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# Lift 2 North extension cave performance

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## Abstract

*Development of the Lift 2 North extension (L2NE) block cave commenced in September 2006, with the production ramp up in early 2008. The extension cave now produces in excess of 380,000 tonnes of ore a month with production planned to continue until the new Endeavour 48 (E48) cave has reached steady state production. Production of the L2NE cave will then resume once the E48 cave is exhausted.*

*Caveability predictions during the feasibility study indicated that the highest risk to cave propagation was related to the higher rock mass strength on the eastern margin of the cave. Furthermore, the potential risk of early clay dilution entry from the depleted Endeavour 26 (E26) Lift 2 (L2) and Lift 1 (L1) caves was a major concern. The issue of poor caveability was addressed through the application of several techniques used to weaken the rock mass, namely, hydraulic fracture preconditioning, pre-split boundary weakening and preconditioning blasts along both the eastern and western margins of the cave footprint.*

*In order to monitor and manage the cave propagation and clay dilution entry into the L2NE block cave, extensive cave monitoring systems were implemented, of which several open holes, over 300 m in length, proved the most valuable in detecting the cave back and muckpile positions. Northparkes was the first block cave mine to successfully trial and implement the Smart Marker technology to monitor cave flow.*

## 1 Introduction

The E26 Lift 2 cave is located approximately 835 m from surface and lies 350 m below the exhausted E26 Lift 1 cave. Production commenced in July 2004, with the plan to mine the 350 m high lift orebody until 2009. Unfortunately however, the Lift 2 cave propagated very rapidly and broke through into the overlying Lift 1 cave at the end of 2005, allowing dilution (clay) from the L1 cave to enter the L2 cave. The dilution material is very fine and thus is able to flow through the cave muckpile a lot faster than the coarser fragmented ore, hence clay dilution entry was observed in the L2 drawpoints within 18 months of breaking through into the L1 cave. As the percentage of clay in the drawpoints increased, problems arose with blockages and mud rushes in the material handling system. Subsequently, the recovery of metal in the mill became more complicated.

The shutting down of drawpoints with high clay content ultimately resulted in a drop in production from approximately 380,000 t/month in January 2007 to only 20,000 t/month in July 2007. As the clay started to move into the cave and it also became clear that an intact wedge of ore did not cave and remained ‘hung up’ on the southern and northern sides of the L2 cave. Once it became evident that the recovery of the hung wedge was problematic, a feasibility study was conducted into the extension of the L2 cave footprint towards the north in order to be able to produce ore until the commencement of the E48 cave. Development of the L2NE commenced in September 2006, with production ramp up in early 2008. L2NE cave now produces ore in excess of 380,000 t/month.

The successful recovery of ore resources through any cave mining method is highly dependent on minimising dilution entry, thus the L2NE cave was designed on the following assumptions and strategies in mind:

- Drawpoint interaction would occur.
- The northeast of the cave would have higher draw rate (to minimise dilution from the L2 cave in the south).
- A variable draw strategy would be implemented and this would be dependent upon the percentage of clay contained in the drawpoints.
- The cave management would focus on strategies that prevent the flow of clay into the L2NE cave thereby controlling the percentage of clay fed into the materials handling system and thus minimising the incidence of blockages in the materials handling system.
- The L2NE cave propagation would be assisted through preconditioning and induction techniques such as hydraulic fracturing preconditioning, boundary cutoff slot blasting and cave back blasting.

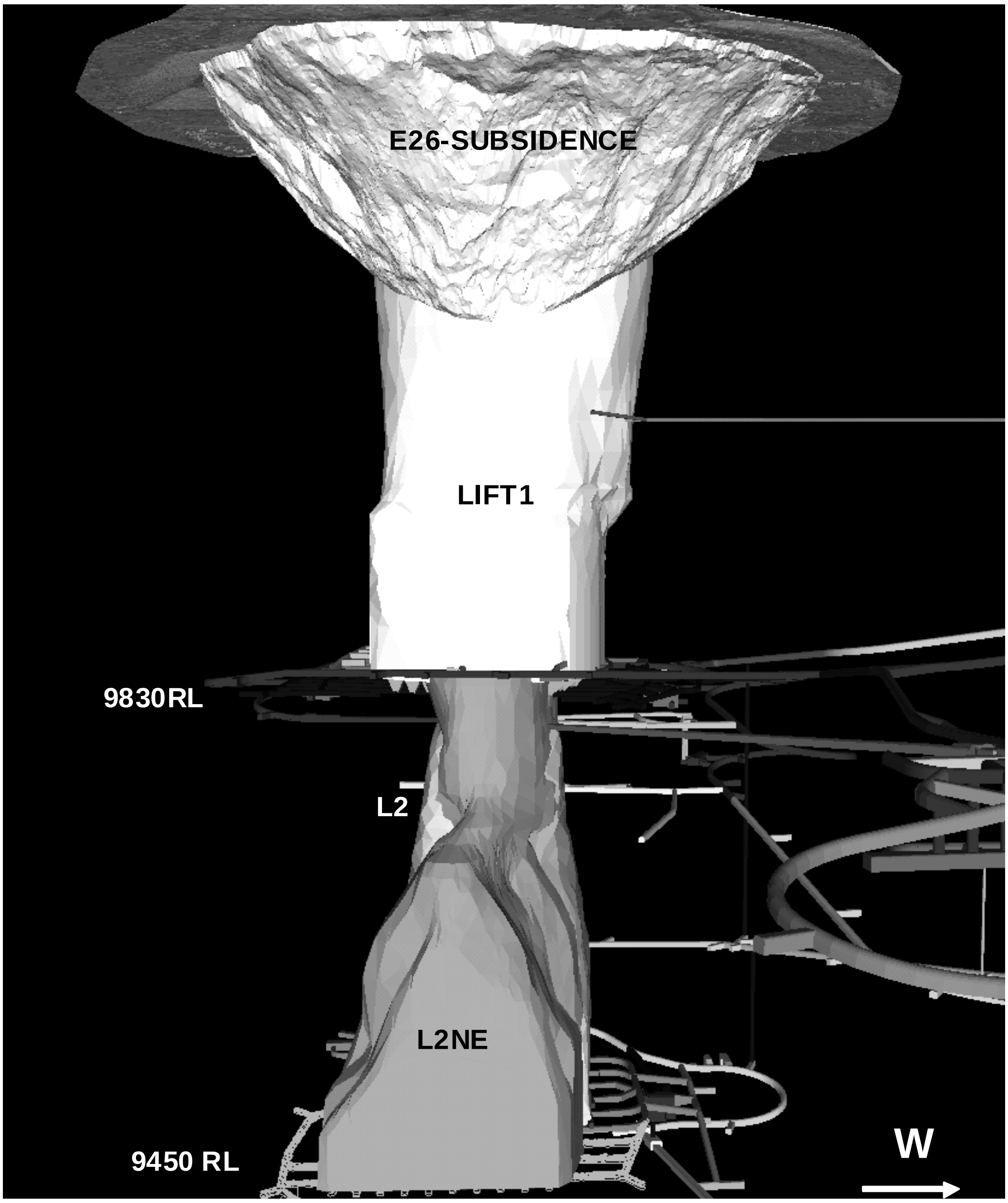



**Figure 1 Isometric view of E26 lifts**

To date the L2NE cave back has developed a complex shape in that it has broken through into the overlying L1 cave in the south, whilst in the north the cave height varies from around 100 m on the eastern side to

190 m on the western side, as illustrated in Figure 2. The caving rate was initially quite rapid, attributed to the success of the various cave assistance methods, though the current caving rate has slowed considerably following the connections with both L1 and L2 caves. The flow of fine material from these caves fills any expansion voids below the L2NE cave back, effectively buttressing the cave back and inhibiting caving.

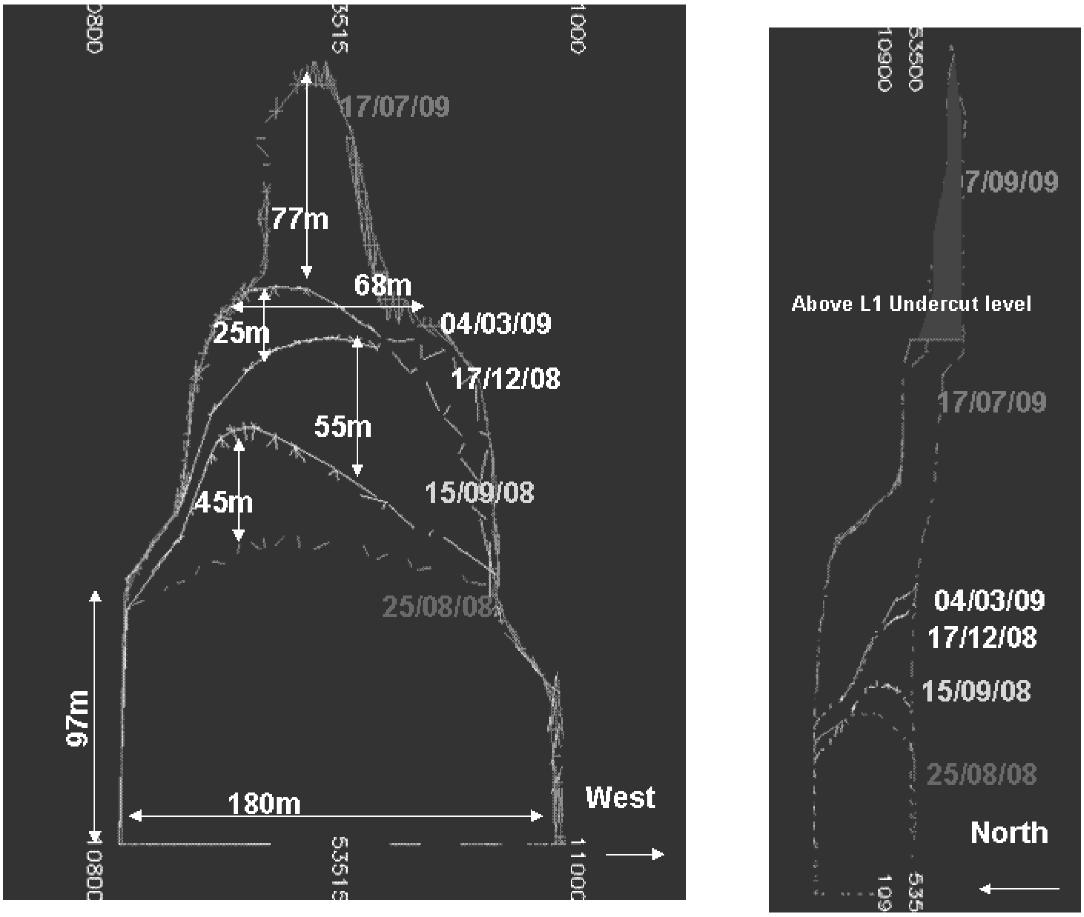



**Figure 2 Cross section of L2NE cave propagation versus time**

## 2 Geology and caveability

The Northparkes deposits are typical porphyry copper systems. Mineralisation and alteration are zoned around quartz monzonite porphyry (QMP) intrusives that form narrow but vertically extensive pipes. The E26 deposit is centred on a series of subvertical porphyry intrusives, including late barren porphyries that straddle the contact between a biotite quartz monzonite (BQM) stock and volcanic rock.

The L2NE rock mass is well jointed, with the BQM in the east being characterised as the least jointed and the volcanics in the west being most jointed, though all rock types appear to contain up to five joint sets. Laboratory strength testing and rock mass ratings (RMR) (Bieniawski, 1976) are summarised in Table 1:

**Table 1 Intact rock strength at RMR76 for the major L2NE rock types**

| | QMP | BQM | Volcanics |
|---|---|---|---|
| UCS | 115 MPa | 144 MPa | 99 MPa |
| RMR76 | | 80 | 65 |

The main geotechnical concerns identified for the L2NE project were related to the caveability of the relatively small cave and the stability of the extraction level extension given the high abutment stresses around the existing cave. Initial FLAC3D modelling demonstrated that the L2NE cave would easily propagate in the volcanics (western side of the cave) to beyond the base of the L1 cave. However, the caveability of the BQM (northeast side of the cave) was predicted to be problematic with a 'haunch' developing similar to that in the L2 cave. Subsequent modelling focussed on assessing the benefits of preconditioning the L2NE rock mass through hydraulic fracturing and drill and blast activities on both the southern and northern sides of the existing L2 cave.

The numerical modelling predicted that hydraulic fracturing would increase the L2NE cave volume by more than 20%, principally through improved mobility of material in the northeast corner, although the drill and blast activities would have only a marginal impact. It was concluded that the L2NE caveability could be further enhanced through targeted hydraulic fracturing in certain areas of the cave back, post-cave initiation.

During the early stages of production ramp up, the L2NE cave propagated steadily at a rate of 2–3 m/week, the cave back averaging 70 m in height with an average expansion void height of 8 m, this yielded 2 million t of ore during 2008. Once steady state production was reached in April 2008, the propagation of cave slowed and caving was more sporadic.

Cave propagation was continually monitored in conjunction with the draw strategy so as to ensure that an effective 'buffer' was created adjacent to the old cave boundary to limit dilution entry. Draw rates were strictly controlled to ensure that they did not exceed the caving rate, thereby preventing the development of an unacceptably large air gap.

In June 2008 the caving stalled in the east of the L2NE cave due to the presence of the more competent and less brittle BQM. Unfortunately, the east side of the L2NE cave also comprised the highest grade ore and thus a campaign of hydraulic fracturing was conducted to promote cave growth in this region.

## 2.1 Cave propagation techniques

The successful propagation of the L2NE cave was imperative for Northparkes Mines life of mine plan in the short term, in that the L2NE cave was required to yield approximately 5 million t of ore, 'breaching the gap' between the closing of the L2 cave and steady state production from the E48 cave. Should the entire L2NE resource cave exactly as planned then it has the potential to produce an additional 15 million t of ore. As mentioned previously, the numerical modelling predictions suggested that the L2NE cave walls would converge towards the L2 northern cave boundary instead of breaking vertically upwards. Thus, in an attempt to promote the vertical propagation of the cave and reduce the tendency of the cave to fail back towards the existing L2 cave, an extensive programme of rock mass preconditioning was undertaken. The cave assistance techniques employed included hydraulic fracturing, boundary weakening and blasting the cave back.

### *2.1.1 Hydraulic fracturing*

The successful application of hydraulic fracturing in inducing failure of the L1 cave back (van As and Jeffrey, 2000) demonstrated that hydraulic fracturing can prove an effective induction technique in promoting caving in the Northparkes rock masses. Thus the L2NE cave block underwent an extensive programme of hydraulic fracture preconditioning prior to mining. The objective being to weaken the rock mass and promote the vertical propagation of the cave.

This technique involved creating a series of horizontal fracture planes within the rock mass that extend for a distance of up to 50 m or more from the injection point. Numerical modelling predicted that the introduction of hydraulic fractures would lead to a 20% reduction in the cohesive strength of the rock mass, and ultimately allow the cave to propagate vertically upwards, thereby preventing the formation of a haunch in the competent BQM rock mass. Figure 3 illustrates the hydraulic fracture design, the wide cylinders indicating the portion of the holes that were fractured.

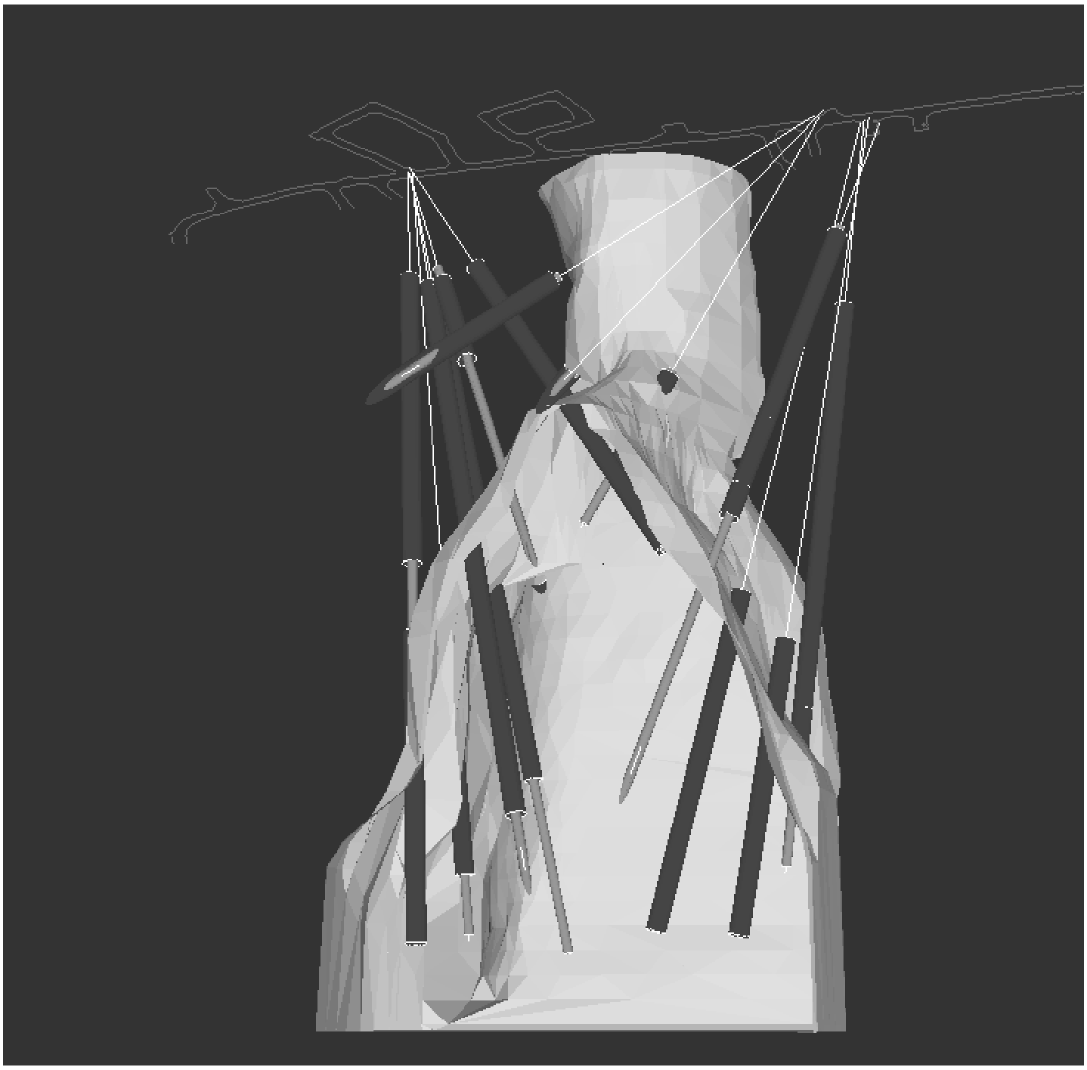


**Figure 3 Final L2NE hydraulic fracturing hole**

*2.1.1.1 Hydraulic fracture preconditioning*

A total of 13 HQ holes drilled on 60 m toe spacing, were fractured every 2.5 m on retreating up the hole. The drill holes varied in length from 200 to 365 m.

This hydraulic fracturing programme was successful in introducing significant, subhorizontal fractures into the rock mass, which in turn aided the initial cave propagation, however, it did not sustain caving on the east and west boundaries beyond 100 m.

*2.1.1.2 Hydraulic fracture cave induction*

Given that the preconditioning was not entirely successful; an additional campaign of hydraulic fracturing above the L2NE cave back was undertaken in June 2008. As with the preconditioning programme, the objective of this campaign was to attempt to reduce the rock mass strength and promote caving (particularly in the east). The programme involved fracturing four holes drilled from the 9830 level on the eastern side of the cave. A total of 78 hydraulic fracture treatments were conducted, however, the programme proved unsuccessful in inducing caving, this was attributed to:

- excessive leak off into the cave thereby preventing efficient hydraulic fracture growth
- absence of any expansion void into which the cave back could fail.

### 2.1.2 East preconditioning through blasting

In June 2008 after the cave back had stalled, observations showed that a void of between 8–18 m had formed between the muckpile and the cave back, this immediately triggered a reduction in the draw rate from the western drawpoints. In an attempt to induce caving, blasting options were proposed in addition to hydraulic fracturing.

The L2NE east blast hole preconditioning programme comprised of 16 × 165 mm diameter holes of varying length, between 150 and 240 m, and spaced on a 15 × 9 m grid pattern. These holes were charged with a total of 56 t of explosives.

In August 2008 the eastern preconditioning holes were blasted, and although they were unsuccessful in propagating the eastern side of the cave they did however, generate extensive seismic activity and propagated the western side of the cave. Subsequently, the western side of the cave has always propagated at a faster rate than the east.

### 2.1.3 Boundary weakening program

The use of boundary cutoff slots to induce stalled caves is well documented and given the limited success of the hydraulic fracturing to induce caving, Northparkes resorted to using more conventional blast options. The boundary cutoff slot comprised of 165 mm cubex holes drilled from the 9830 level, as illustrated in Figure 4. The objective of the boundary slot was to attempt to cutoff the clamping stresses acting across the cave back through the creation of a large destressed zone.

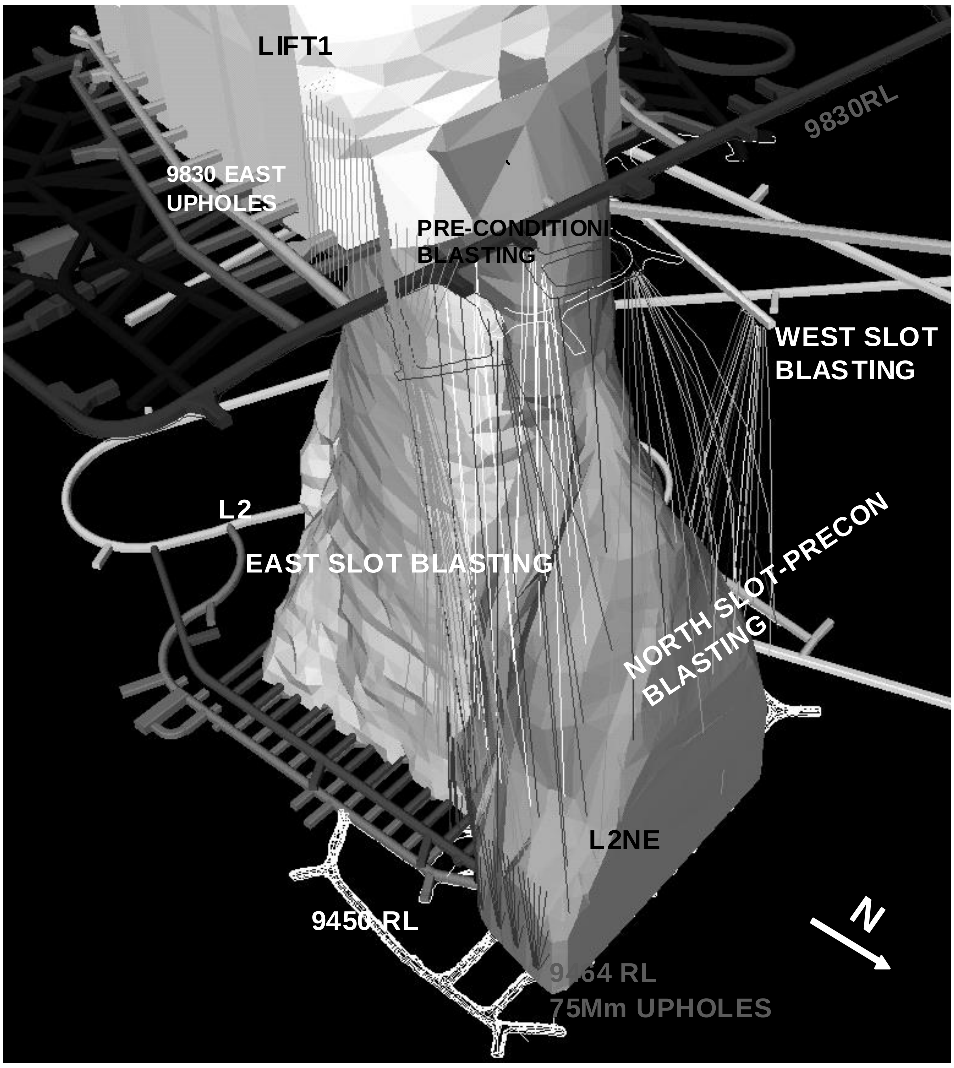



**Figure 4 Schematic of the L2NE cave propagation in response to cave inducement techniques**

#### *2.1.3.1 Boundary pre-split blasting from the undercut level*

A total of 50, 75 m long, 160 mm diameter holes were drilled vertically upwards from the undercut level. Each hole was, charged with 60 t of emulsion and blasted with the last remaining east undercut rings.

#### *2.1.3.2 West boundary slot blast from the 9700 level*

To bring the west cave back up to the same elevation as the rest of the cave, the creation of a western boundary cutoff slot was attempted. A total of 18, 208–248 m long, 165 mm diameter cubex holes were drilled from the 9700 level in the west exploration drive. Of these, 17 holes were charged (one hole was abandoned) with 21 t of explosives, the blast generated a magnitude 2.3 seismic event and was successful in inducing propagation of the cave in the west.

#### *2.1.3.3 East boundary slot blast from the 9830 level – north boundary slot blast*

To induce and sustain caving in the east and also try and control the direction and shape of the cave propagation in the north, the following holes were blasted:

- 26 vertical, 165 mm diameter cubex holes drilled on the eastern boundary of the cave
- 13 vertical, 165 mm diameter cubex holes were drilled along the northern boundary from the 9830 level
- thirty 60 m long, 165 mm diameter, vertical upholes were drilled along the eastern boundary on the 9830 level
- the down holes were blasted several times in decks varying from 14–73 t of explosives.

### *2.1.4 Preferential draw in the north*

Following the 1999 air blast incident at Northparkes Mines L1 cave, stringent cave management protocols have been implemented to ensure that cave draw does not compromise the safety of mine workers. These rules principally govern the cave production rate as a function of the size of the expansion void between the muckpile and the cave back. Key rules include:

- the height of the expansion void between the cave back and muck pile is managed using an approved nomogram
- daily draw rates are consistent with the maximum ramp up rates adopted by other block caves under similar rock mass and stress conditions as well as experience gained from both the L1 and L2 caves.

These rules proved effective in managing the cave ramp up, though once dilution entry had occurred the draw strategies would vary so as to minimise dilution and optimise the recovery of the reserve.

The general draw strategy, based on work conducted by Dudley (2007), was to draw higher from the northeast side of the orebody in an attempt to promote caving of the more competent BQM in the east and induce vertical cave growth in the north, thereby minimising clay dilution from the existing L2 cave in the south.

The size of the expansion void, induced seismicity and cave wall geometry were the overriding controls that dictated the actual draw rate. Any deviation of the draw rates from the general draw strategy were permitted following:

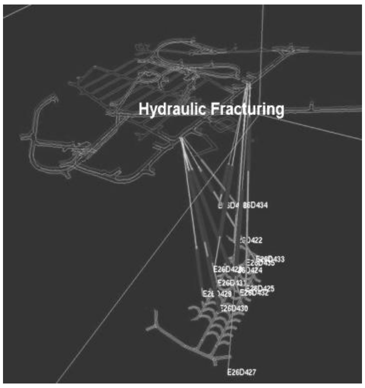
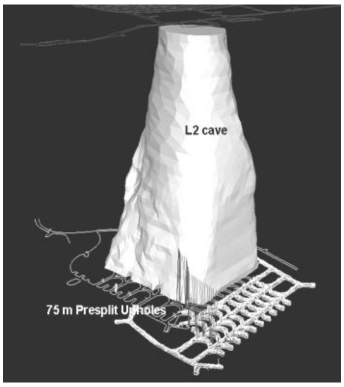
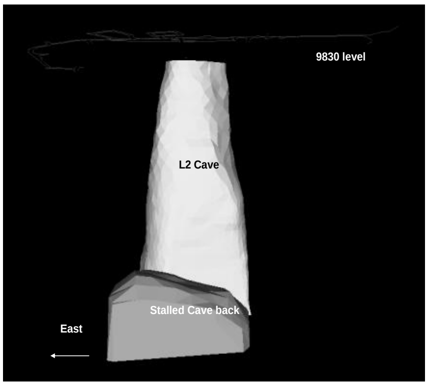
- confirmation from monitoring data that the expansion void was within acceptable limits
- the cave seismicity was within acceptable limits
- consideration of the cave back geometry.

In addition to the draw strategy, the risk of early dilution from the L2 cave was reduced by creating a 20 m ‘span interrupt’ (buffer zone) between the L2 and L2NE caves. Unfortunately, this course of action severely hampered the propagation of the L2NE cave, allowing the cave to arch through the buttressing affect of the stagnant zone. As a consequence it was necessary to resume draw from the northern L2 drawpoints as well as develop southern drawpoints in the L2NE cave, all of which ensured that the cave column became remobilised in this region and led to cave propagation on the boundary between L2 and L2NE.

## 3 Chronology of events

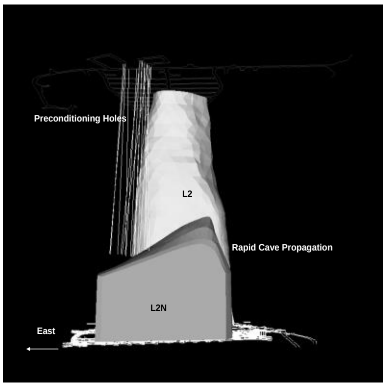
From the underground observations and the combination of monitoring systems the following events in Table 2 was thought to have happened.

**Table 2 Significant periods in the development of L2NE cave**

| | |
|---|---|
| **July 2007**<br>Hydraulic fracturing of some parts of the L2NE block completed prior to undercut blasting. |  |
| **January 2008**<br>Pre-split style blast with 75 m upholes drilled from sublevel on the northeastern cave boundary, blasted with remaining eastern undercut rings. This helped shape the initial 90 m of the eastern boundary. |  |
| **February 2008**<br>Draw is biased towards the northern part of the extension to propagate the cave boundary and minimise clay ingress into L2NE. | |
| **June 2008**<br>Caving stalled with increasing airgap. Drawing from south of the L2NE cave has commenced to destabilise the rock mass between L2 and L2NE caves. |  |

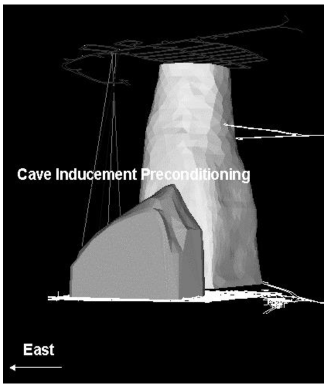
**August 2008**

Successful east preconditioning blast resulted in rapid propagation of the western side of the cave. Clay ingress after the skin failure on the L2/L2NE boundary following the blast was confirmed by the increase in muckpile height whilst the cave back remained stationary.




**November 2008**

An unsuccessful trial of cave inducement by means of hydraulic fracturing in the eastern side of the cave. First clay seen in the south of L2NE cave after 1.8 million t of ore (9 months of production).

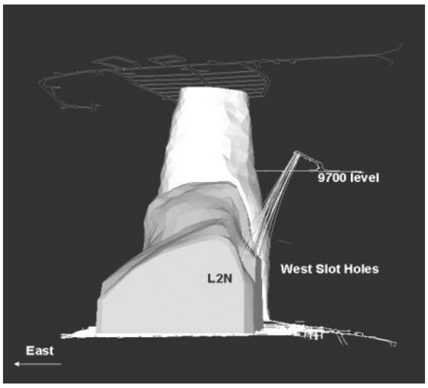



**December 2008**

Clay entered the undercut drawpoints after an average of 30,000 t had been drawn from each draw column. The Smart Marker trial resulted in no indication of interactive draw zones in the undercut level with ore fragmentation of fine to medium size. Fine material migrated through high draw rate channel ways at a rate of 50 m a day. There were little indications of lateral movement of coarse rock between the drawpoints. Presence of dolerite in the undercut draw points proved rilling took place on top of the muckpile from a west to east direction.

**January 2009**

Western slot blasting completed, resulting in rapid propagation in the western side of the cave. Rate of caving accelerated to 3,000 mm per day. The L2NE cave has broken into the L2 cave along the northern boundary.

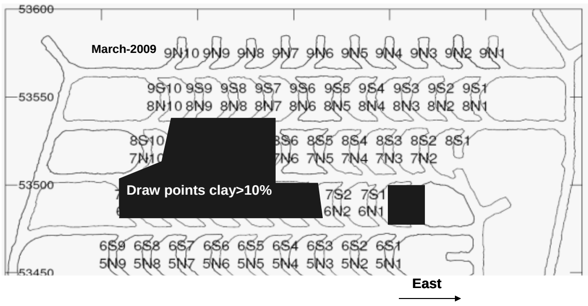



**February 2009**

Cave continued to propagate vertically but also inclined along the northern boundary. Red clay filtered through the southern drawpoints of the cave.

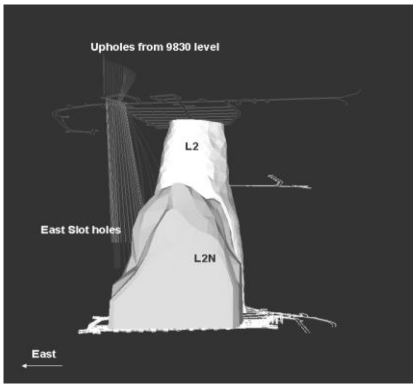
**March 2009**

Clay entered from the L2 cave after the preconditioning blast, spreading across the western draw points of the L2NE extraction level.



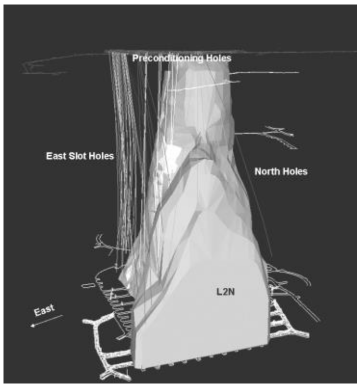

**April 2009**

The L2N cave continued to propagate upwards especially along the northern boundary. The 9830 east slot presplit holes had the toes fired out to improve the caving on the eastern boundary. From the monitoring of the open holes, skin failure in the eastern cave wall was detected. The pre-blasting of the previously fired eastern pre-split holes together with the firing of northern holes was completed to induce propagation, but with minimal results.




**May to July 2009**

A mass blast on the north slot holes, east slot holes and eastern preconditioning holes resulted in a 3.6 magnitude event. Total of 42 drill holes up to 150 m in length were charged and collectively fired on 9 July 2009. Video monitoring of open holes detected clay dilution on the top of the muckpile from the L1 cave. The observations from the 9830 level indicated that the L1 cave is propagating and feeding in to L2NE cave.




**September 2009**

Mass blast on the north slot holes resulted in 1.5 magnitude event. Total of seven drill holes were charged with 14 t of explosive and collectively fired. The blast was followed by an increase in activity rate, which returned to normal levels over the following two days. The blast impact on the cave propagation of the L2NE cave was minimal.

**November 2009**

Cave back on the eastern side remains stationary.

# 4 Monitoring

Northparkes Mines is committed to the responsible management of the E26 block caves which is clearly demonstrated in their comprehensive cave management plan (CMP). The CMP is underpinned by both high level and detailed risk assessments which have led to the development of several Triggered Action Response Plans (TARPS) and a suite of Standard Operating Procedures (SOP). The overall cave management program relies heavily on well designed and managed surface and underground geotechnical monitoring (and reporting) systems. These systems have produced an invaluable archive of data which are constantly analysed to ensure the most up to date information is made available for appropriate cave management decisions. In order to fully comply with the requirements set out in the CMP, Northparkes Mine has implemented the following monitoring systems:

- Open hole videoing used to monitor cave back, muck pile, rock fragmentation, muckpile rilling and borehole wall conditions.
- Seismic monitoring used to locate cave boundaries, locate caving activity and assist in evaluating the safe re-entry to all levels of the mine after blasting.
- Time domain reflectometry (TDR) used to monitor the cave back position.
- Cave markers (Smart Markers and dumb markers) used to monitor cave flow.
- Convergence stations used to monitor excavation stability.
- Extensometers used to monitor excavation stability and rock mass deformations.
- Aerial Flyover surveys used to monitor surface subsidence and track the mass balance between subsidence volume and production (i.e. track volume change inside the E26 cave).

## 4.1 Open holes

Northparkes Mines utilises two open hole monitoring methods to determine the cave back and the muck pile locations. One of the monitoring techniques uses split set, or so called ‘bullet’, to measure the depth of the open hole. The bullet is attached to a wire line which is lowered on a winch with a depth counter. When the bullet hits the muck pile the depth is recorded and on slow retrieval it opens to form a ‘T’ which catches on the cave back, consequently the cave back position is also recorded. These bullets are imprinted with a unique ID number so that once they are released from the wire line (after the cave back measurement) they fall onto the cave muckpile and are used as cave markers to help understand cave flow.

The most accurate open hole monitoring technique employed is using a borehole camera, this records:

- the condition of the borehole walls
- the cave back condition and depth
- the depth of the muckpile and type of material it comprises
- the flow (rilling) of the muck pile material.

To date, camera monitoring of open holes is conducted almost daily, depending on the cave propagation rate. The high resolution video footage is recorded using a portable PC and this allows the operator and engineers to make informed assessments and decisions.

Numerous borehole cameras have been used in the past, however, issues relating to durability and cable length have led Northparkes to purchase a customised unit. The main features of the Northparkes borehole camera are shown in Figure 5, they include:

1. A heavy duty robust polyurethane cable with a centre Kevlar strain cord which can withstand the rigorous environment and reach depths of up to 650 m.
2. A high resolution camera similar to that used for security systems.
3. A large hard drive capable of storing months of continuous footage.
4. A video text overlay with depth counter display (project/date/time) allowing hole and depth identification.
5. A variable speed winch with optional remote control.
6. The unit is powered off a standard 240V power supply.

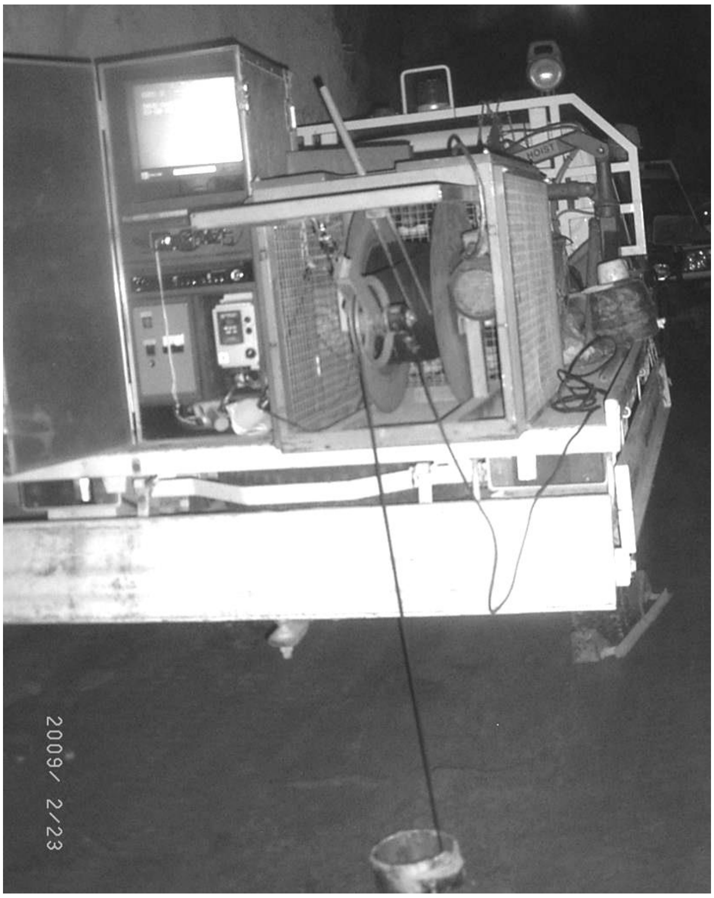



**Figure 5 Picture of the camera set up for operation**

Based on L1, L2 and L2NE experiences the careful design and positioning of the open holes in relation to the cave is crucial for the successful monitoring of the cave back and muck pile positions. To monitor the progression of the L2NE cave back 26 open holes were drilled from both the 9830 and 9700 sublevels with varying depths ranging between 100–350 m. The open holes have proved invaluable for tracking the L2NE cave back progression and the height of the muck pile.

## 4.2 Microseismic monitoring

The L2NE seismic system comprises of eight triaxial accelerometers, providing extensive coverage of the L2NE cave footprint. The initial installation of five accelerometers was designed to cover the early stages of the L2NE cave progression. An additional three sensors (Figure 6) were installed above the 9830 level to ensure that the system continued to provide useful data over the entire life of the L2NE.

Ongoing validation, adjustment and recalibration of the velocity model are conducted regularly to ensure that seismic events are accurately located and reported as part of the cave management process.

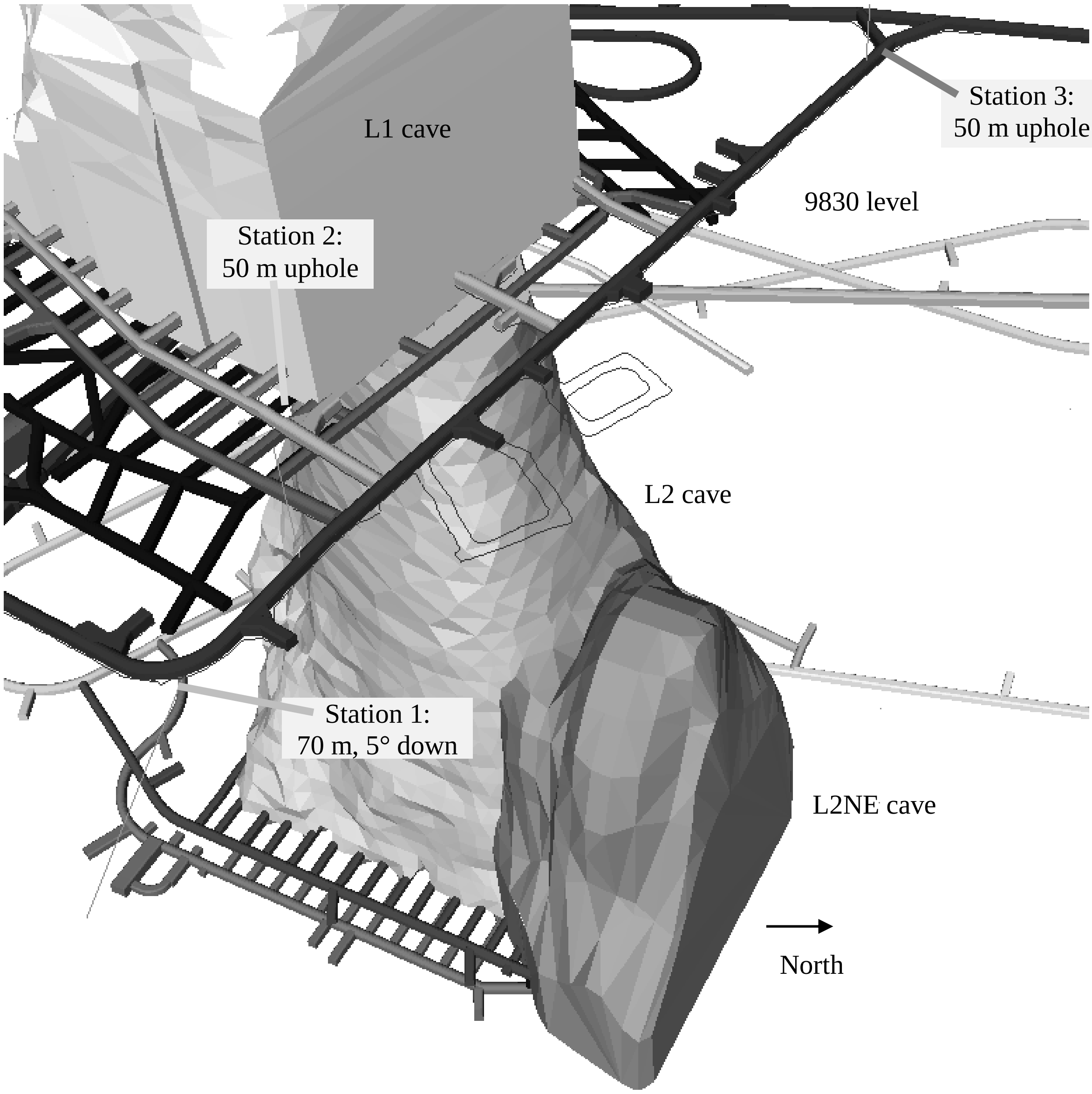



**Figure 6 Additional three sensor locations above 9830 level**

## 4.3 TDR cables

Seven TDRs were installed in holes drilled from the 9830 level drives as the open holes. Unfortunately, the TDR measurements proved unreliable due to cable damage suffered from the cave induction blasting activities.

## 4.4 Smart markers

Recent advances in technology have led to the development and successful implementation of electronic Smart Markers, which, once extracted from a drawpoint, transmit their identity number, and that of the load–haul–dump units (LHD), to receivers on the extraction level. The marked improvement of the recovery of these markers compared to that of the old 'dumb' markers allows for greater application of flow marker monitoring in cave mines, the results of which will undoubtedly improve our understanding of mass flow and assist in the calibration and validation of predictive flow models. The L2NE Smart Marker trial commenced in September 2008. Approximately 25% of the Smart Markers installed have been recovered and detected using the Marker Management System (MMS).

### 4.5 Convergence bolts and extensometers

Convergence pins are used to measure any excavation wall deformation across the extraction and undercut drives. To date, the L2NE readings have indicated displacement of less than 5 mm (horizontally or vertically) and thus it is safe to conclude that no significant convergence of the drives has occurred as a result of abutment or column loading.

Nine extensometers have been installed on the extraction level and four in the undercut level to provide information on rock mass deformations and stress changes. No significant change has been recorded to date.

### 4.6 Aerial survey

Aerial surveys over the E26 surface subsidence zone are conducted monthly. The primary objective of these surveys is to detect any change in the volume of material inside the E26 caves (i.e. an indirect measure of void detection). The results of the aerial surveys have demonstrated that there is a direct correlation between the volume of mined material versus the change in volume of the subsidence zone.

## 5 Discussions and conclusions

- The current interpretation of the L2NE cave monitoring data indicates that the cave has never fully developed over the entire designed footprint. Feasibility estimates of the L2NE cave reserves were calculated at 9.6 million t, and as at November 2009 around 5.6 million t (56%) of the planned reserves has been recovered, containing 300,000 t of clay. It has been calculated that approximately 7.3 million t of caved ore remain inside the cave with a dilution estimate of approximately 20% clay. The cave is currently producing around 14,000 t/day and this rate will be reduced once production ramp up from the new E48 cave commences. This exceeds the feasibility planned volume of 9.6 million t.

- The cave monitoring systems have demonstrated that the L2NE cave (particularly in the east) has propagated better than was predicted by the numerical modelling. However, recent cave propagation has migrated south towards the L2 cave rather than propagating vertically upwards, as illustrated in Figure 2.

- The east preconditioning blasting generated intense caving on the west side of the cave whilst the effectiveness of the slot blasting programs is yet to be seen. An attempt of inducing cave propagation in the east through hydraulic fracturing has produced minimal results.

- Observations from borehole camera video footage and Smart Marker recoveries have revealed that the muckpile surface rilling is a dominant flow mechanism in the L2NE cave. The rilling on the surface of the muckpile appears to be a consequence of the high differential draw rates. This observation is supported by results from the flow markers which tended to travel towards the north eastern boundary, which is characterised by high draw. Unfortunately, none of the existing cave flow models have been able to replicate the cave rilling and thus metal recovery predictions have been poor.

- The surface subsidence monitoring and global stability analyses carried out monthly has showed that the volume of the surface subsidence zone continues to grow. The explanation for these observations is that L2NE cave has now connected through to the old L1 cave which is connected to the surface, hence further drawing of L2NE cave will result in further surface subsidence.

- Given the complex nature of cave flow in the L2NE cave, the flow patterns within the draw columns are perhaps more complex than suggested by conventional theory. Smart Marker movements on the west side of the cave suggested that back calculated draw zone widths ranged from 5–26 m, depending on the draw rate and the cave shape. The issues addressed above highlight the complexity of expanding a new cave from an adjacent mined sector.

- Effective cave monitoring systems are essential for good cave management. There are numerous components to the cave monitoring system, yet the simple, direct monitoring methods of open holes and borehole camera videoing has consistently proved to yield the most valuable and reliable information.

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