Deep-level mining is becoming more prevalent due to the depletion of orebodies closer to the surface – many of the easily accessible orebodies have already been found and mined. In addition, deeper mining is becoming more common in existing mines as the shallower parts of the orebodies have been exhausted, but if the orebody extends at depth, then mine development must drive deeper to unlock further resources. Operations with existing infrastructure can economically mine deeper with limited additional capital investment, and still address the technical challenges that mining at depth presents.

Improvements in technology have also allowed deeper mining than was previously possible. For greenfields projects, deep-drilling technology has continually advanced.

Sandy Watson, vice-president, mining, US and international at Stantec, says: “This advancement in deep drilling provides the capability to identify mineralisation at much greater depths, such that a deposit can be evaluated with a reasonable level of confidence with the ultimate goal of developing the deposit into an operating underground mine.”

In addition, advancing technologies in areas associated with deep-mine hoisting, ventilation/refrigeration and ground support, among others, give the ability not only to operate at depth safely, but also to operate in a manner that is economically viable.

Kevin Melong, senior manager, shaft projects at JS Redpath, adds: “New geotechnical understandings and engineering methods allow computer simulations of potential ground conditions, stresses and other previously limiting conditions in deep mines to be overcome and mineable. Commodity prices have allowed the higher capital development price tags that deep mines carry.”

Of the 10 deepest mines in the world, eight are located in a particular region of South Africa. The other two are both situated in Ontario, Canada. Currently, the deepest mine in the world is AngloGold Ashanti’s Mponeng gold mine in South Africa, which extends to over 3.9km below the surface.

Digging a little deeper

As mines hit deeper levels, more logistical challenges are raised. Ailbhe Goodbody investigates
DEEP-LEVEL MINING LOGISTICS

There are numerous challenges associated with deep-level mining, which largely revolve around the technical capability of economically mining at depth. These include geotechnical/seismic problems, the logistics of moving workers and materials, haulage, the increased ventilation necessitated by higher temperatures, and ground-control systems and monitoring. Watson says: “At these depths, hoist-rope technology and associated rope strengths start to become a concern.”

“In addition, as mining gets deeper, there are ever-increasing stress levels in the rock – including increased ground pressures and loads on the mine pillars/structure and designed entry/ground-support systems. These increasing stress levels result in either reduced excavation sizes and/or increased ground-support requirements in an effort to mitigate the increasing ground pressures and the risks of potential rock bursts.

Generally, deep mining requires significant capital investment in the mine’s infrastructure, which typically involves the development of deep shafts for access, production and ventilation. These shafts are utilised for movement of personnel, hoisting of ore and waste rock, and movement of supplies and consumables from surface to underground, as well as supplying and exhausting the required ventilation to maintain safe working conditions. Deep mines also typically use ramp systems within the mine to move the necessary consumables and materials to the storage areas, with boom trucks used to move the materials to the headings.

In some of the deeper mines, the extreme depths require the need for separate, designated rock and materials/worker access in and out of the mine. As extreme depths require much more effort and time to get material to surface, secondary shafts and ramps may be driven as service shafts or declines, to allow maximum utilisation of the rock-hoisting or haulage/conveyor facilities. This is also true of high-tonnage but shallower mines, where rock movement dictates separate installations.

In an effort to monitor and manage the movement of personnel, equipment and materials, tracking systems are typically installed using Wi-Fi based active radio-frequency identification device (RFID) technology. These systems are not specifically used for deep mining operations alone; however, with deeper operations and more

Case studies: DYWIDAG-Systems International (DSI)

A deep Canadian mine is producing gold with a cover depth of 1,500m. A haulage drift or tunnel was developed through a soft ground zone in mid-2013 to access a new reserve area. Since then, significant drift-wall closure has been occurring with a maximum of wall/rib displacement of 91.4cm.

DSI North America’s underground technology team was called to investigate the situation on March 23 and 24 this year. To minimise the ground movement that was caused by excessive vertical load on the soft ground conditions, a rock-bolting system must be: long enough to anchor into solid rock strata; strong enough to hold the rock strata in place along the entire bolting length; and yieldable enough to provide support to take care of the significant wall or rib displacement to prevent the rock-bolt failure.

DSI proposed the following roof/wall control plan to rehabilitate the 700m-long drift: 4.9m-long, 24t-capacity Omega bolts with an elongation of 30% on a supporting pattern of 4in x 4in (1cm x 1cm), plus 48.2cm pizza pans and zero-gauge wire mesh for surface control.

In addition, 7.3m-long Omega bolts and 6.1m cable bolts with the same supporting pattern will also be tested in the mine drift to see which bolting system is more effective to maintain the long-term stability of the mine drift.
mining levels and mining locations, the need for these tracking systems become more critical to ensure worker safety and operation efficiency.

A spokesperson from DYWIDAG-Systems International (DSI) explains: “Deep level mines will have a mine plan/layout very different from a shallower deposit with the same minerals, to deal with excessive vertical pressure, load-induced rock/coal burst, pillar rib squeezing and the high temperature-induced heating environment.”

With the advent of computer simulations, mine design has launched into a new era, where designs can be validated against any number of scenarios, especially ground stability. In most deep mines, stress fields are simulated for all openings. In some of the deeper mines, the ground stresses definitely dictate mine-opening size and/or orientation.

Melong says: “Orebody geometry and bulk-mining amenability must be assessed for each individual orebody. Depth may or may not play a role in any one of these factors and corresponding mine. The ultimate factor in the design is to be able to extract the mineral economically, and that is the driver of the designs, regardless of depth.”

MINING METHODS
Mining methods are usually decided by the width, length and size of the orebodies. In smaller gold mines, shrinkage mining, paste chute infill or longhole mining are usually used, with overcuts and undercuts where the rock is extracted. Larger-scale mines typically

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**Deep-level mining is becoming more common**

“With the advent of computer simulations, mine design has launched into a new era”
The ability to mine at depth generally comes down to the value of the ore that is being mined. The method used does not necessarily vary depending on the commodity being mined. The ability to mine at depth generally comes down to the value of the ore that is being mined, and the economic viability. The value of the ore must overcome the higher capital and operating costs associated with mining at depth, regardless of the commodity type. The mining methods used to economically extract the resource will vary based on the size, shape, formation and geotechnical characteristics of the deposit.

While the mining methods or techniques used in deep-level mines are broadly the same as those used in shallower underground mines, some mining methods are more challenging at depth. For example, caving methods can be more difficult as they generate caving zones that make the rock mass response and seismic activity less controllable.

However, block and panel caving methods realise significantly lower mine-operating costs compared with some other mining methods, and offer the capability for very high production.
rates (some as high as 160,000t/d), which subsequently enables the operation to offset the high infrastructure costs associated with mining at depth.

Significant advances have been made over the years to mitigate the geotechnical risks associated with deep caving operations. These advances include, but are not limited to, the following:

- Cave undercutting techniques and sequencing;
- Drawpoint design and sequencing;
- Ground-support techniques used for both temporary and permanent support;
- Seismic monitoring systems and seismic data interpretation;
- Draw control and cave propagation interpretation; and
- Equipment and operation automation.

Other frequently applied deep mining methods involve using some form of cemented backfill such as cut and fill and or blasthole stoping with delayed backfill.

Watson explains: “As mining deepens, more restrictions on mining sequences are required to minimise the impact of mine-induced stress and seismic activity – for example, avoiding pillars (rib or sill pillars), avoiding primary-secondary extraction sequences, or incorporating a pillar-less pyramidal sequence.

“Ultimately, the incorporation of these types of mining methods and sequencing restrictions may reduce overall productivity from a given mining area. These mining methods and sequencing restrictions translate to either less overall production, or increased equipment and personnel in more mining areas to maintain production levels, but mitigate the higher stresses realised at depth.”

SAFETY
Deep-level mining can be accomplished safely with proper engineering, monitoring and safety/operational procedures and policies put into place. However, deep mining does have additional challenges for ventilation, and seismic events that can occur due to geologic conditions, especially if the mining sequences are not closely adhered to.

A spokesperson from DSI states: “Deep mining with hard surrounding rock materials experience larger energy events during load transfer associated with mining activities. The higher loads and larger energy releases produce more dynamic ground conditions.”

One issue that can arise is known as 'rock burst', where a sudden rock-mass failure occurs. Watson says: “Because of this risk, “
usually associated with increased seismic activity, sensitive areas may be off limits until seismic activity returns to normal levels. Seismic monitoring systems become more important in deep mining in an effort to better understand the rock-mass response to excavation at depth."

Due to the higher heat loads in deep mines, workers are exposed to higher temperatures and humidity. The exposure of working personnel to these higher temperatures must be monitored and managed in an effort to maintain safe working conditions. Some ways to manage these conditions include shorter shifts or more frequent rests in a temperature-controlled environment to reduce exposure, and/or increasing local ventilation and cooling.

There is huge potential for the use of automation in deep-level mines, and safety is one of the biggest benefits. The incorporation of automation in deep-level mines ultimately reduces the number of personnel working underground who would otherwise be exposed to higher temperatures and higher ground stresses.

The other benefits of remote equipment are reduced operating costs and increased productivity between shifts. Automation provides operational efficiency and productivity improvements that reduce overall mine operating costs, and can result in rendering a deep-mining operation economically viable that otherwise may not be.

**VENTILATION**

Deep mines have extra ventilation requirements. Ground temperature increases as the mine gets deeper, so dealing with increasing heat at depth becomes a significant challenge. In an effort to maintain reasonable working temperatures underground that ensure the safety of personnel, refrigeration/cooling plants must be used.

Watson comments: “These ventilation and refrigeration requirements, and the associated power loads, become both a significant capital and operating cost for deep mining operations.

“Due to higher heat loads generated at depth, groundwater inflow temperatures increase, which present challenges from a personnel-safety standpoint as well as equipment operability and maintenance.”

In many deep mines, especially large-scale mines, refrigeration plants are set up on the surface with large vent fans to push the cool air underground. Other solutions are large-scale ice stopes that can be set up underground, and from these stopes large vent fans will pull the air out of the stopes and push cool air into the underground headings.

Melong says: “There is a wide range of ventilation schemes currently being carried out at the various deep mines around the world. The biggest challenge is no doubt ‘effective temperature’, whereby the wet-bulb/dry-bulb temperatures must be evaluated on a heading-by-heading basis.”

Bulk air coolers (BAC) that spray ultra-chilled water into the ventilating air stream, slush plants that transport slush down to underground BACs, and spot chillers that are moved around the mine to cool exceptionally hot areas are the norm. However, these plants can add significantly to the cost per tonne of ore mined.

**GROUND SUPPORT**

As ground conditions change, rock bolting and shotcreting requirements change; as a result, there are different requirements for ground support in deeper mines when compared with shallower underground mines.

Typically, deep-level mines have a programme for the type of ground being mined and overburden depth, and an engineered pattern of ground-support products are utilised in relationship to the rating system for the type of ground and overburden depth. These programmes are developed by the mine’s engineering/operations/safety departments.

Often in deeper mines, considerably
more attention is paid to extraction sequence, pillar size and strength, secondary ground support and maintenance and monitoring of those systems’ performance. In shallow mines there is more focus on the potential for gravity failure, where the ground support needs to handle dead weight in static conditions.

Deeper mines will design their systems around the strengths and longevity of the support pillars and stoping abutments, which shallower mines do not normally concern themselves with. Redistribution of ground stresses in deep mines call for real-time monitoring and potentially much longer rock-support tendons, and most often require significant rehabilitation efforts to control pillars and peripheral headings, ore haulages, footwall drifts and orebody access.

Randy Demers, area manager, Timmins region at JS Redpath, notes: “In deep-level mines usually you will see on average 7-8ft (2.1-2.4m) rebars in intersections, followed up with 10-12ft (3-3.7m) cable bolts. In main haulage drifts, it’s usually 7ft (2.1m) rebars.”

The support system must be able to handle dynamic conditions, yield to dissipate energy associated with rock burst, and control large rock deformation. Thus, yielding bolts with surface support that can handle large deformation are required for deep mining. Most deep mines would have ground-control engineers to deal with any issues with ground conditions or ground movement.

A spokesperson says that DSI is producing dynamic ground-support products that can aid in ground support in these conditions. Shallow mines would not need these types of dynamic-load ground-support products.

**TRENDS**

Future trends in deep-level mining will depend heavily on market conditions and global minerals-commodity pricing, as well as on the size and grades of the orebodies, as at the end of the day mining is all about the cost per tonne.

**Case studies: Stantec**

Stantec has worked on a variety of deep-level mining projects. Some of these mines include:

- PT Freeport Indonesia’s Grasberg block cave and Deep Mill Level Zone (DMLZ) block caves, Indonesia;
- Glencore Sudbury Integrated Nickel Operations’ Onaping Depth, Ontario, Canada;
- Oyu Tolgoi’s Oyu Tolgoi mine, Mongolia;
- Homestake Gold’s Homestake mine, South Dakota, US;
- Gold Fields’ South Deep mine, Gauteng, South Africa; and
- Glencore Xstrata’s Kidd Creek mine, Ontario, Canada.

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DEEP-LEVEL MINING LOGISTICS

is expected, however, that the drive will be to ensure that deep-level mining risks are managed to ensure the safest possible extraction of minerals at increasing depths.

For deep-level mining, future trends will include automation and remote-control mining techniques – continued work to automate machines that have traditionally been manually operated or manually executed tasks is likely, as well as continued research into the use of robotics for deep mining.

Robotic technology powered by artificial intelligence is being developed and applied to tasks such as production and development drilling and blasting, LHD and truck loading and hauling, and ground-support installation.

Additionally, the continued development of electric-powered mobile equipment should reduce the total ventilation and refrigeration requirements for deep underground mining. These ventilation reductions ultimately translate to less vertical development to sustain safe mining operations, which results in reduced capital infrastructure costs.

Watson comments: “Current data suggests that 70% of existing mines worldwide are open-pit operations, with 30% being underground operations. There is speculation that, by 2018, this ratio will be 50:50, with the trend moving towards more underground mining.

“While this is a result of a combination of existing surface mines transitioning to become underground operations, as well as the ongoing permitting challenges associated with new surface mining operations.”

Ultra-Deep Mining Network

In January, the Centre for Excellence in Mining Innovation (CEMI) received a C$15 million (US$13.7 million) grant for its Ultra-Deep Mining Network (UDMN) proposal. CEMI is based in Sudbury, Ontario, Canada.

The grant was one of four given out by the Canadian federal government’s Business-Led Networks of Centres of Excellence (BL-NCE) programme. The goal of the BL-NCE programme is to address private-sector R&D challenges in Canadian priority research areas through the creation of business-led research networks that increase private-sector investment in R&D, innovation and competitiveness.

Along with the C$15 million received from the BL-NCE, the UDMN has also received significant partnership commitments of C$31 million (US$28.3 million) in leveraged cash and in-kind contributions.

The UDMN is a business-driven network, founded and funded by members of the mining and oil-and-gas industries, with the active participation of small to medium-sized enterprises, industry agencies, research facilities and academia.

Managed through CEMI, the UDMN will lever collaborative, networked solution teams to solve critical private-sector R&D challenges that affect resource extraction in ultra-deep mining environments, as well as in deep, tight, shale-hosted hydrocarbon reservoirs.

CEMI states that addressing these development and operational challenges in some of the deepest mines in the world will result in increased productivity, decreased risk to workers, lower energy utilisation, as well as lower capital and operating costs, achieved through performance and efficiency improvements.

Douglas Morrison, president and CEO of CEMI and network director of the UDMN, highlighted CEMI’s achievements when the award was announced – including in key areas of hard-rock metal mining such as high-stress conditions, mine productivity and mine construction, as well as exploration and environmental sustainability.

He said: “With the UDMN, we will continue to establish collaborative networks with industry, academia and small to medium enterprises, enabling us to play a central role in the kinds of innovations necessary for the global mining industry.”

Automation is likely to become increasingly prevalent in deep-level mines. This loader is part of a Sandvik AutoMine installation