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Interaction between a propagating cave and an active pit at Telfer Mine — Part II: monitoring interaction

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Abstract

The Telfer Underground Sublevel Cave (SLC) Operation is located approximately 800 m below the west wall of the Main Dome Open Pit. The Telfer SLC initiated in late 2006 and is caving successfully at a global rate of approximately 0.6 m per day. The cave is expected to break into the planned 5384 mRL bench on the west wall of the active main dome pit which has a haul ramp running along the wall at approximately 70 m horizontal distance from the edge of the cave.

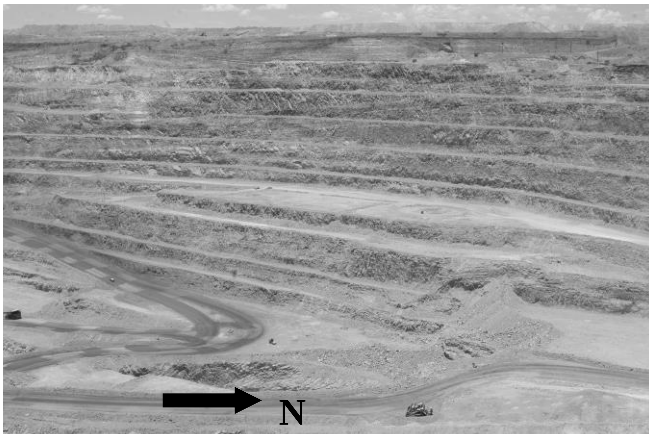
The breakthrough area of the pit was being mined as the cave was propagating, requiring assessment of the potential for rapid propagation and unexpected subsidence. Key trigger points for evacuating and barricading the breakthrough area were based on monitoring of cave propagation, calculation of air gap and risk assessment of the interaction. Monitoring of key parameters was critical for informed decision making and safe management of the interaction.

Part II of this paper discusses the monitoring systems used to track the cave and monitor the interaction area of the pit. These include deep hole extensometers, seismic array, open hole surveys with video cameras, prisms and a radar monitoring system. The monitoring systems are used to determine the cave shape, location, rate of propagation, potential for air gaps and ground response in the open pit. The extensometer array was buried under backfill used to preload the breakthrough area. This required protection for the instrument heads and cabling to ensure that the monitoring continued to function as required. The monitoring systems are critical for indentifying approaching hazards and taking proactive mitigation measures.

1 Introduction

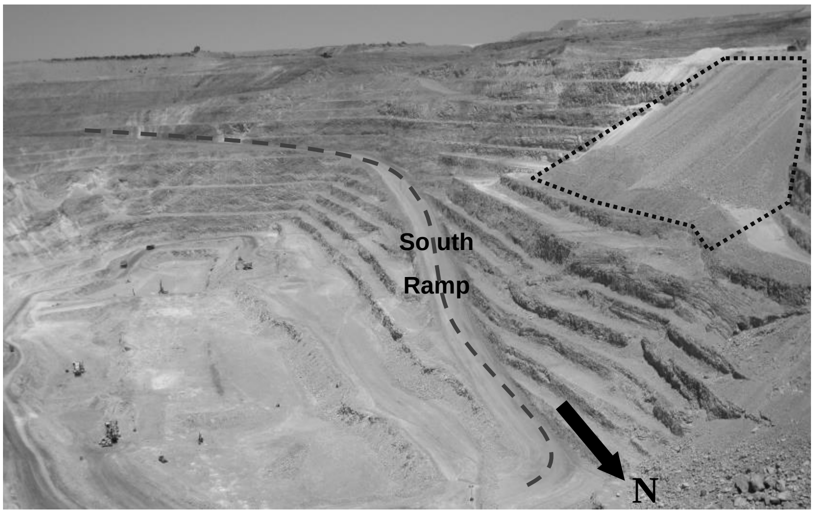
The Telfer Main Dome Open Pit has been mining Stage 3 since 2006 and will continue until late 2010. The Telfer SLC operation was initiated in late 2006 and is located approximately 800 m below the pit. The SLC was planned to break into the 5384 mRL bench on the western wall. The south haulage ramp runs along this wall at approximately 70 m horizontal distance from the eastern flank of the cave (Figure 1). This ramp system will continue to be used for the remainder of Stage 3.

Backfilling of the cave breakthrough area was required to limit subsidence crater extension, and reduce the likelihood of highwall instability. Backfilling of the 5384 mRL bench was completed in two phases. The first phase involved the dumping of mine waste preload material onto the bench. This involved trucks working directly above the propagating cave and was completed in May 2009 with a total of 1.1 Mt material dumped. At this time the bench was permanently closed off in preparation for breakthrough which occurred in late October 2009. The second phase involved tipping material from the top of the western highwall 5480 mRL onto the preloaded bench 65 m below. Backfilling of the area was completed in early October 2009 with a further 1 Mt tipped. Filling of the developing subsidence crater will continue over the life of the SLC, which is currently estimated to be a further five years. This is planned to minimise the instability effects on the pit.



(a) Breakthrough 5384 bench

(b) Preloading of breakthrough bench



(c) Backfilling of breakthrough bench

Figure 1 Stages of preloading and backfilling breakthrough area

The planning and management of the interaction between the propagating cave and open pit is discussed in Part I of this paper. Part II discusses the instrumentation and monitoring which was undertaken to accurately track the cave and manage the associated hazards.

Monitoring of the cave influence on the open pit was critical to enable preloading to continue on the 5384 mRL bench and continued mining in Stage 3. The monitoring systems selected would need to provide information to determine the cave shape and location relative to the 5384 mRL bench, as well as the south ramp. This data would in turn allow for the caving rate and potential for air gaps to be determined. The ground response in the open pit, in particular the cave influence on the western wall directly above the south ramp, and subsidence of the breakthrough area would need to be monitored closely. Finally, the data obtained from the monitoring systems would be used to develop triggers as part of the Trigger, Action and Response Plan (TARP) for cave induced movement.

The selected systems would facilitate identification of approaching hazards and allow for mitigating measures to be implemented. To achieve all of these goals, a suite of both surface and subsurface monitoring systems was implemented at the main dome pit for tracking of the SLC progression and resulting surface deformation. The monitoring systems selected were required to be simple to install and highly accurate. As preloading and backfilling of the breakthrough area had been planned, any instruments installed also needed to be durable enough to withstand backfilling activities and continued mining of Stage 3.

2 Monitoring systems

2.1 Subsurface monitoring

2.1.1 Microseismic array

An Integrated Seismic Systems International (ISSI) real time microseismic system has been installed in two phases. The first phase was installed in August 2005 to capture microseismic activity associated with cave initiation and near mine workings of the SLC. The second phase was designed to capture the full 800 m cave propagation column through to the surface. This phase also aimed to improve the sensor array at the base of the SLC workings.

A total of 26 operating 3D sensors remain, installed below the active underground through to the base of the main dome pit. The system comprises 4.5 Hz triaxial geophones installed horizontally within 15 m deep boreholes and omni-directional 14.5 Hz triaxial geophones installed in 40 m drill holes. Geophones are linked by analogue quake seismometers (QS) accommodating six geophones. QS boxes are linked by digital signal to the run-time system over ethernet based network which is linked by fibre optic through the underground mine.

Residuals for the location are invariably less than 3% of the hypocentral distance (Joughin, 2008). Therefore the location accuracy of events is approximately 10–20 m. Preliminary results from calibration blasts conducted in May 2008, show that the seismic wave velocities recorded on the seismic system are within 10% of actual velocities. The sensitivity of the final network ranges from ML -1.1 to ML -1.3 (Joughin, 2008). The seismic system records over 20,000 events with magnitudes greater than ML -3.2 each month.

2.1.2 Deep hole extensometers

A series of six deep hole extensometers (Figure 2) were installed from the 5384 mRL bench in August 2008. The six holes were drilled to depths ranging from 180–305 m. The holes were installed prior to the cave breaching the 300 m pillar between the cave and pit. In each hole 20 anchors were installed at equal spacing and connected to stainless steel wires which were in-turn connected to spring loaded pulleys in the headframe. Displacement is measured using potentiometers.

This monitoring method was selected as it offered the following advantages:

- each anchor can measure up to 3 m displacement
- anchors can function under shear and extensional conditions
- the 20 anchors are all independent
- ability to create data link between the system and the office
- frequency of the readings can be controlled – readings were taken for each anchor every hour
- installation is relatively simple and quick, with no grouting required

- headframes and cabling could be protected allowing for machinery to continue working in the area
- the instruments had been used in the underground mine previously with success
- Ridgeway Mine has previously used these instruments for monitoring SLC progression (Pfitzner, 2003).

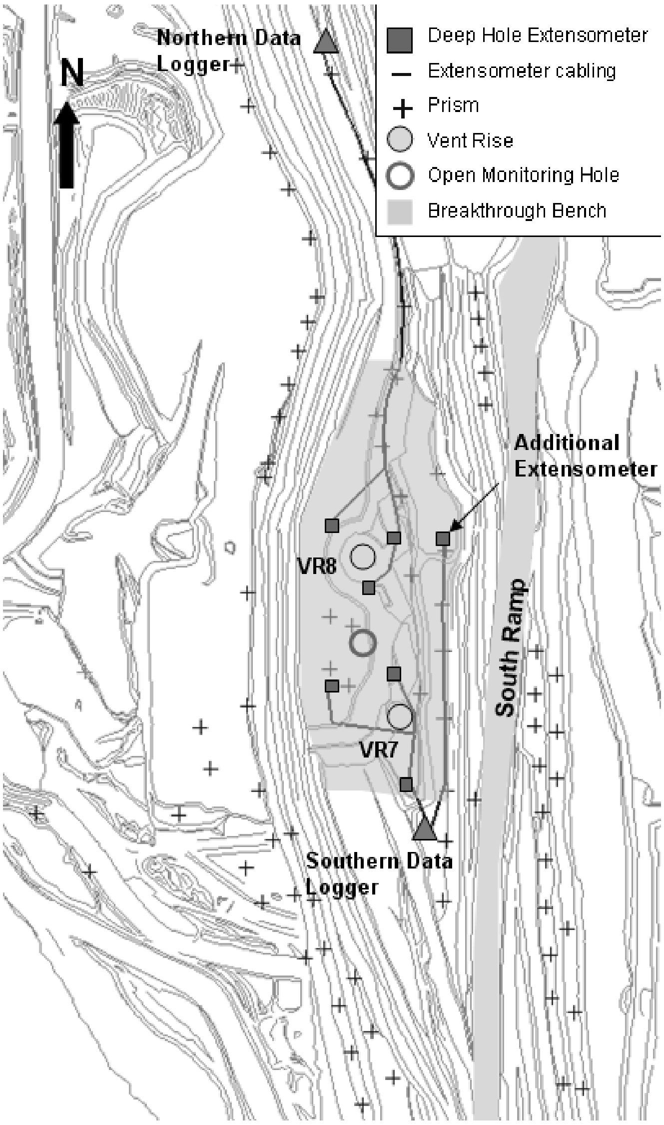


Figure 2 Monitoring plan of cave influence area

To allow for preloading and backfilling activities to take place on the 5384 mRL breakthrough bench it was important that the headframes and all cabling were protected. The six headframes were covered with reinforced cement culverts and then with fine-medium grade rockfill material. All cabling was run through polypipe and covered with rockfill. In areas where heavy machinery was required to transgress over cabling, trenches were dug and the polypipe buried. Whilst trucks were dumping on the preloading bench the headframe locations were delineated to minimise travel directly over them. These protective actions proved successful and the extensometer array continued to function during and after preloading and backfilling. The array was also split into a southern and northern section, with cabling run to each end of the breakthrough bench. This was done so that in the event that cabling was damaged it did not affect the entire array.

In late 2008 it was identified that the cave apex was tracking northeast. The most easterly extensometer was indicating displacement at a depth of 235 m below the breakthrough bench and seismic data was being used to determine the eastern extents of the cave. One additional deep hole extensometer was designed for monitoring of the cave progression east towards the primary haulage route, the south ramp. This extensometer was installed in February 2009 and integrated into the existing array. The design was based on the cave apex at the time. In May 2009 displacement was identified on the deepest anchor at a depth of 180 m below the breakthrough area. This movement was 65 m west horizontally from the south ramp, and 113 m below ramp level. Figure 3 shows the cave apex tracking between December 2008 and February 2009. The outlines shown are for the top 50 m vertically of the cave column.

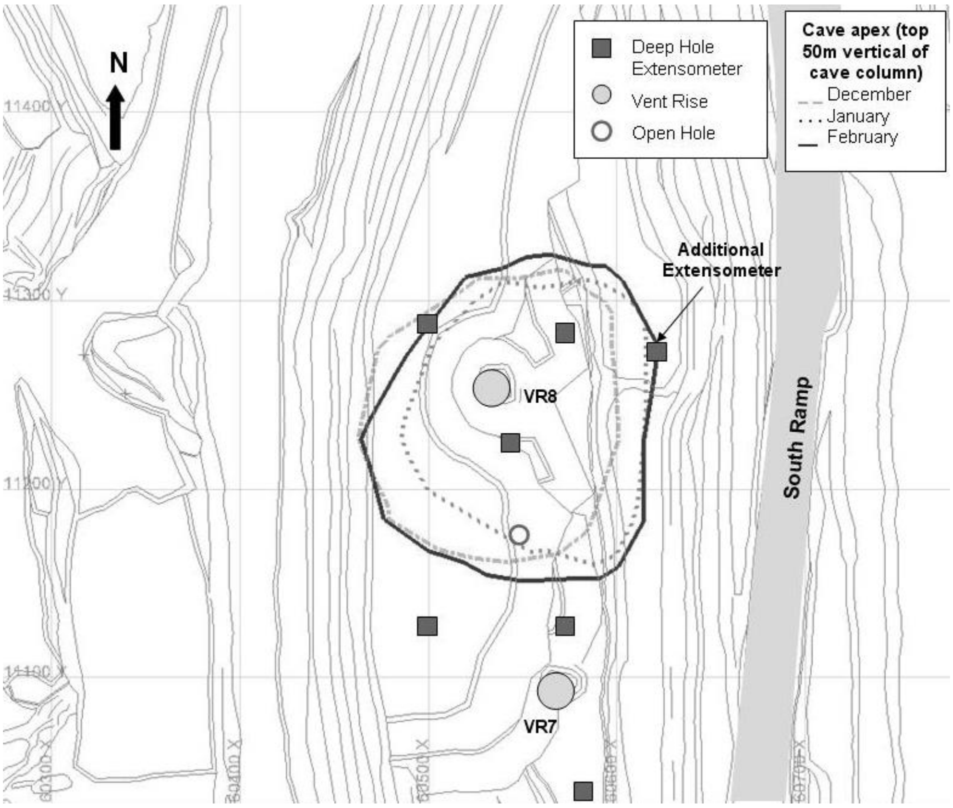


Figure 3 Cave apex tracking

Some disadvantages were identified with this monitoring method. Firstly, following initial installation the weight of the deepest wires resulted in the pulleys creeping and showing anomalous readings. This was overcome by fitting small braking devices to each of the pulleys prior to filling over the headframes. Secondly, when deeper anchors reached their 3 m displacement limit, they broke off and appeared to become tangled with other wires in the hole causing anomalous data. This was the suspected scenario, however, as the headframes were buried it was hard to confirm that this was the case. Finally some anchors did prove to be defective, however, the reasons for this could not be identified.

2.1.3 Open hole monitoring

One open hole was drilled at the centre of the 5384 mRL bench and two decommissioned vent rises were located above the cave. Vent Rise 8 (VR8) located at the northern end of the bench, and the open monitoring hole were used for camera surveys. VR8 was a 520 m deep, 4.5 m wide vent rise which had been backfilled. Once the 5384 mRL bench was excavated an air blast platform and alarm system for rapid subsidence was fitted to the vent rise. The alarm system featured a weight and pulley system which was connected to an audible siren and flashing light. The alarm was activated if the backfill in the rise slumped more than 0.5 m.

Once connected with the cave the backfill material in VR8 began to displace. Two deep hole extensometers and seismic data suggested that that the cave apex was located in close proximity to VR8. The first camera survey of the rise was conducted at this point in December 2008, where the cave back was observed at a depth of 260 m. The final camera survey was completed in late March 2009 with the cave back at 190 m below the 5384 mRL.

The camera surveys of VR8 confirmed the depth of the cave back beneath the northern end of the bench and also the extent of the air gap. Deformation of the vent rise itself was also noted with the opening of structures above the cave back within 20 m. Due to the impact that the connected rise was having on the underground ventilation system, the vent rise was backfilled following each camera survey. When the backfill had drawn down a significant amount the rise was again surveyed.

The open monitoring hole which was located at the centre of the breakthrough area connected with the cave in late November 2008. This hole proved to be less useful as it was not located in close proximity to the cave apex. As the preload material was added to the breakthrough bench, casing on the open monitoring hole was extended in 12 m lifts to allow for continued surveys. When the 150 m pillar initiated the closure of the 5384 mRL, camera surveys ceased.

2.1.4 Correlation between subsurface monitoring systems

The rate of seismicity was tracked daily and compared with SLC production to determine relationships (Figure 4). A relationship was seen to exist and was particularly evident during two shutdown periods in December 2008 and March 2009 when minimal material was extracted from the SLC. When production tonnages were down, the rate of seismicity immediately decreased. However, when production began to increase there appeared to be a lag of 2–3 days to when the seismic rate increased. This information was used to interpret that minimal air-gap existed between the muck pile and zone of loosening above.

In mid January 2009 it was observed that the rate of seismicity was steadily decreasing, however, SLC production remained consistently high. This was highlighted as a concern and an investigation was conducted into the reasons for this trend. It was found that the cave back was approximately 80 m from the M30 mineralised reef (Figure 5) and that the seismogenic zone was concentrated in this reef, which is more ductile than the surrounding rock (Watt, 2009). Seismicity then increased as the seismogenic zone moved past the reef. A similar decrease in seismicity occurred in April 2008 when the cave was approximately 80 m from the M50 mineralised reef.

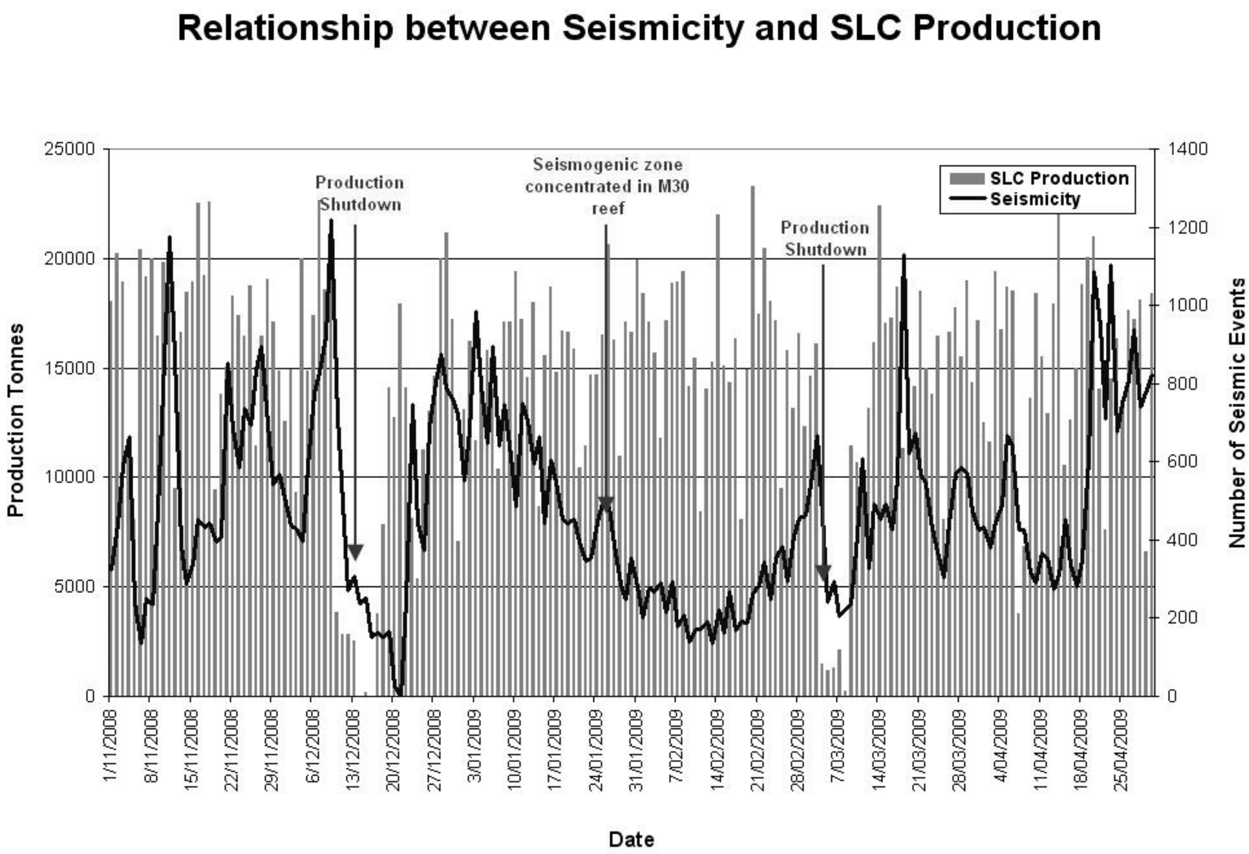


Figure 4 Seismicity and SLC production

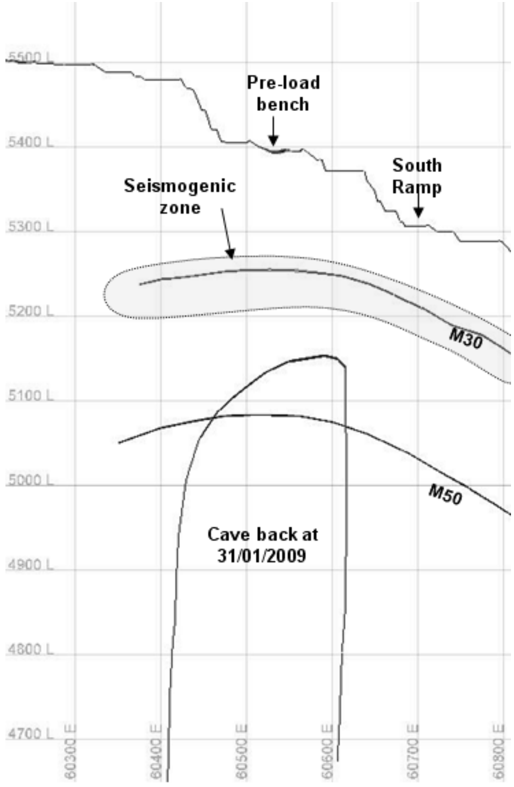


Figure 5 Cross-section through cave and M30 reef, January 2009

The displacement data collected from the extensometer array (Figure 6) was used to confirm that cave propagation was continuing. The data was compared with microseismic and SLC production figures regularly. It was found that a similar relationship existed between extensometer anchor displacement and SLC production. When SLC production was lower, displacement recorded in anchors was also lower. As with the microseismic data this was most evident during shut down periods of reduced production in December and March 2009.

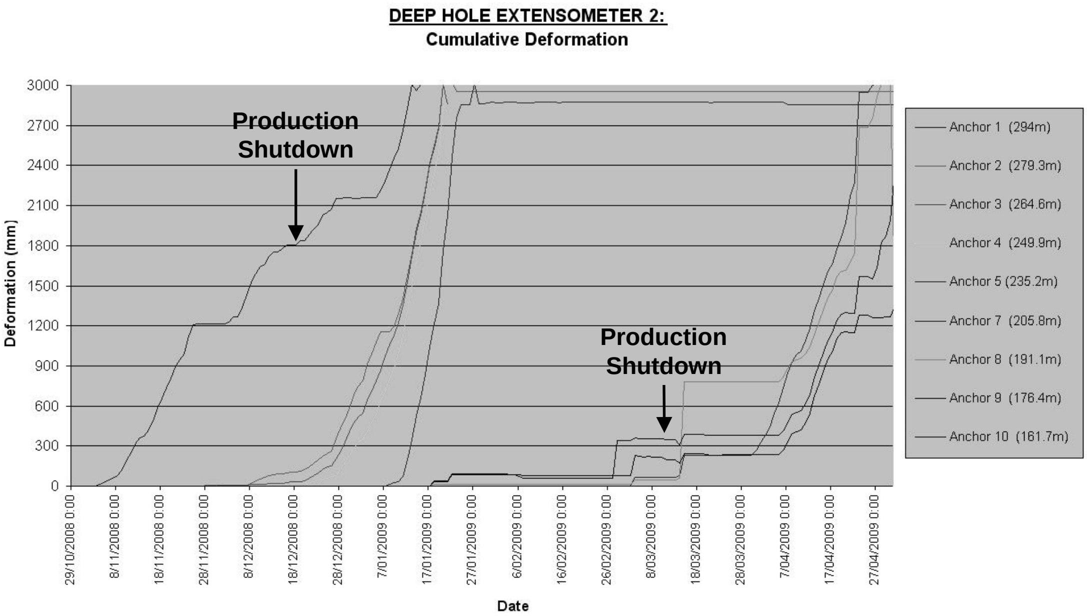


Figure 6 Deep hole extensometer data

Displacement of extensometer anchors also decreased in the period between mid January and late February 2009 when the cave seismicity decreased. A lag was seen to exist between the SLC production recommencing in March 2009 following the shutdown and extensometer anchor movement increasing. Microseismic activity recommenced within days of the resumption of production, however, it was approximately three weeks until extensometer displacement increased again. This was due to SLC production being focused away from the cave apex during this period. Cross cuts were beginning to finish on the 4600 Level below the apex and primary production areas were located at the northern, southern and western extents. Cave growth for February mainly occurred in these areas away from the apex and microseismic activity confirmed this growth. Data from open hole surveys of VR8 was used to confirm that minimal growth had occurred in this area and that no hang-ups or air gap existed in the area around the cave apex.

2.2 Surface cave influence monitoring

2.2.1 Movement and Surveying Radar (MSR)

The Movement and Surveying Radar (MSR) is manufactured by Reutech Radar Systems and distributed by Rock Australia. The MSR 300 has been monitoring the western wall cave influence area since February 2009 (Figure 7). The system was introduced to monitor the highwall above the 5384 mRL bench whilst preloading activities were occurring. It is also used to monitor the western wall immediately above the south ramp (the wall below the 5384 mRL) for instability due to the cave breakthrough occurring behind the wall.

This monitoring method was selected as it offered the following advantages:

- highly accurate system able to detect sub-millimetric movements
- operating range up to 2.5 km; the current main dome pit is in excess of 1 km wide
- fully geographically referenced surveying information
- integration of all measurements with digital terrain map (DTM)
- survey and movement data can be exported into mining software packages, such as *Vulcan*
- alarming capabilities.

Movement of the western wall cave influence area was first detected with the MSR in early May 2009. When breakthrough occurred at the end of October 2009, this section of wall had recorded on average 450 mm total displacement. Alarmed monitoring via mine dispatch was introduced in October with alarm thresholds based on a previous failure which was detected by the MSR.

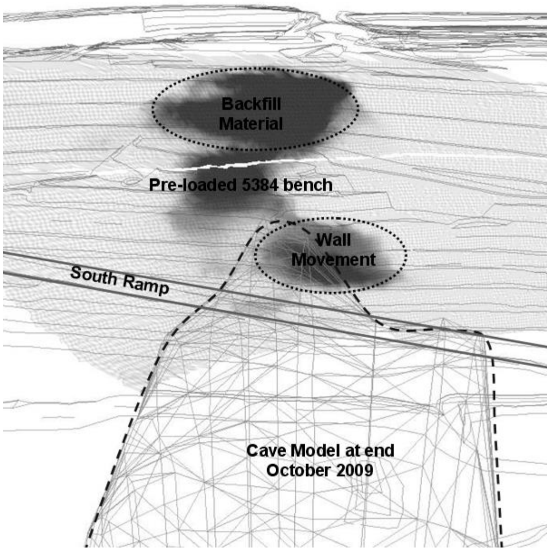


Figure 7 Radar monitoring: section looking west indicating wall movement areas relative to cave, October 2009

2.2.2 Prisms

The main dome prism array consists of 158 prisms, with 55 of these located around the cave influence area, as illustrated in Figure 2. All prisms are measured automatically from two monitoring stations, with email alerts sent if prism displacement exceeds defined velocity thresholds. Prior to the MSR arriving on-site prisms were the primary form of surface monitoring. The advantages of prism monitoring are that it is relatively inexpensive and that movement trends for the cave influence area can be correlated with MSR data.

Another advantage is that the MSR is only able to detect movement towards or away from the unit; the prisms around the breakthrough area were used primarily to track subsidence of the 5384 mRL bench and berms below. As the breakthrough area was covered by preload and backfill material, surface deformation of the bench by way of cracking and minor subsidence could not be observed visually. The prisms were then critical for determining the level of surface deformation occurring. Prism data suggests that vertical subsidence commenced in June 2009. The degree of subsidence recorded in the prisms was used as one of the tools to establish when breakthrough to the bench had occurred in late October 2009. As at the end of October 2009, prisms in the breakthrough area had recorded in excess of 1.5 m subsidence. Movement of some prisms located closer to the south ramp indicated movement towards the east, which correlated with MSR data.

2.2.3 Visual observations

At least twice daily inspections of the 5384 mRL bench were undertaken whilst preloading was occurring on the bench. Regular crew awareness presentations were completed detailing what visual triggers to note as part of the TARP. This included observations of cracking, subsidence of the bench, rockfalls or ground vibrations. A rockfall reporting system exists where all rockfalls are immediately reported to the production supervisor and geotechnical engineer.

Visual observations became increasingly important in the final months prior to cave breakthrough. Routine photographs were taken of the area and compared. No evidence of rockfalls from the west wall, cracking or deformation was observed prior to October 2009. In the month leading up to cave breakthrough cracking of the berm immediately below the 5384 mRL breakthrough bench became evident. Dilation of structures in the western wall above the south ramp and cracking and heaving of the inside of the ramp at the toe of the slope was noted. All of these observations corresponded with surface influence monitoring data from the MSR and prism system.

3 Cave apex tracking

A cave model was produced at the end of each month based on all monitoring data (Figure 8). Initially the cave was modelled using microseismic data only, however, once the cave was within 300 m of the 5384 mRL bench data from the deep hole extensometers was used in conjunction with seismic data to determine the cave shape. The monitoring data is taken into a mining package to generate the monthly shape. Caving rates are then determined based on the cave growth for the past month. Triggers were built into the TARP relating to caving rate.

In May 2009 when the cave apex was 124 m below the 5384 mRL bench, a seismic gap began to develop around the apex. From this point onward the two extensometers which were located in the cave apex became the primary means of determining the apex location.

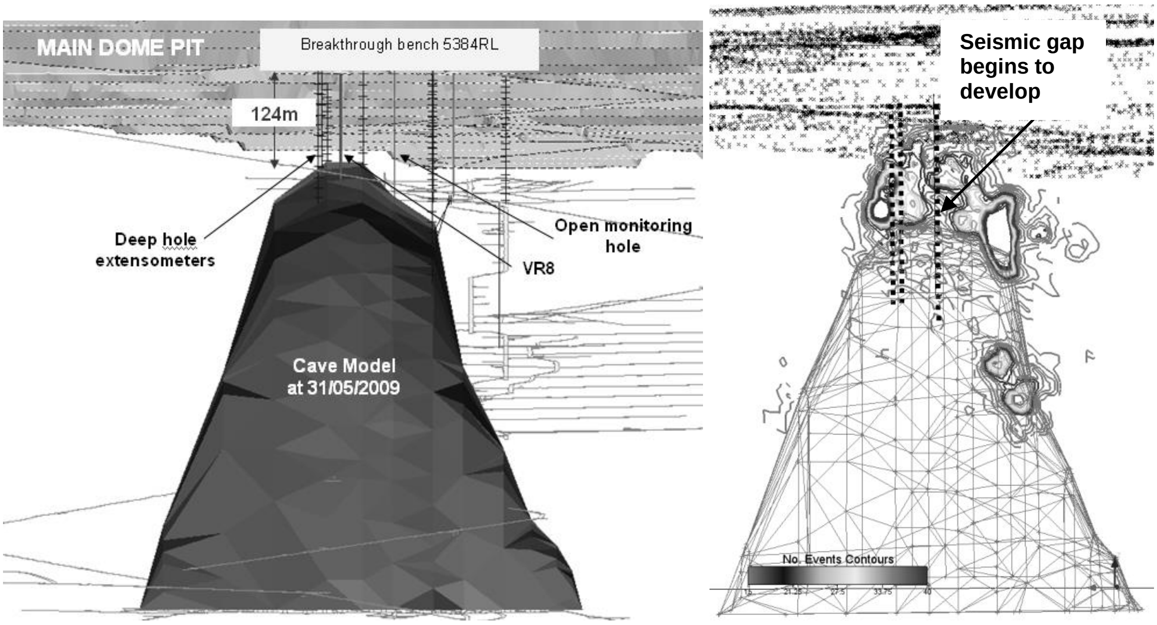


Figure 8 Cave model and microseismic event contouring at end of May 2009

Figure 9 shows the cave progression from December 2008 up until breakthrough occurring in October 2009. From December 2008, the highest rate of cave growth occurred at the northeastern extents of the cave. The additional extensometer was installed in February 2009 for tracking of the cave progression east towards the south ramp. The global caving rate for the SLC was 0.6 m/day and the monthly rate recorded was up to 1.2 m/day in the months leading up to breakthrough. From August 2009 when the cave was estimated to be within 50 m of breakthrough, surface influence monitoring was used as the primary means of determining cave proximity to the pit.

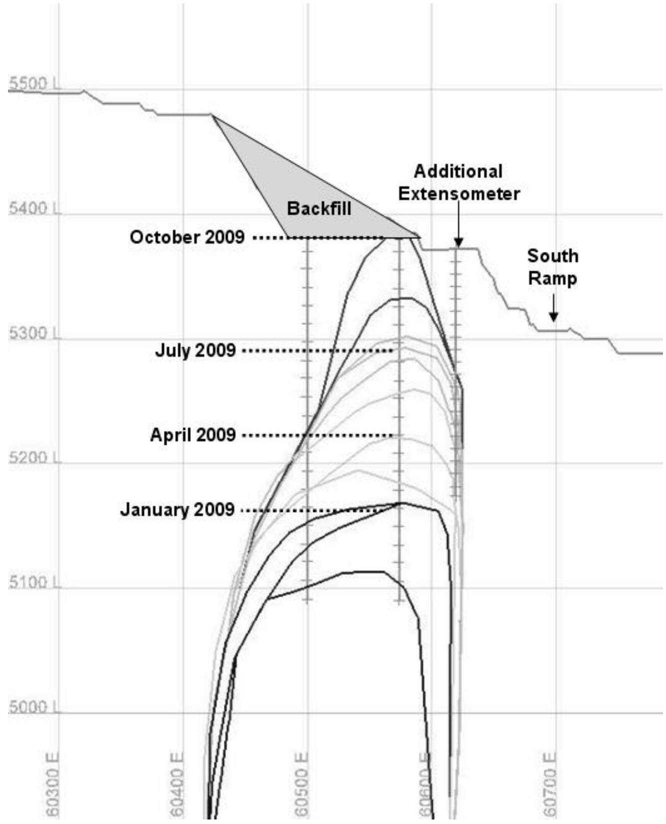


Figure 9 Cave apex tracking December 2008 to October 2009

4 TARP

A TARP was developed as part of the Major Hazard Management Plan for Cave Pit Interaction. This was discussed in Part I of this paper (Singh et al., 2010). The TARP outlines the triggers and planned responses when hazards are identified. All triggers are based on monitoring data and hence the monitoring systems played an integral role in managing the cave breakthrough into the main dome pit. Some examples of the types of triggers featured in the plan include:

- Cave back cannot be estimated and cave propagation rate cannot be determined through extensometer, microseismic or open monitoring hole data.
- Average propagation rate for a week exceeds 1.5 mm/day or drops below 0.2 m/day. This was determined through extensometer, microseismic or open monitoring hole data.
- Cave stalled and/or air gap is sufficient to create a potential instantaneous collapse. Determined through extensometer, microseismic or open hole data.
- Subsidence or cracking noted on the south ramp or batters or berms above the ramp, from visual observations, prisms or MSR.
- Subsidence or slumping of the backfill tip-head, from visual observations.
- Evidence of rock noise, ground vibration, cracking or rockfall events from walls above or below the south ramp, determined through visual observations and seismic data.
- Irregular movement in deep hole extensometers detected, i.e. movement in anchors closer to surface detected or a large increase in movement rate.
- Wall movement indicated by MSR or prism instrumentation.
- Fill levels in vent rises slump by more than 5 m in a single event. This was determined through the alarm system on VR8 and visual observations of the other rises.
- Significant rainfall events.
- MSR is down and not scanning.

All triggering events were recorded in a database and at the end of each month a formal review of these was conducted. At the end of October 2009 a total of 27 TARP triggers had been recorded.

5 Conclusions

Effectively designed monitoring instrumentation, routine observations, as well as hazard management systems such as the TARP were implemented to manage a major geotechnical hazard at Telfer. Comprehensive design highlighted the need for a suite of monitoring systems to be implemented to achieve the desired monitoring goals for the SLC breakthrough into the main dome pit.

The systems utilised were user friendly, easy to install and continued to function during and following preloading works occurring around them. An improvement to the systems to limit issues encountered would be to install fewer anchors in the deep hole extensometers, reducing the potential for interaction between wires in the borehole. This however, would provide less redundancy in the event of faulty anchors. Another improvement would be to incorporate additional open monitoring holes, which would increase the likelihood of a hole being located in close proximity to the cave apex.

The incorporation of several monitoring systems allowed for the SLC to be accurately tracked. In the event that anomalous data was experienced from one monitoring source this could be verified or excluded using an additional independent monitoring system. This enabled Stage 3 production, preloading and backfilling activities to occur without incident in the cave influence area as the cave was propagating, and ultimately breaking into the 5384 mRL bench in October 2009.

Further expansion of the main dome monitoring system is ongoing. An array of in-place inclinometers will be installed behind the backfill tip-head at the top of the western highwall in the coming months. This will monitor the predicted long-term subsidence extents.

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