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Installing Smart Markers to monitor Lift 2 North extension ore flow behaviour

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Abstract

Numerous attempts have been made to study the mass flow of rock within block cave mines using markers installed in the uncaved cave rock mass. The markers are subsequently retrieved as they are recovered from drawpoints on the extraction level. The success of the markers has been questionable, largely due to their poor recovery, and hence most block or panel caving operations have been reluctant to seriously invest in flow monitoring on a large scale. As a result the flow monitoring employed (if any) comprises typically of 'dumb' markers in the form of old concrete filled tyres, concrete blocks and steel tubes, opportunistically scattered throughout the block.

Recent advances in technology have led to the development and successful implementation of electronic 'Smart Markers', which, once loaded from a drawpoint, transmit their identity number and that of the loader to receivers on the extraction level. The marked improvement on the recovery of these markers over 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.

This paper describes the successful trial of prototype Smart Markers at Northparkes Mines, the objectives of the trial being to test the recoveries and the ruggedness of the markers to withstand the internal forces within the moving ore column as they make their way from their initial position to the drawpoints below. It is Northparkes Mines' vision to implement a full, mine-wide scale flow monitoring programme for their future caves, of which Smart Markers will form a major component.

1 Introduction

Understanding the movement of caved rock within the ore column has been a topic of much debate and research over many years. The successful extraction of ore from a cave depends on the amount of dilution that occurs during draw, thus to optimise the recovery of the resource and minimise dilution it is believed that interactive draw between operating drawpoints is a prerequisite. Various cave flow mechanisms have been proposed, most of which are based on laboratory, physical modelling experiments along with some mine observations and a few (unvalidated) numerical models. With the exception of a few sublevel caves, there have been no significant attempts to monitor the flow of caved material on a mine-scale. Thus all of the tools that have been developed over the years to predict cave flow and resource recovery are essentially based on empirical relations.

The ultimate decision facing the design engineer is what drawpoint spacing to adopt that will ensure the greatest recovery of the resource over the life of the cave. It may well be that other constraints (such as rock mass strength and stress) ultimately dictate the final drawpoint spacing so as to ensure the integrity of the production and/or undercut levels over the life of the cave, nevertheless the models used to predict resource recovery, which ultimately feed into the financial evaluation, must represent reality so that an informed assessment is made of the project risk. Experience form Rio Tinto's Northparkes, and to some extent

Palabora, operations suggest that this has not been the case and as a result significant reserves have been unrecovered.

In an attempt to better understand the flow mechanisms operating in a block cave, Rio Tinto have embarked on an extensive cave flow monitoring programme for one of their newest block caves at Northparkes Mine. In so doing they have engaged Elexon Electronics, the developers of the latest cave Smart Marker technology, to first test the reliability and robustness of their markers in the existing Lift 2 North extension (L2NE) cave.

The L2NE Smart Marker trial involved placing both Smart Markers and simple metal markers on top of the cave muckpile through open holes. Over a period of sustained draw, these markers, along with the caved material, flow down to the extraction level drawpoints where they are mucked out by load–haul–dump units (LHD). Smart Marker Readers, mounted to the extraction drive backs along the tramming routes, are able to detect the signal (unique identification code) transmitted by the Smart Marker as it is trammed to the crusher tipple. Thus the Smart Marker ID is time stamped and logged by the reader, which transmits the information to an internal logger, referred to as the Marker Management System (MMS).

As mentioned, the objective of the L2NE Smart Marker trial was to specifically address the issues of durability and reliability of both the markers and the entire MMS, prior to embarking on an extensive mine-scale flow monitoring programme.

Although Rio Tinto are actively involved in the research and development of real-time cave tracking technologies, Elexon’s newly developed Smart Marker has significantly improved the reliability and thus, feasibility of cave flow monitoring on a mine-scale. The results from this monitoring are expected to challenge conventional and numerical theory and provide greater insight into the complexity of cave flow.

2 Cave markers history in Northparkes caves

Previous attempts at monitoring cave flow have been made using dumb markers such as old loader tyres and various steel tube designs. The recovery of these dumb markers have proved particularly unreliable (simply due to poor detection), and thus understandably no significant investment in cave flow monitoring has been made in the past.

For the Endeavour 26 (E26) Lift 1 (L1) block cave, markers comprised of sections of drill steel and old LHD and truck tyres, each with their own identification number. The steel markers were grouted into old exploration holes whilst the tyres were placed on the undercut and exploration level (located halfway up the cave). By surveying the location of the markers and noting the approximate date at which they entered the cave, it was envisaged that these markers would eventually flow through the caving and finally be detected in the drawpoints below, the marker ID, drawpoint ID and date of extraction being recorded so that the marker (caved material) movement can be inferred. Unfortunately, the majority of the steel markers passed undetected through the drawpoints and those that were recovered where generally found on the conveyor magnets, thus providing practically useless information. The detection of the tyre markers fared only marginally better, although a couple of tyres were recovered in reasonable condition, the majority were completely shredded and recovered in pieces, with no discernable ID.

Similarly, the use of steel dumb markers (refer to Figure 1) were once again attempted in the E26, Lift 2 (L2) caves. Unfortunately these markers suffered from the exact same problems, primarily poor detection in the drawpoints.

The problems experienced using dumb flow markers are summarised as follows:

- poor detection in the drawpoints or on the extraction level
- grinding damage to the marker IDs makes identification difficult
- exposure of personnel to metal debris in the conveyor magnet/tramp bin area
- interruption of mining operations for marker recovery
- uncertainty in the reliability of the data (i.e. accuracy of the date and location of recovery)
- overall a low percentage of recovery and even lower percentage with reliable data.

Figure 1 L1, L2 and L2NE dumb markers

The new automated Smart Marker system eliminates all of these problems in that the markers, when loaded from the drawpoints, are able to transmit their IDs through the LHD bucket load to the readers with the date and time stamp. The elimination of all manual intervention (detection and logging) ensures the efficient and reliable detection of all Smart Markers 24/7, thus providing real-time Smart Marker data from a single point of control.

Several attempts have been made at developing similar smart cave markers in the past; however, there are no documented cases where these have been shown to be successful. Early versions have generally been unsuccessful for the following reasons:

- their inability to transmit a radio frequency through 10 tonnes of broken rock and the LHD bucket
- not robust enough to withstand the crushing and grinding forces within the cave column or the undercut blasting
- insufficient battery life, i.e. the life of the marker battery is shorter than the marker residency time in the cave muckpile, thus the marker is unable to transmit its ID to the reader – this issue is particularly relevant to modern, high lift caves
- ineffective communication with the readers due to fast LHD tramming speeds.

Fortunately, Elexon Electronics has successfully managed to overcome all of these shortcomings and over the past couple of years have been working closely with Rio Tinto and Northparkes Mines to test the robustness and reliability their Smart Marker system in an operational block cave environment.

3 Objectives

The goal of the Northparkes Mine trial was to prove that the MMS could reliably operate in a block cave environment. The success of the system was therefore measured though:

- *durability* – to test that the Smart Markers could withstand the stresses, strains and grinding forces as they make their way from their initial position (high above the extraction level) down to the draw point

- *reliability* – to test that the Smart Markers loaded at the drawpoints can successfully transmit and be detected by the readers mounted in the back of each extraction drive
- *longevity* – to test the Smart Markers battery life in the harsh caving environment.

4 Installation

4.1 Smart Marker

Smart Markers are 13.56 MHz RFID devices, designed to withstand a production blast and grinding forces within the caved material. The Smart Marker dimensions are 65 mm external diameter with a length of 300 mm. Each marker contains 3V, C size Lithium batteries.

A total of 90 Smart Markers and 85 steel markers (dumb markers) were installed in pre-existing open holes drilled from 9830 level and 9700 level, commencing September 2008. Some markers were also grouted with time domain reflectometry (TDR) coaxial cable inside the 165 mm diameter Cubex drilled holes in 9830 level. Upon cave propagation towards 9830 level the remaining open holes will be grouted with more Smart Markers and TDR cable.

The steel markers are used to compare the recovery rate of Smart Markers and are installed in the holes together with these markers. During installation, the marker IDs, installation hole ID, installation depth and date has been recorded.

Installation to depth is done by lowering an insertion tube which houses the markers, as shown in Figure 2, down the hole using a wire line. When the desired depth is reached the marker is released from the tubing by pulling on the release wire on the underside of the tube.

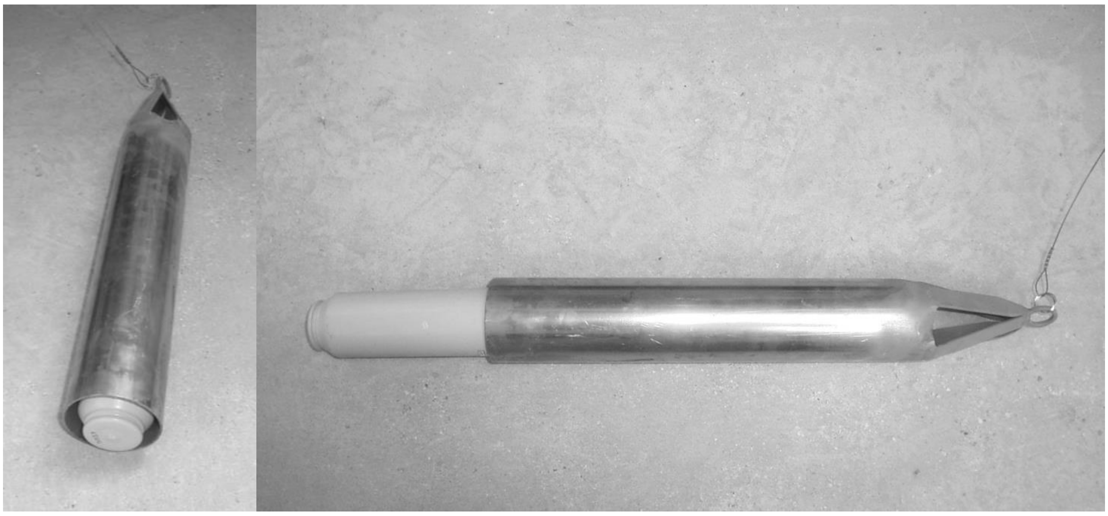

Figure 2 Smart Marker in release tube

4.2 Readers

Eight readers were mounted in the backs of the extraction drives along the L2NE cave tramming route. Each Smart Marker reader enclosure is fitted with a mounting bracket that is attached to the tunnel backs as shown in Figure 3. A power outlet (240V AC) is connected to the readers. In the case of a power outage the unit has its own battery backup supply which can last for up to two days. The unit is fitted with a blue strobe light to indicate when a smart marker has been detected inside a passing LHD. During the Northparkes Mines trial it was standard practice for the LHD operator to dump the load and recover the marker so that it could be examined closely for damage prior to passing through the crusher.

Originally the readers were planned to be installed along the perimeter drive at the intersections with the extraction drives, however, this resulted in the Smart Marker transmission being detected by neighbouring readers. As a consequence, it was necessary to install the readers back in the extraction drives, approximately 40 m from the perimeter drive intersection.

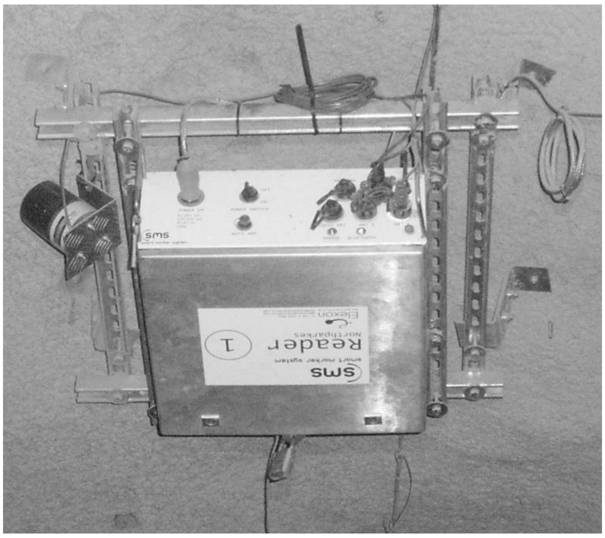

Figure 3 Typical reader installation in USA

4.3 Data recovery (reliability)

The reader data was checked weekly throughout the trial period to monitor the marker extraction rate and calculate the percentage of markers that had been detected. Data logged by each individual reader was retrieved using a hand held wireless scanner which downloaded all of the existing data. The hand held wireless scanner takes approximately one minute to download the data once the connection is made. Another function of the hand held scanner is to upload software updates to the reader. For the upcoming, full mine-scale monitoring, Northparkes Mine plans to hardwire the readers into the existing underground Ethernet or leaky feeder communication systems for remote access.

To date, 20 Smart Markers have been successfully retrieved; their residency times in the L2NE cave varied widely from 279 days to six days to travel vertical distances of approximately 100–380 m respectfully.

The initial installation on the west side of the cave involved lowering two Smart Markers and one dumb marker in each of the 9700 level presplit blast holes that were open to the cave. From these holes, hole 16A had one Smart Marker retrieved after 279 days and one dumb marker retrieved one day later. This suggested similar flow behaviour for both the dumb and Smart Marker, though unfortunately the extraction location of the dumb marker was unknown as it was picked up by the magnets on the material handling system.

All markers installed in the blast holes in the south of the 9700 level have yet to be recovered as the draw rate on this side of the cave is three times less than that of the north side.

The final installation took place on the old L1 undercut level (9830 m RL), where seven Smart Markers and eight dumb markers were lowered to the muckpile from open hole 14 in the northeast side of the cave. Of these, six Smart Markers and three dumb markers were recovered over a period of 6–123 days. Thus one could conclude that the reliability of the Smart Markers is at least twice that of the dumb markers.

First Detected	Last Detected	MarkerID	Comment
23/04/09 08:54:55	15/05/09 21:04:03	2174	Makers in transit in back of ute confirmed by Remeth Henry Installed 05/05/2009 "9830 north - hole 10" Detected 15/05/2009 by Reader 1
31/05/09 13:53:44	31/05/09 13:53:46	2210	Installed 25/05/2009 "9830east - OH14" Detected 31/05/09 by Reader 1
18/06/09 08:30:48	18/06/09 08:34:01	1052	Installed 12/09/2008 hole 16a Detected 18/06/2009 by Reader 5
24/06/09 11:10:38	24/06/09 11:15:12	1138	Installed hole 11, 30/12/08, 160.4m Detected 24/06/2009 by Reader 5
27/06/09 05:41:54	27/06/09 05:42:47	2157	Installed 18/05/2009 in 9830 crosscut Detected 27/06/2009 by Reader 6
29/06/09 11:43:45	29/06/09 11:49:30	2165	Not in installation list. Assume one of Markers not recorded... Installed 18/05/2009 9830 crosscut Detected 29/06/2009 by Reader 1 first, then with less signal strength by Reader 6
29/06/09 19:44:04	29/06/09 20:39:19	2068	Installed 29/05/2009 9830east- OH14 Detected 29/06/2009 by Reader 1 first then with less signal strength by Reader 6
30/06/09 08:36:16	30/06/09 03:38:34	2178	Installed 25/05/2009 9830east - OH14 Detected 30/06/2009 by Reader 1 first then with less signal strength by Reader 6
10/06/09 09:54:40	08/07/09 19:02:15	2191	Marker detected in transit in back of ute under Reader 1 on 10/06/2009 Installed 10/06/2009 9830 crosscut Detected 08/07/2009 by Reader 1
22/04/09 04:19:42	19/07/09 16:15:49	2819	Installed 25/05/2009 9830east - OH14 First detected by Reader 1 (then Reader 6 between 17:27:03 to 17:30:19 same day)

Figure 4 Recovered data form MMS

4.4 Marker recovery (durability)

As mentioned, one of the objectives of the trial was to assess the durability of various Smart Marker casings and note how they performed when subjected to the internal cave stresses and grinding forces whilst travelling through the muckpile. To ensure that the markers were examined immediately after recovery, prior to entering the crusher and materials handling system, one of the readers was fitted with a flashing light. On detecting a Smart Marker the reader would trigger the flashing light to alert the LHD operator that a Smart Marker was present in the bucket. The LHD operator would then dump the load and retrieve the marker for inspection.

Four Smart Markers have been retrieved in this manner and their physical damage assessed, on average these markers have travelled over 380 m through the cave column with a residency time of up to 123 days. As can be seen in Figure 4, three of these markers were completely unscathed revealing no physical damage, whilst the fourth showed only minor external damage to the casing, the internal casing remaining intact.

In addition to these four Smart Markers another 16 Smart Markers have been successfully recovered, some markers residing in the cave for up to 279 days, and all travelling a minimum vertical distance in excess of 300 m. To date the evidence suggests that these Smart Markers are indeed sufficiently durable to withstand the internal cave stresses and grinding forces within the cave muckpile.

Figure 5 Photos show slightly damaged marker on top, uninstalled marker on the left, recovered marker on the right

4.5 Analysis

Previous studies and numerical modelling have demonstrated that the horizontal movement of caved material is possible though vertical movements tend to dominate under uniform draw conditions. An analysis of the L2NE cave markers has demonstrated that markers can travel significant horizontal distances whilst others seem to move almost vertically. Thus the flow mechanisms in the L2NE cave (as with all caves) are far more complex than suggested by cave flow models or basic theory. The marker results and inferred conclusions for the L2NE cave flow are summarised as follows:

- Initial results indicate that the Smart Markers installed on the western side of the L2NE cave moved up to 57 m horizontally and a minimum total travel distance of 118 m. Whilst, due to the steepness of the cave back on the eastern side of the L2NE cave, the horizontal travel of the Smart Markers in this area increased to a maximum of 120 m with a minimum total travel distance of 370 m. Borehole video of the top of the muckpile coupled with the production draw information indicates that the draw cones in the east have broken through to the top of the muckpile. The rapid movement of some of the Smart Markers seems to coincide with the rilling trajectory towards zones of higher draw.
- The faster rate of Smart Marker movement in the east of up to 50 m/day suggests that isolated draw is occurring with draw cone diameters as narrow as 5 m in diameter calculated. These narrow draw cones are believed to be a consequence of the higher draw rates in the east and the presence of very fine clay material being extracted. These draw cones are believed to be connected to the overlying L1 cave, thus allowing both clay waste and rock to enter the L2NE cave.
- The relatively slow (and more vertical) movement of the Smart Markers in the west of the L2NE cave suggests that wider, interactive draw cones up to 26 m in diameter may be present.
- One may then conclude that the flow mechanisms occurring in the L2NE cave is a combination of rapid surface rilling on the top of the muckpile and vertical (isolated draw) material flow. This would

explain both the large horizontal movements (as observed from the borehole video) where the cave back and muckpile are steep and as well as the more vertical movements where the cave muckpile is flatter (and rilling is less dominant). One could then argue that the effect of the cave back shape and the cave back – muckpile interface plays a major role in dictating cave flow behaviour, with material rilling dominating mixing as the cave propagates. Once the cave has broken through then rilling will be confined to the cave boundaries and the outer draw cones, whilst the central draw cones are likely to show more vertical flow (and possibly narrower draw cones).

Further Smart Marker recoveries are needed to gain more of an understanding of the L2NE cave flow – these will help to calibrate and validate numerical models and improve cave management.

5 E48 – future installation

Cave flow and ultimately resource recovery predictions in block caving have been based on empirical observations and physical model experiments, though little or no data from actual block cave flow markers on a mine-scale.

The purpose of the E48 block cave, marker programme is to acquire, high resolution marker data that can be used to interpret cave flow mechanisms. This data will allow Rio Tinto to calibrate and validate their flow modelling tools, ultimately improving the current knowledge on mine-scale cave flow behaviour.

The Northparkes, E48 block cave provides Rio Tinto with a unique opportunity to easily deploy thousands of Smart Markers within the cave column from the undercut and from the surface via existing vertical holes. Furthermore the E48 cave is well instrumented and cave propagation will be closely monitored so that important information, such as the date at which the markers are released into the cave and the cave and muckpile geometries, will be available to assist in the flow analyses. Data from the E48 cave marker programme should become available as soon as production commences whilst the caves relatively short life makes it an ideal case study from which the learning can be timely transferred to future Rio Tinto caving operations.

Markers in the E48 cave are planned to be installed on:

- the undercut level in 20 m up holes drilled in various locations above the major apexes, four to five markers will be grouted at various distances up each hole, the objectives of these markers being to:
  - determine whether a stagnant zone exists above the major apexes
  - determine the extraction zone diameter near the base of the draw column
  - confirm early caving.
- the top of the muckpile via open holes from the surface, these markers will not be grouted in place but rather regularly deployed at a rate commensurate with cave propagation
- grouted in holes drilled from surface just prior to surface access becoming prohibited (due to the proximity of the propagating cave). These Smart Markers will be grouted every 4 m from collar to the toe of the hole. In addition to the markers, TDRs will also be installed in the holes to provide an indication of the date at which markers become released to the cave muck pile.

6 Conclusions

Using RFID technology, the MMS allows Smart Markers placed in the cave to be automatically detected once extracted, with their ID and extraction date and time logged by the system in real time.

The L2NE Smart Marker trial is the first known RFID technology, cave flow monitoring programme attempted on a cave scale in a block cave mine.

The objectives of the trial were primarily aimed at testing the reliability, robustness and longevity of the markers in NPM L2NE cave, and to date this has proved highly successful with all extracted markers detected and found to be fully functional.

The results from the L2NE cave trial have demonstrated:

- the Smart Markers are able to withstand the significant stresses and grinding forces induced from both blasting and within the moving cave muckpile
- the Smart Markers are able to transmit through a steel LHD bucket filled with broken rock and be detected by readers installed on the tunnel backs
- the Smart Markers are able to successfully communicate with the readers even at fast LHD tramming speeds
- the Smart Markers battery life has been designed to last for over five years of life; to date marker life of a year has been demonstrated
- the ease of use of the technology (system) has been impressive; this has proven to be an important factor in its successful implementation on the mine
- the Elexon Smart Marker System has proven to be far more efficient and reliable than dumb markers with 24/7 automated coverage and greater recovery percentage. Thus the Smart Marker MMS has ensured that cave flow monitoring is now a worthwhile investment.

By examining each marker's extraction location relative to its installation location, along with its residency time in the cave, valuable information has been gained to help better understand cave flow mechanisms.

The next phase of cave flow monitoring involves deploying thousands of Smart Markers over the entire Endeavour 48 (E48) block cave. The objective of the E48 cave flow monitoring programme is to calibrate and validate existing cave flow models and ultimately improve the reliability of Rio Tinto's predictive tools.

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