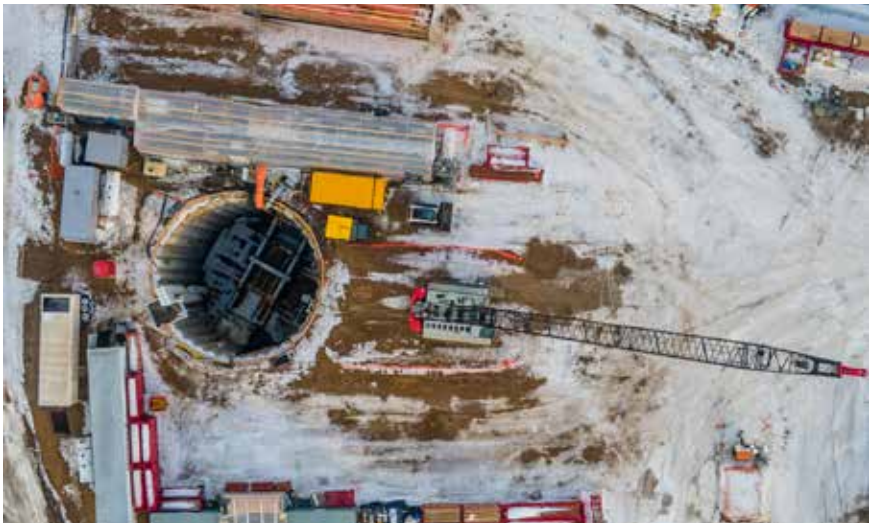

Rely on Michels for unwavering solutions in the underground construction industry. We lead the way by innovatively designing and expertly installing a diverse range of trenchless pipe installation methods and pipe rehabilitation techniques.

Our commitment extends to meticulous site preparation, encompassing ground improvement, earth retention solutions and deep foundations. Trust Michels for unparalleled expertise in shaping the future of underground infrastructure.

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WE DO THAT … & MORE

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EOE/AA/M/F/D/V

Gall Zeidler Consultants

Gall Zeidler Consultants is an engineering consultancy firm specialized in innovative solutions for tunnel and underground projects across the US, Canada, as well as internationally. For over 20 years, we use our broad expertise in transportation, infrastructure, water conveyance, energy and mining projects to help our clients overcome challenging conditions and providing innovative solutions from conceptual and planning phases through construction and operation.

Our tunnel and geotechnical engineering services cover all stages of a project:

- Conceptual to Final Design
- Program & Construction Management
- Construction Site Support
- Tunnel Inspection & Rehabilitation
- Mine Access Tunnels & Shafts
- Independent Design Verification Services
- Building Information Modeling (BIM)

With our diverse team of experts and young professionals, we are represented in all major global markets with offices in North America, Latin America, Europe and Asia.

GZ Gall Zeidler Consultants

Kelley Engineered Equipment

Kelley Engineered Equipment (KEE) enters their 17th year of supplying custom equipment solutions and professional engineering services to the tunneling and underground construction industries. A growing team of 40+ professionals, TBM experts, the Kelley team has decades of underground experience and PE Licenses in 12 states with more on the way. KEE accepts your challenges and provides solutions with unmatched quality and customer support.

We get it - We understand what you need and know how to build it
Unequaled Experience - We are licensed, qualified & utilized by all the major civil contractors
Simple-Safe-Fast - We deliver safe, elegant solutions to complex problems when you need them

Contact KEE for: Tunneling Equipment, Pipe Carriers & Installation Systems, Custom Cranes, Below the Hook Lifting Systems, Gantries, Mucking Systems, Trailing Gear, Tunneling Shields, Rolling Stock, Hydraulic Attachments, Conveyors, Lift Cars, Equipment Mod, Heavy Load Handling, Personnel Access Systems, Bespoke Engineered Solutions, etc.

KEE is proud to represent Terratec TBMs in the USA and Canada.

Kelley
Engineered Equipment

TBM DRY SCRUBBER

Project specific solutions, tailored to your exact needs!

16K TBM SCRUBBER

This is a 16,000 CFM Dry Scrubber used on a refurbished 4M Atlas-Copco TBM used for a short section of the Bill Bishop Toronto City Airport Tunnel. It was mounted centrally on the trailing gear and since there was not enough overhead clearance to accommodate a screw conveyor and rotary airlock, it discharged automatically from a unique clamshell dump hopper, through the trailing gear floor to the invert. This scrubber collected dust from the cutter head as well as several conveyor drops.

TBM SCRUBBER

Envirosystems has designed several TBM scrubbers for specific projects, and would welcome an opportunity to talk to you about yours. We have designed TBM dry scrubbers for TBM's from 1M to 5.5M in diameter. We can design to locate outside the gantry or inside the trailing gear and are very flexible with regard to volume required. Volumes above 30,000 CFM are not out of the question. We can now provide both Dry and Wet collectors.

Envirosystems has developed several types of roadheader scrubbers including both Dry and Wet collectors. We can design a custom "ride along" unit or one that sits nearby and collects dust, mud and spray as it comes off the cutter head. Give us a call and let's talk about your application!

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A Dust Collection & Blasting Technologies Company

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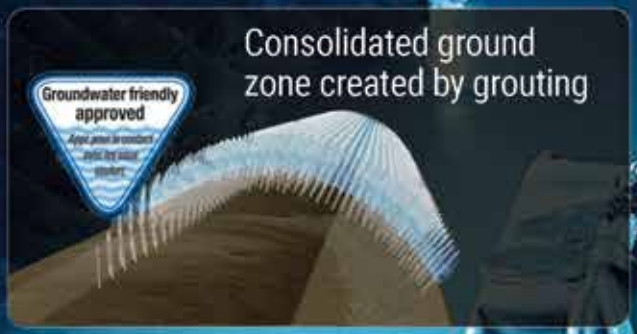

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- Cleaning and finishing magnetic elements improve selective separation

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