Keeping up with caving

Caving mining techniques are experiencing a surge of interest, thanks to a combination of favourable metal prices, high forecast demand and the need to exploit deeper, more complex orebodies at the lowest cost possible. Carly Lovejoy investigates the current market.
Both surface and underground mass mining methods have generated increasing interest in recent years, as mining companies look to exploit large orebodies faster and more economically. Underground mining methods such as block, panel and sub-level caving continue to be the premier choice for deeply situated massive orebodies, thanks to the high potential production rates and low operating costs involved. Recent technological developments and improved solutions for designing, planning and modelling caving operations mean that these techniques can now be applied at greater depths, in more competent rock masses with greater geotechnical challenges than ever before.

GLOBAL INTEREST
A combination of factors that include relatively higher metal prices, high projected supply and demand forecasts and a lower discovery rate of significant new near-surface deposits have helped to drive global interest in cave mining methods.

Simon Hanrahan, principal consultant (mining) based in SRK’s Perth office, explains: “In addition, a number of large open pit mines across the globe, some producing in excess of 50,000t/d, are coming to the end of their lives. These make up the bulk of world copper production, and many mining companies are examining the feasibility of shifting to low-cost, large-scale underground operations in order to continue exploiting these orebodies.

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Aside from strip ratios, other factors influencing the economics of open pit projects include the increasing escalation of energy prices, together with a focus on reducing carbon emissions.

A number of large-scale, low-grade underground operations are also considering expanding in order to access areas of the orebodies previously thought to be uneconomic to exploit. These are challenging applications that will require careful front-end investigation and analysis, innovative engineering design and a strict approach to development and operation.

Sourcing of skilled labour is also a significant problem in the mining industry today, so a mining method such as caving that has a low reliance on skilled labour pools can be an interesting factor for mining companies to consider.

Otto Richter, principal consultant at Snowden, says: “The recent interest in...”

“Caving is the only underground bulk mining method able to offer continued production at a comparably high rate with low operating costs”
Block caving comes down to two factors – less access to large orebodies near the surface and an improvement in the knowledge of caving mining methods. 

"It is becoming increasingly difficult to find large, near-surface orebodies that are suitable for open pit mining methods which will also yield high production rates and low operating costs. Those open pit mines that are currently operating in these conditions are becoming deeper, and now have to consider closing operations or changing to an underground method that will produce at a similar rate with low operating costs."

He adds: "In recent years a lot of effort has been applied to understand how the internal mechanics of the caving process works, thereby removing a lot of the uncertainty previously associated with these mining methods. As caving has proven to be a safe and effective mining method, its popularity has increased around the world."

**BLOCK AND PANEL CAVING**

Block caving is an underground mining method that uses gravity to exploit massive, steeply dipping orebodies located at depth, particularly those with disseminated mineralisation or that are low-grade in nature, but too deep to be extracted using open pit methods. Block caving also depends on in situ stresses and the host rock's ability to fracture in the correct fashion, although this can now be overcome using pre-conditioning.

The term 'block' refers to the mine layout, which usually divides the orebody into large sections, although in some cases the block can represent the full footprint of the orebody. Upward caving of the rock mass is induced by undercutting the block and blasting it. This destroys its ability to support overlying rock, and fractures spread throughout the rock mass, forming a cave.

Following extensive preparation and development work in order to access the orebody at the correct depth, a set of parallel, horizontal tunnels is created on the upper level, known as the undercut level. A set of holes are then drilled into the roof, which are filled with explosives and blasted. The tunnels collapse in sections and broken rock is removed via sections of the tunnel not yet affected by blasting. This process initiates the development of the upper cavern of broken rock, ie the block cave.

A second series of tunnels is then developed beneath the ore block, on the production level, in which a series of tighter, vertical drill hole patterns are drilled into the broken rock above. These allow the formation of tunnel-shaped structures called drawbells, which act as conduits for the broken ore and connect the block to the production level.

From the drawbells, the ore is funnelled into drawpoints. The broken ore is then loaded by load-haul-dumpers (LHDs) and delivered to ore passes or an underground crusher, prior to hoisting to the surface in skips or by conveyor.

Ore in the column is diluted by the material in adjacent columns and ultimately by overburden and lateral waste. When the column drawdown is complete and the drawpoint grade drops below a minimum value, the drawpoint is abandoned.

Technically, once the drawbells have been created, no further drilling is necessary. The speed at which ore travels through the drawbells is effectively controlled by the speed at which it is removed from the drawpoints. As broken ore from the block exits via the drawbells and drawpoints, the roof of the cavern gradually collapses under its own weight to create more broken rock, forming a continuous process.

Block caving offers lower operating costs than many open pit mining methods and, in many cases, lower environmental impacts. However, it is a very capital-intensive, and one of the primary disadvantages is that it removes much of the supporting rock from under the overburden, which can lead to subsidence at the surface.

Caving-induced subsidence might endanger mine infrastructure and is a major concern for operational safety. Changes to surface landforms brought about by subsidence can be dramatic and may lead to a pronounced environmental impact. Therefore, the ability to predict subsidence has become increasingly important for operational hazard and environmental impact assessments.

There are numerous variations of the block caving technique that use different layouts and extraction patterns. The choice will depend largely on the orebody characteristics, the nature of the host rock, and the associated development and production costs.

Panel caving allows the extraction of very large orebodies by dividing them up into 'panels', which are mined progressively, although, as with block caving, the panel can in some cases cover the full footprint of the orebody. The fundamental difference between the methods is that block caving produces from the full orebody footprint, while in panel caving the active caving zone moves across the panel – ie while one end is being undercut, the other end is producing.

Once a panel becomes depleted, the adjacent panel is mined in sequence until the orebody is exhausted. Like block cave mining, panel caving offers low operating costs, and lower development costs due to its progressive approach.

**SUB-LEVEL CAVING**

Sub-level caving is sometimes used where large open pit mining operations transition to underground extraction methods, although it is often used for independent underground projects too. Once the orebody is developed, it is then drilled and blasted on progressively lower levels until it is depleted. The waste rock above the orebody caves gradually upwards as the ore is extracted.

Sub-level caving is typically used where the orebody has a smaller footprint and/ or more competent rock mass that prevents the continuous caving required for a block cave. Blasting of the entire orebody is required to produce a production ore flow.

As sub-level caving uses a 'top down' approach, it requires less upfront capital than a block cave operation and much less time to reach full production.
could be also advantageous where high-grade ore is located near the top of the orebody.

Mr Hanrahan explains to MM: “A significant difference between sub-level caving and other caving techniques is that multiple levels of development are required, many times more than a block cave requires, and ongoing ring blasting is used for production.”

Mr Richter adds: “Sub-level caving operations typically find applications between the traditional large open stoping methods and block or panel caving methods.

“The caved material forms a relatively small portion of the total production and is typically considered as external mineralised dilution. Sub-level caving also allows for a slightly more selective extraction of the orebody than is attainable through block or panel caving. Production rates achieved in sub-level caving operations are typically lower than for block caves but higher than for stoping methods.”

CAVING REQUIREMENTS
Caving is a non-selective, bulk mining method. It requires large-scale mineralisation in all three dimensions (length, width and height), in rock conditions that are sufficiently weak to allow caving and have suitably fine fragmentation, yet strong enough to ensure that the excavations will last the 10- to 50-year life usually associated with caving operations, although preconditioning can be used to weaken rocks that would otherwise be unsuitable. It is of key importance that the hydraulic radius required to initiate caving can be achieved and is typically exceeded.

In a block or panel cave only a relatively small percentage of the orebody is drilled for production. This represents a large upfront expenditure (CAPEX). Today, several caving operations are producing in excess of 50,000t/d, and newer operations are being constructed with capacities in excess of 100,000t/d. However, there are also some caves being planned with smaller scale and shorter mine lives – the key inputs will determine the value of a project and its feasibility.

Mr Hanrahan says: “Cave mining differs significantly from other typically more selective underground mining methods in a number of areas. Because cave mining is a ‘bottom up’ method that relies on first establishing a large fixed infrastructure underground that will provide a very long-term production platform, the initial capital costs are typically very high. This infrastructure consists of shaft and/or decline access for men, materials, production hoisting and ventilation. Today, this infrastructure is state-of-the-art in many instances and has a high degree of automation. Similar to providing a processing infrastructure ahead of production, this represents a large upfront expense.”

He adds: “A noticeable difference in building a caving operation [compared with other methods] is the finished build quality, particularly on the extraction level. Because this level must remain in place and active for many years, ground support and roadway conditions are important. The production drives are finished with shotcrete, steel brow sets and, in certain situations, reinforced concrete. The roadways are completed with engineered roadway concrete that supports high-speed tramming of ore from the drawpoints to orepasses or crushers.”

As a result of establishing a high-performance, large-scale infrastructure, it
with most open pit operations. Typical production rates are in the range of 2-20Mt/y, with a few cave complexes able to produce in excess of 45Mt/y – El Teniente is a good example.

**GOING UNDERGROUND**

As large open pits become deeper, they often become uneconomic to continue to mine from surface, mainly due to material movement costs. Where the orebody is suitable, many established operations around the globe are opting to use caving methods as they expand.

Large open pit mining operations are typically associated with a large-scale processing facility. If a deposit continues at depth, then there is often significant project value to be achieved by continuing large-scale and low-cost mining underground in order to feed what is an already established high-volume processing facility.

As open pits get deeper, the waste-to-ore mining ratio becomes less favourable. In addition, the environmental impact and large footprint area required for a waste rock depository could prevent further continuation of surface mining. Cave mining on the other hand has a much smaller surface impact and almost no waste rock storage requirements.

Cave mining offers the advantage of being the only underground mining method that can match the production rate and low-cost profile of surface mines,” explains Mr Hanrahan. “The disadvantage of choosing cave mining to replace a surface mine is the long lead time required for study work ahead of an investment decision, which often makes it challenging to provide a good level of production continuity between a closing open pit and a ramping-up underground operation.”

Given the high capital investment required to establish a caving mine, the initial challenge when considering whether to transition an operation from open pit to underground is to carry out a thorough study in order to define project value, and understand and manage project risk. One of the most critical items in support of this is an adequate level of orebody knowledge, including the geological, geotechnical and hydrogeological characteristics. It takes time and often significant pre-project approval capital to obtain this data so that it can be used in the study process. This data provides the foundation for much of the study work in support of developing a workable mine design and production schedule.

“..."The disadvantage of choosing cave mining to replace a surface mine is the long lead time required for study work ahead of an investment decision"...
The period between discovery and steady state production can be 15 years or more

“The header frame and winding room at a shaft of Newcrest Mining’s Telfer mine in Australia

Photo: Bloomberg News

The decision to proceed to the return on investment. Underground caving methods can have a lead time of anywhere between five and 15 years before significant production is realised. This is associated with the amount of development work required, and improving rates of advance for development is a key area of focus for the mining industry.

Mr Hanrahan says: “Once approved, project delivery time depends on a number of aspects, including the depth below the surface, which is required for infrastructure to be established. Creation of a 1,000-1,200m below-surface shaft can take up to three years, and a further three years might then be required for access development before a production ramp-up can commence.”

Mr Richter adds: "Due to the sheer amount of data that needs to be gathered to properly understand the geological, geotechnical and metallurgical nature of such large orebodies, data collection and analysis is frequently the most time-consuming activity.

"Another critical factor in the project development timeline is undertaking negotiations with local land owners and authorities to gain access and ownership. For these reasons, the period between initial discovery and steady state production can be 15 years or more."

Mr Richter tells MM that detailed design and study work (prefeasibility and feasibility studies) typically take three to five years. The production ramp-up for a block or panel caving operation is dependent on the size of the cave footprint, but typically these are also in the three- to five-year range.

In an average rock mass, approximately five drawbells a month can be established, which then allows incremental production to build up gradually. Typical production rates are in the order of 150-300mm of insti material drawn from each drawpoint per day, or about 0.3t/m² of footprint area per day.

Depending on the size and scale of the operation, block/panel caves usually contain 200-500 drawpoints, with about 60-80% in operation at any time. This results in average production rates of 5-20Mt/y for most operating caves, although there are some cave complexes in the pipeline with thousands of drawpoints, which will produce much higher amounts of ore. However, orebodies suitable for this size operation are few and far between.

Mr Richter adds that multiple lifts do not usually significantly increase the annual production capacity at caving operations, due to the risk of lower panels undermining higher panels. It does, however, extend the life of the operation, as lower panels can be brought into operation as higher panels are depleted. Production rates also depend on factors such as: available orebody footprint, rock mass competency and infrastructure in place. A number of large cave projects are planning production rates above 100,000t/d but these high rates typically require multiple blocks or panels.

Mr Hanrahan says: “Greenfield projects, unlike an existing mine expansion and brownfield projects, are particularly challenging, since limited or no exposure of the orebody is available and there is no experience of the rock mass behaviour. This type of project requires a longer lead time and high capital investment for exploration drilling, laboratory and insitu testing and underground confirmatory programmes.”

Snowden believes that the highest value in any block or panel cave project is achieved by getting the initial plan correct. When constructing a cave footprint infrastructure, there is little room for error, and any design issues can result in decreased recovery, increased dilution or increased operating costs.

When determining the best approach for a project, Snowden says it combines the skills and experience of its mining personnel with its in-house design and optimisation software (Stopesizor and Evaluator) to select the best strategic plan within each project’s set of constraints. Once the strategy has been confirmed, more detailed planning and design work can start using cave planning software, such as Gemcom’s PCBC and PCSLC.

“Greenfield and brownfield projects, and mine expansion programmes all have a unique set of constraints and requirements that can be incorporated into the optimisation,” says Mr Richter.

“With greenfield projects we will build the mine plan up from first principles and determine a zero-based cost and mining schedule, whereas brownfields projects often have more accurate site-specific information available and current operational constraints to be incorporated. We understand that our clients know their operation and strategic objectives, which may impose a unique set of constraints to be taken into account for the evaluation.”

The early stages of a block cave development involve a high level of construction activity, as the undercut and extraction infrastructure is created to last for the life of the orebody. “During the construction period, the total number of personnel can easily reach 3,000 for a small block cave and up to 10,000 for a large block cave,” explains Mr Richter. “Once steady state production is achieved, the ongoing demand on logistics is drastically reduced, and is low compared with other underground mining methods.”

Once approved, establishing a cave mine can be very complex. Speed is of the essence, and it is not uncommon for development in the order of tens or even hundreds of kilometres to be required on some of the larger operations. This can be challenging, particularly if ground conditions are weak or wet in areas.

EQUIPMENT

In the past, caving has generally only been considered for rock masses that cave and fragment readily. However, improvements in mine planning and design software, a better understanding of geotechnical conditions and the...
fragmentation of rock masses, plus the availability of more advanced equipment for drill-and-blast and load-and-haul duties are enabling mining companies to exploit more competent orebodies with coarser fragmentation than was previously thought to be economical. Operators also have greater control over development and production rates at these operations than ever before.

Most mining companies realise the importance of time when developing caving infrastructure, and many are looking at methods and equipment that will speed up the process. As a result, equipment, methods and control systems that were previously only used in civil tunnelling have started to migrate to the underground mining environment. Other areas under consideration include: overbreak control, drilling accuracy, long rounds, blasting fragmentation, type of explosives, fumes and re-entry times, haulage speeds, loader and truck capacity, and adaptive ground support schemes.

“Companies are also finding ways to reduce wasted time and inefficiencies, and refining the development process to a predictable and repeatable process. Time after all costs money,” explains Mr Bray. “The ability to produce even a few weeks earlier than conventional development methods can mean millions of dollars in advance earnings.”

Production tasks for cave mines are dominated by loaders taking ore from the drawpoints and transporting it to another location. Many of the repetitive tasks associated with moving ore from drawpoints to ore passes carry the potential for automation, and many equipment manufacturers are able to offer semi- or even fully automated loading equipment.

Other production tasks may involve secondary breaking, crushing, conveyors and shaft haulage. The trend in this area is the ability to automate and monitor as many activities as possible using a mine-wide control and monitoring network. This allows for better efficiencies in equipment utilisation, people management, safety and energy consumption.

Automated and semi-automated equipment is often able to perform tasks faster than the manned equivalent and, more importantly, automated systems do not carry the human error factor, meaning less equipment damage and operating mistakes.

Leaving aside the obvious advent of equipment for rapid development in cave mines and other underground mass mining methods (which is addressed in a separate article in this issue), this section examines some recent trends in the application of more traditional equipment for development and production activities at caving operations.
DRILLING AND BLASTING

The creation of the block cave from the undercut level and the drawbells from the production level require specific drill patterns and depths of holes, and therefore certain drill rigs and drilling methods are more suitable for each task.

Whereas horizontal jumbos are used to create the access levels, vertical in-the-hole (ITH) and top hammer production drills are more commonly used in developing the block cave.

Three main factors must be taken into consideration when drilling for both undercut and drawbell development. First are the rock properties; these will influence the powder factor required to fracture the rock mass when blasting (powder factor is a combination of explosive type/power, hole diameter and hole spacing). Rock properties also play an important role when considering rock mass damage due to blasting.

“This is especially important when developing the drawbells,” says Mr Bray. “As drawbells need to remain in place for a long time (often the life of the mine), it is advisable to practise smooth-wall blasting techniques.” This entails using lower-power explosives coupled with close-spaced holes along the desired final design boundary in order to create a pre-split. The resulting rock boundary is less likely to be fractured and will remain more stable.

The second factor is the drilling accuracy required to achieve the desired blasting results. Mr Bray explains: “It is often considered that ITH drilling is far more accurate than top hammer drilling, especially for longer holes (greater than 30-35m). However, most undercut and drawbell development work does not require longer holes. Hence, top hammer drilling is the method most commonly employed.” Regardless of the drilling method, it is important to select the drill rig and string that maximises drilling accuracy results, particularly for drawbell development.

Harold Jonker, applications engineer at Cubex, agrees. “Drilling accuracy for up-holes is a prerequisite, as this affects the undercut and extraction level stability due to the elimination of pillars on the undercut,” he says. “Customers are demanding better operational efficiencies and more maintainable machines. Trends in terms of measuring the efficiency of the various processes are developing. This entails on-board and vital signs monitoring, as well as measurement of the drilling process in order to deliver to the planned production requirements.”

The third factor is the capabilities of the drill rig. This can be expressed as a combination of possible drilling angles, hole diameter range, the stability of the drilling platform, the length of hole possible and automation capabilities.

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“There is a wide selection of long-hole drilling methods available, but the choice will depend on the specific site conditions.”

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during mine development, there are typically many kilometres of drives to be excavated, and many thousands of metres that need to be drilled for undercut and drawbell development. Due to the quantities involved, and the requirement for rationalising and improving efficiencies, the use of semi- or fully automated equipment has high potential. Drill rigs that have on-board drill plans and the ability to drill automatically between shifts are just one example of how equipment utilisation and therefore development rates can be increased.

Atlas Copco has supplied equipment to many of the world’s existing and developing block caving operations. Customers include: Codelco, Climax Molybdenum’s Henderson mine, Newcrest’s Cadia East project, Rio Tinto and Ivanhoe Mines’ Oyu Tolgoi mine, and Rio Tinto’s Northparkes mine.

Oyu Tolgoi copper mine in Mongolia has a drilling fleet that includes Atlas Copco Boomer M2 C30, Boomer E2 C30 face drills, and Boltec MC and Cabletec LC bolting machines. These share common intelligent control systems and have high levels of automation. The face drills feature COP 3038 rock drills to assist with increased drive development rates. Mr Bray says that to date the machines have been running well, and the customers are very pleased with the results.

Atlas Copco has recently delivered a Boomer E2 C30 face drill to Rio Tinto’s Northparkes operation. The machine will be used to access and develop a new block caving area. “There are high expectations that the machine will contribute to faster development rates, due to the use of the 30kW Cop 3038 rock drill, long rounds and accurate drilling systems,” says Mr Bray.

Given the extreme quantities of lateral development required at caving operations, mine operators are keen to minimise overbreak for several reasons; firstly, it creates excessive rock to handle during development, and secondly, it creates a larger void that will require secondary support.

To help minimise overbreak, many drill rig manufacturers have developed automated programmes that allow increased accuracy when drilling a face. Where a rock mass does not have enough natural inherent jointing to cave, operators are often now looking to precondition a rock mass ahead of caving. Preconditioning involves drilling a series of holes into the lower portion of the rock mass that is to be caved and then, by means of either hydrofracturing or explosives, inducing manmade fractures.
two Cubex ITH drills have been used for drilling service and preconditioning holes up to 240m in length. This is part of cave propagation in lift 2 of the E26 orebody. Codelco’s El Teniente mine in Chile has also utilised a Cubex ITH drill for drawbell development. A contractor has drilled 200 raises, each 760mm in diameter and 15m in length. The average total time per raise was 28h including mobilisation, setup, pilot hole drilling, reaming and de-mobilisation.

Cubex ITH rigs are also at work at New Gold’s New Afton block cave mine in Canada, where they are being used to develop drawbells. Twin 760mm pilot holes are used for the drawbell construction using the V-30 drilling method.

In some mines, oversized rock can be a major challenge in the production cycle. Mr Hanrahan of SRK explains: “Given that some of the more competent orebodies are now being caved with consequent coarser fragmentation, a sophisticated secondary breaking fleet is often required to quickly and efficiently reduce oversized material ahead of transport to the primary crusher. Much of this material may have to be handled within the throat of the drawpoint (up in the drawbell area).

“Mobile equipment has been developed to drill and charge in this zone remotely, so that no personnel are exposed to this task other than from a remote control cabin. Additional equipment such as water cannons has also been developed to blast hang-ups with a stream of high-pressure water and dislodge them for treatment in a more accessible location.”

Jay Klinko, senior global product manager at Boart Longyear, says that mobility and flexibility are also a challenge for drill rigs at caving operations. Due to the tight constraints and narrow passageways, miners need safe, portable, compact equipment.

Boart Longyear recommends its StopeMaster and StopeMate rigs for production drilling at caving operations. These feature heavy-duty hydraulic hoses and guarding to protect the driller from ruptures and moving parts. Miners can operate the rigs from up to 25m away via a remote positioning system. The rigs have emergency stop circuits to cut the power in the event of an incident.

For low-profile situations, the rigs can tram through openings just under 1.5x2m, and can be used for back height drilling as low as 2.4m. Both Stope drills feature hydraulically driven wheels to allow for skid-steer mobility, maximising manoeuvrability in tight spots.

The smaller, lightweight StopeMate drill accommodates drilling depths of 12-15m. It weighs 3.7t and is small enough to be loaded into a lift cage. The rig can also be broken down into six manageable pieces in order to gain access to captive areas.

The StopeMaster HX model was used extensively in the development of Rio Tinto’s Palabora block cave mine in South Africa. The extensive infrastructure required rapid drilling of the drawbells and for ground support cables. Boart Longyear says the HX drill helped to keep work within schedule.

Mining contractor and equipment manufacturer Redpath specialises in raisedrilling and shaft sinking for mine development, and frequently uses boxhole boring and Alimak for work at caving projects.>
Mike Kelly, senior vice-president of the Redpath group, explains: “Raisedrilling is the fastest and safest method of developing raises, provided you have the infrastructure (and power) to utilise the method. Workers do not have to enter the raise, you do not have to support the ground, and the capital cost of the equipment is relatively low.”

The company is currently undertaking boxhole boring at Codelco’s Andina and El Teniente operations using its Redbore 50 machine. “We are also manufacturing a Redbore 30 for future use at these projects to allow setups in drifts under 3.2m in height,” says Mr Kelly. “At PT Freeport’s mines we use an Alimak machine for raises. This has proven to be the most effective method there, in part due to the time lag in getting power distribution in place that a raisedrill would require. To streamline the operation, we developed a ‘portable nest’, which significantly reduced the traditional setup times and makes Alimak cost effective.”

Redpath is the primary development contractor for the Freeport underground mines. The company’s scope of work covered constructing the Big Gossan shaft, excavating roughly 2,500m per month of lateral drifts, providing mass excavation for crusher stations and conveyor ways, as well as raising and Alimak services. “We have a workforce of 1,100 at present and another three years on our current contract,” says Mr Kelly. “We have been at this site for 28 years.”

Redpath has developed four drills specifically for use in block cave operations: the Redbore 30 for small boxhole raises (up to 0.9m diameter) in low back height applications; the Redbore 40UR for raises to 1.2m in diameter; Redbore 50 for raises to 1.3m in diameter in low back applications; and the Redbore 70 for downreaming 1.2m raises to connect to ore passes.

In Mongolia, Redpath is the primary development contractor for shafts and lateral development at the Oyu Tolgoi copper mine. The company has 500 staff working on the project, and has completed the OT#1 shaft, which is 6.8m in diameter and 1,000m deep. It has also completed 400m of the OT#2 shaft (10m diameter and 1,375m deep), and will begin shaft sinking on OT#5 (6.7m diameter, 1,250m deep) in June. Shaft OT#4 will measure 11m in diameter and 1,375m deep. Work will start on this in the June quarter of 2013.

Mr Kelly adds: “We also have two development crews working at Northparkes in Australia doing lateral development. Redpath is currently involved with over 25 shafts around the world. We have the world’s largest underground fleet of Alimak climbers, and the largest capacity raisedrill package on the planet: the Redbore 100.”

LOADING AND HAULING

The fixed footprint and layout of a block or panel cave lends itself well to partial or full automation, especially for the production loading equipment, and truck or train haulage of loaded material. Mr Hanrahan says one of the systems that have proved most effective is LHD automation. At operations/projects that use this system, significantly higher productivities have been achieved at a lower unit operation cost due to lower manning costs, increased trarming speeds (fewer loaders are required for the same production throughput) and minimal damage. Higher effective utilisation is also possible due to the elimination of operator constraints.

However, automation does not come without challenges; it requires much stricter safety controls, such as completely removing people from the working area. Roadways must also be well maintained to...
realise the full benefits of the higher tramming speeds. Currently, manual intervention is still common in the form of tele-remote loading, as this typically results in improved bucket fill factors. People will always be required as part of the operation to perform routine inspections and maintenance, but full or partial automation can reduce the exposure time of personnel in the production environment.

Sandvik was one of the first suppliers to introduce automated systems for underground hard rock operations with its AutoMine automated loading and hauling system. AutoMine is a flexible modular system that can be adapted to small- or large-scale block caving operations. The system incorporates functions and applications that allow it to interface with third-party IT systems at mine sites.

AutoMine allows operators who would otherwise drive a single vehicle underground to work from a control room on the surface, and simultaneously monitor the movement of a fleet of driverless loaders or trucks underground. Sandvik loaders or trucks navigate between the load and discharge points under the control of a supervisory system, which manages traffic and monitors the machines. Sandvik says increased fleet utilisation ensures constant performance level enhancements and optimum use of the workforce, so there are no breaks during shift changes. Increased productivity is achieved through a continuous process enabling integration of information on site.

Codelco’s El Teniente mine has been using the AutoMine system for a number of years. The company invested in two systems to exploit its Pipa Norte and Diablo Regimiento deposits more efficiently. The Pipa Norte system was installed in 2005 and commissioned by December 2009. The mine currently uses LHDS17 17t LHDs in three tunnels. The system for the larger 28,000t/d Diablo v

"Automation does not come without challenges; it requires much stricter safety controls, such as removing people from the working area"
Regimiento is in early stages of operation. Three semi-automated LHDs were used in the first phase, but the fleet could potentially increase to 10 LHDs when the full production stage is reached.

Other mines that use AutoMine include Newcrest’s Ridgeway Deeps mine in Australia, which has five LHD514Es (electric loaders). Rio Tinto’s Northparkes E48 mine, Australia, also has five electric loaders, and Petra Diamond’s Finsch diamond mine in South Africa (formerly of De Beers) also uses an automated trackless load and haul fleet. In addition, Oyu Tolgoi mine will have more than 40 automated LHDs when operating at full capacity.

In September 2011, Sandvik won a contract to supply 14 fully automated LHS17 LHDs for the initial production phase at Newcrest’s Cadia East mine in New South Wales, Australia. The machines are now on site and being used in Lift 1 as part of Sandvik’s AutoMine system. The project is slightly behind schedule so the machines have not yet been used to their full potential, but Sandvik says the results so far have been promising. Service and support for the loaders is being carried out by Sandvik’s Orange service centre, plus an onsite product support team in the Cadia Valley.

Mr Richter comments: “Typical modern block and panel caves are designed to efficiently utilise large, mechanised trackless equipment fleets. The mine layout and activities are designed to be repeated at high frequency with little variability. This makes caving one of the mining methods most suited to automating loading and drilling equipment.”

The fixed layout of a caving operation also lends itself to utilising electrical equipment, which offers a reduction in noise, heat and diesel particulates. New technologies are continuously being tested, such as using vibrator plate feeding of trucks instead of loaders, and utilising road header equipment instead of traditional drill and blast techniques for development. However, these technologies have to meet the safety requirements of each operation and prove that they will outperform the current tried and tested methods before they will be widely accepted.

Accurately tracking material as it flows through the cave is critical for understanding the internal mechanics of the operation, and for predicting grades and dilution. Mr Richter explains that research is under way to develop ‘smart markers’ that can be placed inside the cave to track the material flow throughout the life of the operation. These markers require long operating lives and must be extremely durable to survive while moving through the cave.

**CURRENT/FUTURE PROJECTS**

There are a number of established mines that use caving techniques to exploit orebodies successfully, and due to newly realised economies of scale, there is a large number of greenfield and brownfield caving projects, as well as mine expansions in the feasibility/development pipeline. The following section looks at how a few of the most prominent projects are progressing. Of the international-scale operators, Codelco has the greatest experience of developing and operating caving projects, followed closely by Rio Tinto. Codelco also operates the world’s largest cave mining operations, including El Teniente (the largest) in Chile. Other companies include: Newcrest Mining and Ivanhoe Mines, which are relatively new to the caving arena; LKAB, which specialises in sub-level caving; and Freeport McMoRan, which is involved with caving via its subsidiaries PT Freeport Indonesia (which operates the Grasberg mining complex in Indonesia) and Climax Molybdenum Co (which operates the Henderson mine in Colorado, US).

**RIO TINTO**

Rio Tinto says its main mines/projects that use caving techniques are: Northparkes (Australia), Palabora (South Africa), Oyu Tolgoi (Mongolia), and Resolution Copper and Kennecott Utah Copper (both US). Northparkes and Palabora are operating mines, while Oyu Tolgoi and Resolution are in development.

Rio Tinto is currently transitioning one of its most established operations, Kennecott Utah Copper (KUC), to an underground block caving operation, which will be located beneath the Bingham Canyon open pit mine. The company increased its copper resource for the mine in late 2011 by 20Mt to 106Mt. The resource, known as the North Rim Skarn, is a high-grade copper-gold deposit located 300m below the current pit. Rio Tinto has committed US$165 million to complete the next stage of exploration and development studies by 2014. The prefeasibility programme includes final shaft rehabilitation, an access decline from the pit and further underground exploration drilling. The investment follows the approval of US$238 million to advance studies extending the open pit life to 2028 and to purchase associated long-life time equipment.

Northparkes in NSW, Australia, boasts both open cut and underground mining operations. The E26 underground block cave mine was Australia’s first, and lift 1 reached design production of 3.9Mt/y in 1997. Northparkes commissioned its second block cave mine, E26 lift 2, in...
is the world’s undeveloped copper-gold project, containing 46 Moz of gold in measured, indicated and inferred resources. The project is owned by a joint venture consisting of Rio Tinto, Ivanhoe Mines and the Government of Mongolia, although Rio Tinto is managing the development of the operation.

Construction of the Oyu Tolgoi complex is advancing toward its planned start-up later this year and commercial production in the first half of 2013. The project is initially being developed as an open-pit operation, with the first phase of mining to start at the near-surface Southern Oyu deposits, which include Southwest Oyu and Central Oyu. An 85,000t/d underground block cave mine is also being developed at the Hugo North deposit. The throughput capacity of the concentrator plant is expected to be 160,000t/d of ore when underground production begins. Overall construction of the project was 82% complete at the end of April 2012, and approximately US$4.6 billion has been invested so far.

Underground lateral development at the Hugo North Deposit was suspended in February as planned to enable the upgrading of hoisting equipment at Shaft #1. This is expected to continue until August. Development is scheduled to resume in September. Construction of Shaft #2 at Hugo North is progressing well and the headframe has now reached a height of 78.5m above surface. The final height of the shaft will be 97m. The headframe and ancillary buildings were 87% complete at the end of March and ahead of schedule. Shaft-sinking activities began in December 2011 and had reached 226m below surface on May 12.

The Resolution copper project is in Arizona, US, near the depleted Magma mine. Rio Tinto has a 55% share in the project in partnership with BHP Billiton. The project has an inferred resource of 1,600Mt of copper and operations are expected to last 40 years. The preferrability study is currently under way, and is expected to be complete by 2013, with production at the new mine targeted to start in 2021, eventually ramping up to 500,000t/y of copper. Resolution will use panel caving methods to extract the ore, which is located 2km below the surface. Temperatures at this depth can reach 70°C. In addition, Rio Tinto took the decision in 2005 to extend the Argyle diamond mine in Australia, with an underground block caving project at a cost of US$760 million, which would prolong its life by at least another 11 years. However, in January 2009, the decision was made to slow the development of the underground project in response to global market conditions. Construction was scaled down to only critical development activities, resulting in a workforce reduction and a demobilisation of contractors.

PT FREEPORT

PT Freeport’s Grasberg complex in Indonesia includes both open pit and underground operations. Open-pit mining of the Grasberg orebody began in 1990 and is expected to continue until mid-2016, at which point the underground mining operations – the Deep Ore Zone (DOZ) and Big Gossan mines – will take over the bulk of production. The DOZ orebody lies below the now depleted Intermediate Ore Zone. Production from the DOZ orebody began in 1989 using open stope methods, but was suspended in 1991 in favour of the Grasberg deposit. Production resumed in September 2000 using block caving and is expected to continue until 2019. Beginning in 2015, Freeport plans to ramp up production at the Deep Mill Level Zone (DMLZ) block cave mine, which lies below the DOZ mine and is currently under development. The Big Gossan mine lies underground and adjacent to the current mill site. It is a tabular, near-vertical orebody. Production began in the December quarter of 2010 and is to ramp up to 7,000t/d by mid-2013.

LKAB

Swedish iron ore miner LKAB took the decision in 2008 to expand its Kiruna and Malmberget sub-level caving operations. New main levels are being built at both operations; Kiruna’s at a depth of 1,365m and Malmberget’s at 1,250m. The new
M1250 level at Malmberget will be designed to handle the extraction of 18Mt of crude ore, plus 1.2Mt of waste per year. Workable ore reserves are estimated to be around 140Mt, which will yield around 84Mt of finished product. An annual production of 8-10Mt will extend the operating life of Malmberget by about 10 years to approximately 2020. Sections of the new main level were put into operation in the September quarter of 2010.

At Kiruna, the new KUJ 1365 level will accommodate remotely controlled shuttle-train traffic, similar to the present-day haulage level. Remote-controlled trains will transport the ore from gravity shafts to the crusher, and from there it will be skip-hoisted in two stages 1.4km vertically to processing plants at surface level.

Mining will take place in 10 production areas, each with its own access road, media systems, gravity shafts and ore chutes. Ore will be mined in stages between today’s 1,045m track level and the new 1,365m level. Based on an annual production of around 19Mt, the operating life of the Kiruna mine will be extended to 2030. Operations are expected to begin in the first sections later this year.

NEWCREST MINING

Newcrest Mining is focused on securing high-quality gold-copper resources and converting them into low-cost, high-margin operations. To help achieve this, the company has chosen to employ caving methods at a number of its mines. These include the Telfer and Ridgeway sub-level caving mines (in operation), and the Ridgeway Deeps block cave and Cadia East panel cave projects. Newcrest expects the cost of mining at Ridgeway Deeps to be significantly lower than at Ridgeway due to the combined impact of lower block cave mining costs and the use of semi-automated LHDS. A capital cost for the project of US$511 million comprised: construction of the block cave, extension of the existing underground ore handling system (including two new primary underground crushers), development of bulk underground mining technologies, including the application of automated remote loaders, and modifications to the processing plant (adding additional secondary crushing and regrind facilities).

Exploration drilling below the Ridgeway Deeps block cave has also indicated a continuation of the orebody, and preliminary assessments are being undertaken into the potential development of a second block cave.

The Cadia East project is located on the eastern edge of the Cadia Hill orebody (one of Newcrest’s open pit operations.) The project, which is currently under construction and about to enter production, will be Australia’s first, and the world’s deepest, panel cave operation. The Cadia East orebody holds a reserve of 18.7Moz of gold and 3.1Mt of copper, which Newcrest expects will underpin production for at least the next 30 years. The estimated capital cost of the project is approximately US$1.9 billion, and to date it remains on schedule and in budget.

The project also requires expansion and upgrade of the existing Cadia Valley processing plant as the ore at Cadia East is harder than that at Cadia Hill and Ridgeway. Capacity will also be increased from 24Mt/y to 26Mt/y.

The project will increase production from Newcrest’s Cadia Valley operations to 700-800koz of gold and 75-100kt of copper per year over the first 10 years. The project is 75% complete with first commercial production scheduled for the December quarter this year.

The Cadia East panel cave will be conducted in two lifts. Mining will extend from 500m below the surface to 1,450m. Work is currently under way to establish panel cave 1 and the associated underground infrastructure. Development of the decline toward the deeper panel cave 2 is also under way. Preconditioning blasts are now complete in panel cave 1.

Newcrest and will be the deepest block cave in Australia. The mine is expected to produce 1.6Mt of gold and 210,000t of copper over the project life of eight years. The mine began transitioning from Ridgeway to Ridgeway Deeps ore in 2010, and ramp-up of production is currently under way to 8Mt/y.

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“The Cadia East project will be Australia’s first, and the world’s deepest, panel cave operation.”

The block cave operation below the Chuquicamata open pit contains 1,700Mt of copper

Photo: Bloomberg News
Discovery Metals is developing a sub-level caving operation at the Boseto copper project in Botswana

and its drawbells continue to be fired, with the first ore from the blasted drawbells and undercut processed in the March quarter this year. To date, over 300,000t of ore has been treated through the process plant.

The crushers for the underground materials handling system remain a work in progress and the conveyer system is largely complete. Newcrest says that an accelerated temporary crushing capability and a substantially complete conveyer system will allow the ramp-up of production from panel cave 1, albeit at lower initial rates than expected.

On the surface, the concentrate handling, power, tailings and water infrastructure have been commissioned. The flotation plant and the regrind Vertimill are both now complete and are in the final stages of commissioning. The high-pressure grinding rolls circuit is also well advanced, and commissioning took place in May.

CODELCO
Codelco has a number of caving projects in the pipeline. The Chuquicamata mine complex in Chile currently produces copper from two open pit operations (Chuquicamata and Mina Sur). However, these will cease to be profitable in the next decade, and construction work began in 2011 for a new underground mine.

The operation, situated below the current Chuquicamata pit, is estimated to contain 1,700Mt of copper (0.7% grade) and molybdenum (502ppm) reserves. The project will use block caving to extract ‘macro blocks’ of ore. Work has begun to establish the four production levels; a 7.5km-long main access tunnel; five clean air injection ramps; and two air-extraction shafts. Development is expected to be complete by 2019 with a production rate of 140,000t/d of ore.

Work is also under way at El Teniente’s New Mine Level Project, which began construction in 2011. The new level (an addition to El Teniente’s current underground workings) will extend the life of the mine by another 50 years using panel caving. The level will be developed at a depth of approximately 1,880m above sea level and adds around 2,000Mt of reserves to the mine. Production from the new level will begin in 2017. El Teniente has been successfully using Sandvik’s AutoMine system since 2005 to exploit the Pipa Norte and Diablo Regimiento deposits and is expected to use a similar system at the new level.

DISCOVERY METALS
Discovery Metals has just completed the definitive feasibility study for the Zeta underground mine at its 100% owned Boseto copper project in northwest Botswana. Open-pit mining operations have already begun at Zeta, and production is due to start later this year. The underground mine at Zeta was a key component of the Boseto Development Plan, which anticipates open cut and underground mining to produce 35,000t/y of copper for at least 15 years.

Discovery says that sub-level caving has been chosen for the underground portion of the project, as it is the most appropriate mining method that took into account the safety of operating personnel and the mine itself, maximisation of resource recovery, capital and operating costs and operating risk (Zeta has weak hanging wall conditions and it is the hanging wall that contains the mineralisation). Sub-level caving allows maximum extraction of the ore at the lowest mining cost. The underground mine extends over a strike length of 2km and is situated immediately under the Zeta open pit, extending from 150m to 630m below the surface. The operations will be assisted via a decline from twin portals, one developed from within the Zeta open pit and one from the surface. It is planned that all lateral development will be within ore. Access on each level will be developed to the periphery of the orebody and the sub-level caving conducted on retreat to the decline access points.

The opportunity exists to trial the sub-level caving method at relatively shallow depths (55m below surface) in the southern end of the planned underground mining area. This will allow confirmation of the feasibility assumptions early in the development phase of the mine. Ore from both the development and caving operations will be trucked to the surface, stockpiled and then trucked approximately 8km to the Boseto concentrator.

The optimum extraction and processing sequence for the combined operations at Boseto has not yet been determined, with the final sequence being dependent on the timing of the planned expansion of the Boseto concentrator to a throughput of 3Mt/y. Discovery intends to maintain the option for an early start date at Zeta while these studies continue.

To that end, recruitment of a project development team for the underground operation has started and Discovery plans to award the mining contract in early 2013, with development to provide underground access beginning in late 2013. Infrastructure completion is slated for the December quarter of 2013.

OTHERS
SRK recently completed a contribution to a scoping study for Oz Minerals’ Carrapateena deposit in South Australia. The study examined a range of mining methods appropriate to the deposit, including sub-level open stoping, sub-level caving and block caving. SRK conducted the sub-level caving and block caving studies.

Work on the scoping study by Oz Minerals will continue in parallel with diamond drilling of the orebody from surface. In addition, SRK mining engineers have been involved in aspects of cave design and operation on almost all caving projects globally over the past decade. Snowden recently completed an options study, followed by a detailed scoping study, for a caving project in Asia, allowing the project to progress to the prefeasibility stage. The company has also recently completed a number of caving reviews in Australia.