Some may think of the company as an open-pit miner but Freeport Indonesia’s first block caving operations began in 1980 with the Gunung Bijih Timur – East Ertsberg (GBT) mine. This achieved a maximum production rate of 28,000 t/d and was depleted in 1994. The IOZ mine began production in 1994 and ramped up to a maximum production rate of 32,000 t/d. It was in 1997 that the pre-production development of the DOZ block cave mine began, and caving was initiated in November 2001. That same year the combined Grasberg/Ertsberg District operations achieved new record copper production of over 1,640 Mlb of copper. In 2002 the record was raised to over 1,800 Mlb of copper and DOZ achieved a sustainable production rate of 25,000 t/d. In 2003 the DOZ expansion to 35,000 t/d was approved and completed. The following year DOZ operated at 43,600 t/d, over 8,000 t/d above design-capacity and expansion to 50,000 t/d was approved. Today the mine has reached a sustained production rate of 80,000 t/d – the 80K project.

DOZ is the third level of block caving to exploit the copper-gold Ertsberg East Skarn System. GBT mined upper levels of the deposit, from which 68.7 Mt at a grade of 1.93% Cu was extracted. The IOZ mine produced from the deposit between the 3,456 m and 3,706 m elevations, with 43 Mt of ore averaging 1.21% Cu and 0.43 g/t Au extracted.

The geology of the deposits was described in last month’s feature on the Grasberg open pit. Geologically, the DOZ mine is part of the East Ertsberg Skarn System (EES). The EES is a subvertical tabular skarn body at least 2,000 m tall by 1,500 m long that occurs where the northern edge of the Ertsberg Diorite is in contact with the upturned limestones and dolomites of the Waripi and Faumai Formations on the south limb of the Yellow Valley Syncline. Skarn rock types that host
ore include magnetite skarn, forsterite skarn, mixed forsterite-magnetite skarn, brecciated hydrous skarn, and endoskarn altered Ertsberg Diorite. Copper mineralisation is predominately in bornite and chalcopyrite, with gold occurring largely as inclusion within the copper sulphide minerals.

Reflecting the ever-changing situation at Freeport, the block cave exclusivity (as the only mining method) will no longer apply when Big Gossan development is completed soon as it will employ an open stoping with cemented paste backfill mining method.

The Grasberg article (December 2009) noted the support provided by PT Redpath Indonesia (PTRI), a wholly owned subsidiary of Canadian based J.S. Redpath, established in 1997. Underground, Redpath’s involvement is much greater, reflecting its primary goal to support Freeport Indonesia’s development projects. PTRI is at work in developing mines such as the Big Gossan, Grasberg Block Cave and DMLZ mines (which will be examined in February). It is also heavily involved in supporting operations within the DOZ mine.

Dating back to the 1980s when Redpath first entered into a contractual agreement, services provided include the construction of ore passes and ventilation raises with raisebore drills and mechanised raise climbers.

In 1992, Redpath expanded its services to include drift development. Its drift/tunnel development program now uses more than 20 drill jumbos throughout the underground operations.

Services provided by Redpath to DOZ include:

- Raisebore development
- Mechanised raise mining
- Mechanised jumbo drifting and mass excavation development
- Ore flow maintenance and repair including ore passes, grizzlies, conveyor drifts and transfer chambers. Inflatable bulkheads are employed in ore passes as part of the service and repair program

- Underground ground support services include shotcrete primary support, reinforced shotcrete arches, and rehabilitation of production drifts.

Over the years Redpath has developed and maintained a close working relationship with Freeport Indonesia’s Underground Group. Redpath says “this can be attributed to the joint co-operation in planning and executing joint projects within Freeport Indonesia’s various operations. This stems back to the development of Grasberg’s underground ore flow systems some 14 years ago to initial development of the DOZ mine.”

“In the beginning Redpath did not have a dedicated safety, maintenance or engineering resources. These resources were provided by Freeport Indonesia, thereby creating strong bonds and joint ownership for daily concerns, solutions and accomplishments. This relationship has encouraged a strong ‘can do’ attitude.”

The DOZ mine exploits the EESS deposit between 3,470 m, the base of the IOZ mine and 3,120 m, the DOZ Extraction level. Draw column heights are 350 m where mining is below the IOZ, and a maximum of 500 m elsewhere. The DOZ block cave mineable zone extends some 900 m along strike and varies between 200 and 350 m wide. It is an advanced undercut, mechanised block cave mine, employing truck haulage and two underground gyratory crushers.

The extraction level has been developed at the 3,120 m elevation. Panel drifts are oriented perpendicular to the strike of the deposit and are developed on a spacing of 30 m. Drawpoints, developed in an offset herringbone layout, are spaced at 18 m along the panel drifts.

For DOZ to achieve 80,000 t/d of production the mine requires 2,300 m³/s of ventilation air. This is provided by two sets of fans in different locations. The first set is five centrifugal fans (each 750 kW) located at the Dom Valley area, at the surface above and to the south of the active cave. The second set is three 1,600 kW mixed flow fans at the Amole area, which is below the DOZ elevation, and just above the mill.

The post undercutting method was used in the IOZ mine and was therefore familiar to management and crews alike. For this reason DOZ initially employed a conventional post undercutting system during cave initiation. However post undercutting system had caused stress damage problems in the IOZ resulting in the premature closure of some drawpoints and additional repair activities.¹

Early on in the undercutting sequence at DOZ, the decision was taken to change from post
undercutting to the advanced undercut method. This resulted in a significant reduction of stress related damage to the extraction levels and was a major influence in reducing panel and drawpoint repair requirements.

DOZ’s key geotechnical issue is the extreme variability of rock types encountered in the ore zone across the strike of the orebody, from the footwall to the hanging wall. Starting at the north (hanging wall) and proceeding to the south, ground conditions change from very poor to very good. Rock strengths (unconfined compressive strength - UCS) vary from a high of 219 MPa in the massive magnetite skarn ores to less than 10 MPa in the retrograde altered skarns of the DOZ breccia. The rock mass rating (RMR) varies from a low of 25 in the poorest ground to a high of 65 in the most competent ground.

For planning purposes the mine was divided into three rock quality categories: good, medium and bad. This simplification allows planners and supervisors to look ahead and prepare for a change in ground support, caving rates etc. Shotcrete use is considered later in this article.

The underground equipment fleets support the 80,000 t/d DOZ mine and three other mines under development (more details to come, see IM, February 2010). The majority of the fleets are used in development efforts with projections of over 40,000 m of drift openings required for the coming year. Like the open pit, the fleets are predominantly Caterpillar, with Sandvik drilling equipment and hydraulic secondary breakers (IM, August 2009). The make-up of the fleets is as follows:

- Sandvik Axera jumbos – 28 units
- Sandvik Commando production drills – 9 units
- Caterpillar (R1300, R1660, R1700 and R2900) LHDs – 72 units
- Caterpillar AD30 and AD55 trucks – 43 units
- Getman support vehicles and trucks – 90 units
- Miscellaneous Caterpillar equipment (930, TH, IT, 960, DP40) – 70 units

Ore handling
The ore handling system uses 0.8 m spaced grizzlies on the extraction level on top of an orepass located in the centre of each panel drift, as ground conditions allow. A single bored orepass was designed for each extraction level panel to service up to 20 drawpoints. The Caterpillar Underground LHDs service the drawpoints and orepasses. Freeport has the largest fleet of these machines in the world, comprising:

- Three R1300s – bucket capacities 2.4-3.4 m³
- 17 R1600s – standard bucket capacity 4.6 m³
- 39 R1700s – standard bucket capacity 5.7 m³
- Eight R2900s – standard bucket capacity 7.2 m³.

At the bottom of the 35-45 m long orepass raises, a 2.4-m wide centre chute is used to load ore into the Cat Underground production fleet of AD55s – nominal payload 46 t. The trucks dump to one of two 54” x 77” gyratory crushers. Redpath raisebores the transfer raises between...
the extraction and truck haulage levels. These raises are 4.1 m in diameter, ranging in length from 35 to 60 m and are inclined at 75-80°.

Redpath also undertakes a wide range of mechanised raise mining services to the mine. This includes ongoing monthly requirements such as the development of the drawbell initiation slot raises required for the block cave mine. The mechanised raise mining method employs a mechanised raise climber (MRC) to excavate raises from a bottom access. It uses mechanised raise mining to complete development projects for raise excavation, widening, and ground support; sublevel development; and ore pass excavation and repair.

Vertical man-ways providing service access and emergency egress between undercut, ventilation and extraction levels are also mined by Redpath.

In developing and repairing transfer raise grizzlies and chutes, Redpath’s work includes removal of caps from the transfer raise grizzly and installation of rebar and work platforms for Freeport Indonesia construction crews.

Installation of protective bulkheads at the bottom access to a transfer raise provides safe access for Freeport Indonesia crews to the loading pocket chute. Activities include the installation of an inflatable bulkhead into the orepass and the construction of a protective bulkhead consisting of wire mesh and wire cables. Inflatable bulkheads vary from 2 to 4 m in diameter and are installed from the upper grizzly access with air winches.

Orepass maintenance and repair is an important area of expertise for Redpath. Freeport Indonesia’s ore pass system is extensive and provides service for both the Grasberg open-pit and DOZ mines. Repairs range from the routine replacement of steel liners at orepass collars to orepass rehabilitation including installation of lining systems and ground support.

There are times when the work requires large suspended work stagings with a second means of access through the use of mechanised raise climbers. Such projects have included orepasses ranging from 20 to 530 m in length and 2.1 to 10 m in diameter.

Each standard orepass in the DOZ, when kept three-quarters full, is designed to give up to 800 t of storage. With up to 20 passes in production during peak production considerable tonnes can be ‘stored’, which enables the mine to compensate for disruptions in the system.

Redpath excavates and is responsible for ground support of the loading pocket chambers on the truck haulage level. These require precise excavation techniques to achieve strict design tolerances. The lower section of the chamber is completed ahead of excavating the back and the chute access into the
transfer raise. Each chamber requires one month to develop.

Block cave development
Slot raises are required during the development of each drawpoint in the DOZ. In a block cave as large as this mine, this now represents close to 300 raises. Raises are driven at 90° with an average length of about 12 m. With the need to develop many short raises, Redpath introduced a specialised mining method that uses a portable Alimak mechanised raise climber nest to excavate raises safely and efficiently. The slot raise program has developed a skilled Indonesian workforce that has been successful in achieving excellent safety and productivity.

The portable MRC is compact and can be relocated from one drawbell to another in three hours. Ahead of relocating the portable MRC an initial raise excavation 2 m in length must be completed. The design of the portable MRC nest has the raise climber, work platform, safety canopy, hose, drills, man basket and rail sections assembled as a complete unit within a structural steel frame. It can be moved between drawbells without the previous need for disassembly and reassembly. The design includes four telescopic legs which can be adjusted independently to accommodate the height of the drift. This mining method provides for an efficient and cost effective method to excavate raises to a minimum of 10 m in length. At the same time this significantly improves overall safety and ergonomics for the raise crews.

The DOZ mine design includes an undercut level that requires slot raises to initiate the caving process. These raises are generally located near the north end of the orebody where weakened ground conditions are best suited for block caving. Slot raises differ in design from those used for drawbelling in that they are longer with some dipped on degree. Here again the portable Alimak raise climber nest is used with the Indonesian crews averaging 100 m/month of drawbell, undercut and ventilation raises in the mine.

As we have seen in previous articles, Freeport Indonesia puts tremendous effort into the training of indigenous peoples, and this applies equally to contractors like Redpath. Its Indonesian employees are certified thorough a detailed training program that includes theoretical and on-the-job training and aligns with internationally recognised standards and requirements.
A skilled mechanical department is essential to support mechanised raise climbing operations. Candidates were selected and trained at Redpath’s central MRC facility in Canada to ensure that proper skill sets were developed in order to maintain safe and reliable programs in the mine. Today all components of the MRC are maintained by a certified and experienced national maintenance team. In addition to maintenance work, this group is also responsible for specialised fabrication including work stagings, manway components, and specialty items such as hydraulic liner arms and ring drilling equipment. The MRC shop is vital to Redpath’s operations.

**Draw control**

Draw control has become progressively more sophisticated over time as the operation has proceeded through the successive lifts of the mine. Effective draw control has many goals:

- Minimise dilution
- Prolong drawpoint life
- Control convergence at a safe level
- Control water influx and wet muck
- Maximise ore recovery.

Wet muck has been identified as a risk to safety and productivity at the DOZ mine. The Underground Division has made great efforts to mitigate the risks associated with wet muck, and to improve productivity. These focus on wet muck production, wet muck handling procedures, mucking strategy, remote control mucking, modified chute designs, a trial of fully automated loaders (the MINEGEM installation) and a comprehensive dewatering program.

The production level of the DOZ block cave lies at a depth of about 1,200 m below surface and has column heights up to 500 m. The western part of the DOZ is about 250 m below the IOZ block cave. The cave zone of the DOZ has merged with the caved zones of the GBT and IOZ block caves and breached the surface in 2003.

Increased amounts of fine material resulting from increased column height, existing fine material (DOZ breccia and marble), water increase, and high...
DOZ employs the largest fleet of Caterpillar LHDs and underground trucks in the world

Production rates have resulted in increased risk of wet muck spills, especially on the extraction level. Freeport defines wet muck as “a mixture of fine grained material and water which has the potential to result in a sudden outflow from the draw point or other underground excavation.”

Other factors contributing to wet muck include the presence of water-bearing and transmitting zones within the caving area, the high level of rainfall rate in the catchment and recharge area, and the connection of the caving areas to depleted production areas above the active cave and to the surface subsidence zone. Wet muck occurrence predictions consider the quantity of fine material present or anticipated from the production schedulers, and the other contributing factors. The output and recommendations from these predictions are the number and approximate location of wet drawpoints anticipated per year. This data is used to predict the number of remote loaders required, the numbers of chutes requiring conversion over to wet muck standards and the eventual impact on mine production.

Remote loaders have been operated since wet muck was first encountered in IOZ in 1999. At DOZ they are operated from a control room, which currently allows up to eight remote loaders and nine rock breakers to be operated from an adjacent control room rather than from the active extraction panels. The underground crushers and conveyor feeders are operated remotely from an adjacent control room.

To improve the handling of wet muck, Freeport is running one of Caterpillar’s latest MINEGEM systems on four of its LHDs making it the only block cave mine using MINEGEM and the only one using it on R1600Gs. The system allows for remote LHD operation using three settings. Trakindo Underground Technician, La Ode Huru Hara explains: “In teleremote the operator is in full control at all times, while the copilot setting allows automated steering whereby the operator can control forward and reverse movement. In autopilot mode, the loader is semi-automated and the operator can load the bucket on the tele-remote and then simply monitor loader movement computer screen.” Training for the operators took an average of three weeks. “Safety is the biggest driver for automation,” explained Freeport Underground Technical Expert Scott Wilson. “With the wet muck we find in our underground mines, the MINEGEM system is one of the tools we can use to limit hazards in these work areas for our operators and improve safety. Its reactive navigation system compensates the position and steering of the loaders according to the terrain.”

If successful, automation will ultimately replace the teleremote control units. One major advantage is that a teleremote loader is limited to only first and second gear; the automated loaders can be operated up to third gear. It is necessary to operate at slower speeds, as the teleremote operator cannot react fast enough to prevent the loader from hitting the rib during operation. The automated loader systems are able to avoid most such collisions using the onboard steering systems and as a result are able to go faster. The trial result in a long panel showed productivity was increased by 48% due to a better cycle time as well as improved operating hours compared to remote loader operation.

Another benefit is that the automation system acts as a very accurate method of recording buckets from individual drawpoints as part of the draw control system. It does not need to rely on operator counts or the existing Dispatch tagging system in place in the mine. Generally wet drawpoints must be mucked out at a rate of six buckets per shift.

To avoid spills from the chutes, wet and dry muck are mixed in the orepasses. In addition, some chutes have had their flow-chains replaced by a single solid metal plate. Dedicated underground dewatering drifts have been developed outside the perimeter of the predicted ultimate cave zone. With dewatering drilling averaging thousands of metres each year, several major aquifers have been intersected and significant depressurisation has been achieved.

**Mobile fleet control**

DOZ employs Modular Mining’s Intelimine Dispatch software system, a large scale and computer based mine management system, to monitor and control production loaders and trucks. The hardware system consists of a central computer, a network of micro-cells, equipment field computer systems (FCS) and fixed radio frequency (RF) tags. Communication between the FCS and the micro-cell network and the RF tags is by UHF radio transmissions. Hubs manage communication between the equipment and the central computer system. Dispatchers seated in a central underground location, shown in the figure, monitor dispatch operations. It monitors precise compliance of actual production to the long-term plan and aids effective management of the DOZ cave.

In extraction operations, the system provides an effective means to communicate the details of the production plan to the trackless equipment operators. Also it collects accurate actual production data, which allows calculation of compliance to the production plan. Daily actual production is summarised for transfer to other production planning tools.

It will identify circumstances when equipment operators are not producing to plan and allow the LHD and truck operators to effectively communicate with the dispatcher.

Intelimine also allows haulage operations to be conducted and optimised with only minor active input from dispatchers or supervisors.

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**Existing underground DISPATCH® configuration**
One chute per production panel
40-50 m orepasses
Diameter 4 m at 75-85°
Centre loading chutes
Mud rush protection

Use of the system, in general, provides a continuous monitor of all production activity. Information stored to the database provides the basis for calculating equipment productivity and efficiency. Since allocation of equipment to a particular task is automated, supervisors are left free to instead focus on resolving mine issues.

Shotcrete use
The rock mass is regularly classified using the Q-system and the RMR system\(^2\). The diorite is the highest quality rock – a high strength, well jointed rock mass that comprises most of the footwall. The DOZ Breccia (a.k.a. Highly Altered Locally Ore - HALO) is typically the lowest quality rock mass. This forms pods of low strength, highly fractured and brecciated rock within the ore zone. It cuts all other units and almost without exception results in poor ground conditions.

The characteristics of the other main rock types in the EESS are as follows. The forsterite skarn is a massive unit adjacent to the Ertsberg Diorite Contact and is generally a hard competent rock unit with good ground conditions. The magnetite-forsterite skarn is generally hard and competent; giving good ground conditions, but may contain localised zones where ground conditions are poor.

The mineralised marble is highly fractured with fracture spacings between 50 and 100 mm. There is also a very low-grade marble that is soft and moderately fractured. It can be hard and massive near the contact with skarn.

Shotcrete (typically designed to achieve a compressive strength of 40 MPa) is applied to large openings, the surface of fractures, soft ground and weak joints, long-term drift openings and in heavily blasted ground on the extraction level. Ranges of 12 permanent support designs have been used throughout the DOZ, based on rock type and mining conditions, besides 50 mm development shotcrete support. The Geotechnical department works closely with the Pre-Production (Ground Support) Engineer to decide which type of shotcrete support is appropriate. It has been found with experience that the best shotcrete design is a combination of personal experience, empirical methods and analysis.

In the northern extraction steel fibre shotcrete has been applied with two layers of 6 mm rebar mesh, where the ground is soft and moderately fractured. Just one layer of rebar mesh or development shotcrete is generally all that is needed in the southern extraction area.

In HALO areas development shotcrete is applied very soon after drift and drawpoint excavation. Final support is provided by a combination of a steel frame and conventionally placed concrete.

In some areas, the installation of steel sets has proven to be problematic and inefficient, incurring high risk. Redpath evaluated the use of rebar arches reinforced with shotcrete. A drill jumbo positions and secures the arches with rock bolts to the back and ribs. When encapsulated in shotcrete this provides for a structurally sound reinforced concrete beam. This method of ground support removes the need to construct forms and pour concrete behind and between steel sets. This method has proven to be a safe and efficient alternative to traditional steel set installation.

Like a growing number of mines, Freeport has installed rescue chambers for safety in the event of underground disasters. There are over 20 of MineARC’s standard hard-rock refuge chambers in the underground operations. Each self-contained unit can accommodate 25 persons and is designed to clean air of harmful gases and toxins. These chambers provide ease of use and extended time periods between chemical change outs. Occupants who have to use the refuges are protected from deadly gases present in smoke filled environments. MineARC’s standard hard-rock refuge chambers in the underground operations. Each self-contained unit can accommodate 25 persons and is designed to clean air of harmful gases and toxins. These chambers provide ease of use and extended time periods between chemical change outs. Occupants who have to use the refuges are protected from deadly gases present in smoke filled environments. MineARC systems recognise that the chamber’s environment must be cooled due to the potentially fatal build-up of metabolic heat created by occupants in confined spaces. They are designed to be easily transported and placed where needed.

There is a filtered and silenced compressed air supply system. The chambers feature a patented \(\text{CO}_2\) and \(\text{CO}\) scrubbing system. There is a split-system air conditioner and digital gas monitoring provides real time gas monitoring for \(\text{O}_2\), \(\text{CO}, \text{CO}_2\). This ensures safe and accurate air quality. Medical oxygen cylinders are available in a removable cylinder rack for easy transport.

The control system features internal/external battery sensing, one touch emergency operation, automatic programmable testing and keypad control. The external battery and back-ups, in case of mains power failure, provides power for up to 36 hours.
DOZ new oreflow system

The design of the DOZ mine includes a number of ventilation raises (mined by Redpath) originating from the surface area at the DOZ. These raises typically range in length from 150 to 350 m. Redpath undertakes additional fresh air and exhaust raise development between the undercut, extraction, ventilation and truck haulage levels. These raises range from 20 to 65 m in length and are required due to the mine’s ever increasing production.

It is often assigned projects that require rapid development or those with difficult and potentially high risk mining conditions. For example, in another project to improve ventilation, NED (New Exhaust Drifts) required mountainside breakthroughs to establish portals 3 and 4. Driven through surface material, with no outside access, these breakthroughs proved to be technically challenging. The installation of spilling, rebar arches and shotcrete were used in order to safely complete this project.

Excavating the NED fan chambers was a mass mining project that required precise mining methods. Two chambers were required to house the 1,600 kW fans for the 80K expansion. IM

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