Caving 2010 — Y. Potvin (ed)

doi:10.36487/ACG_rep/1002_42_Whiteman

The Smart Marker System — a new tool for measuring underground orebody flow in block and sublevel mines

D.S. Whiteman *Elexon Electronics Pty Ltd, Australia*

Abstract

In the past, measurement of ore flow in block and sublevel caves has been performed with passive 'markers' (often made from steel pipes) embedded into the orebody. Extracting passive markers along with the ore is labour intensive and often requires many years of commitment. The Smart Marker system uses hardened Radio Frequency Identification (RFID) technology to automate the marker detection process, allowing the measurement and analysis of underground ore movement to be carried out without affecting production draw rates.

This paper presents the results from block and sublevel cave testing of the Smart Marker system from late 2008 and throughout 2009. Block cave testing was carried out at Rio Tinto's Northparkes E26, and sublevel cave testing was done at Newcrest's Telfer Mine. The test results demonstrated the successful use of the automated system in the underground production environment and provided high resolution, real-time extraction data suitable for the analysis of underground orebody movement.

This paper also addresses the use of real-time marker data in the analysis of back-break, ore flow rates, dilution entry and rill detection.

1 Introduction

In the study of underground rock movement in mass mines, it is acknowledged that fundamental unknowns stem from a lack of cave measurement data. This is primarily due to the lack of suitable instrumentation required to make underground rock flow and movement measurements.

In block caves unknowns include, but are not limited to:

- fundamental gravity flow data
- effects of draw rate
- height of interaction
- isolated movement zone (IMZ) and isolated extraction zone (IEZ) characterisation
- effectiveness of different drawbell spacing and geometries.

In sublevel caves (SLC) the unknowns include:

- fundamental gravity flow data
- rock movement and subsequent flow patterns due to blast geometries
- ring to ring dynamics
- effect of draw rates
- the actual development of the extraction zone during ore extraction.

To address these unknowns, a significant amount of work has been undertaken to help characterise underground rock movement.

Studies have ranged from granular flow tests in bins (Kvapil, 1965) to very large scale marker trials (Power, 2004), to computer simulation methods (van As and Van Hout, 2008). A summary of work covering the SLC case is presented by Hustrulid and Kvapil (2008).

Ultimately, the motivation for carrying out these fundamental studies is to improve mine productivity by (amongst other things) controlling fragmentation size, reducing the incidence of hang-ups and maximising recovery from the available deposit.

With the exception of marker trials, most investigations have either sought to model rock movement and flow using small scale physical models (relative to mine sizes) or using computer simulation models. While physical and computer modelling work have offered useful insights, there is still debate as to how accurately they portray actual rock behaviour in the mass mining situation.

Passive marker trials carried out to date have also offered a greater understanding of underground rock movement. Due to the difficulties in carrying out these trials however, the Mass Mining Technology project (MMT) requested Elexon Electronics to develop the automated Smart Marker System for SLC and block caves.

2 Comparing Smart Markers with standard passive markers

Marker trials (smart or passive) are typically executed as follows:

- a large number of markers are placed in the orebody at known locations
- during extraction the markers are recovered
- the extraction point of recovered marker/s is determined (this is where the key difficulty lies)
- patterns of rock movement and flow are determined by examining the insertion and extraction points.

The Smart Marker System (Figure 1) has been designed to simplify the process of carrying out marker trials by eliminating the difficulty associated with manually recovering passive (typically steel) markers. The system also offers higher resolution rock movement data than is possible with passive steel markers.

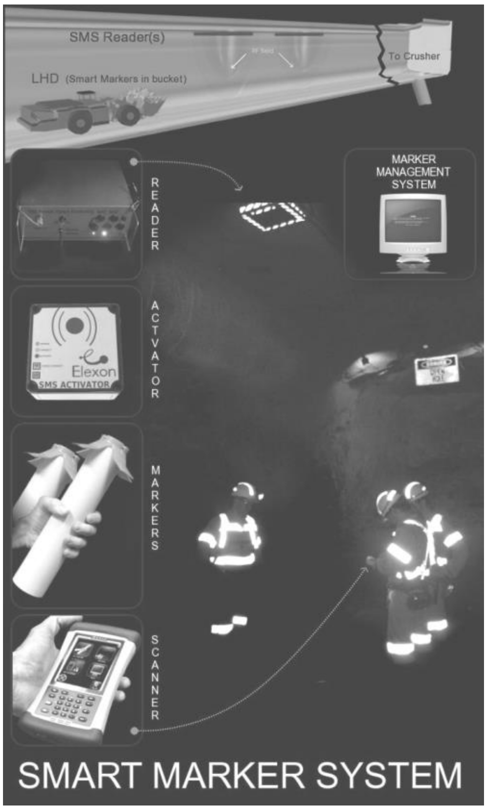


Figure 1 Markers are wirelessly activated prior to installation and have an operational life of 10 years. Smart Markers in the load–haul–dump unit (LHD) bucket are automatically detected by Readers as ore is extracted

The highest quality marker data is obtained when the exact extraction time and location can be determined. It is important to know the extraction drawpoint location because this enables the marker movement path from the insertion point to the drawpoint to be established. It is important to know the time of extraction as this allows movement rates to be determined, and the sequence in which markers reached the drawpoint. In the SLC case, when the extraction time information is coupled with the number of tonnes drawn from a ring, it is possible to determine how the ring develops during the extraction process.

With passive marker trials there is often a degree of uncertainty with respect to the time at which a marker was extracted and location it was extracted from. Passive steel markers are flung into tramp bins along with other waste metal by the ‘tramp magnets’. They are recovered when mine personnel climb into the tramp bins to look for the markers. To improve the accuracy of the data, the bins need to be checked more often. An uncertainty in extraction time leads to an uncertainty in extraction point.

In terms of data quality, waste bins need to be checked for the presence of passive markers as often as practicably possible. Maintaining a marker program over several years, where metal waste bins are thoroughly searched every day, requires a great deal of effort and diligence. Staff turnover adds an additional challenge.

With passive markers, when high resolution data is required, production schedules can become affected. High resolution data is required when measuring the movement of small rock volumes (e.g. in an SLC ring). Production may be slowed if, for example, production at a drawpoint has to cease for every 400 tonnes drawn (to allow any passive markers to be searched for and recovered). At the very extreme end of the spectrum, one or two trials have been done in the past where every LHD bucket must be tipped out and manually searched for passive markers.

With the Smart Marker System, Smart Markers are automatically detected by ‘Readers’ mounted to the back of cross cuts, perimeter drives or orepasses (see Figure 2). The Readers operate automatically and do not require any slowing of production to detect markers.

Because the Smart Markers are instantly detected as the LHD drives under the Reader, the exact time of extraction is known. The exact drawpoint from which markers were extracted can be determined because each LHD is fitted with an ‘LHD Marker’. As the LHD passes under the Reader, its ID is logged, along with that of any other markers. Identifying the LHD can also help determine the draw tonnage and relate the flow of material with the tonnes drawn.

The time stamping of the detected markers allows an animation to be generated that shows exactly which volumes of rock were moved for every bucket of ore extracted. No changes need to be made to draw schedules to achieve this – it is provided automatically as soon as the system is switched on.

The high resolution data allows various draw strategies to be compared. For example, a mine can compare the rate of draw with the resulting effect of rock movement within volumetric zones. A mine can also compare the effects of drawing only from the left or right of the drawpoint; or the effect of ‘rocking’ the drawpoint by drawing from each side in a determined pattern.

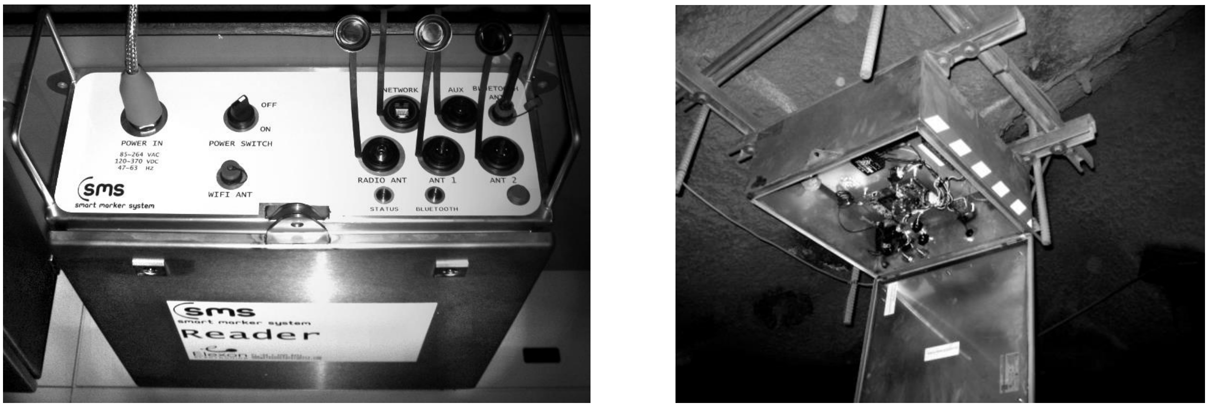


Figure 2 Smart Marker System Reader

3 Smart Marker system operation and installation

The operation of the system is conceptually simple. As Smart Markers are extracted by LHDs, they are electronically detected (while still in the LHD bucket) by Readers mounted to the back of the mine (see Figures 1 and 2).

Marker detections are automatically logged by Readers and can be sent to the surface using a variety of methods. Data can be wirelessly downloaded from the Reader into a handheld Scanner (Figure 3(a)) and then transferred to a computer on the surface of the mine. The wireless download can be performed from within a light vehicle, without exiting the vehicle. If a Reader is connected to the mine's LAN or WiFi system, data from Readers can be instantly transferred to a surface computer (the Marker Management System) for databasing and analysis.

Markers are physically hardened, allowing them to withstand the large rock forces found in block and sublevel caves. Markers are also blast hardened, allowing them to be placed 0.65 m from blast holes.

The underground operational life time of markers is either five or ten years, depending on the type. To ensure a long life, markers are wirelessly activated (using an Activator, see Figure 3(d)) immediately prior to insertion in the installation holes. The unique ID of each marker, along with its installed position, is automatically stored at activation time by the Scanner for a later download into the Marker Management System. This removes the need to manually record the installation details on paper, and then to re-enter them into a spreadsheet.

Readers have an internal backup battery that can power the Reader for two days in the event of a power cut. Readers automatically resume operation in the event of long-term power outages.

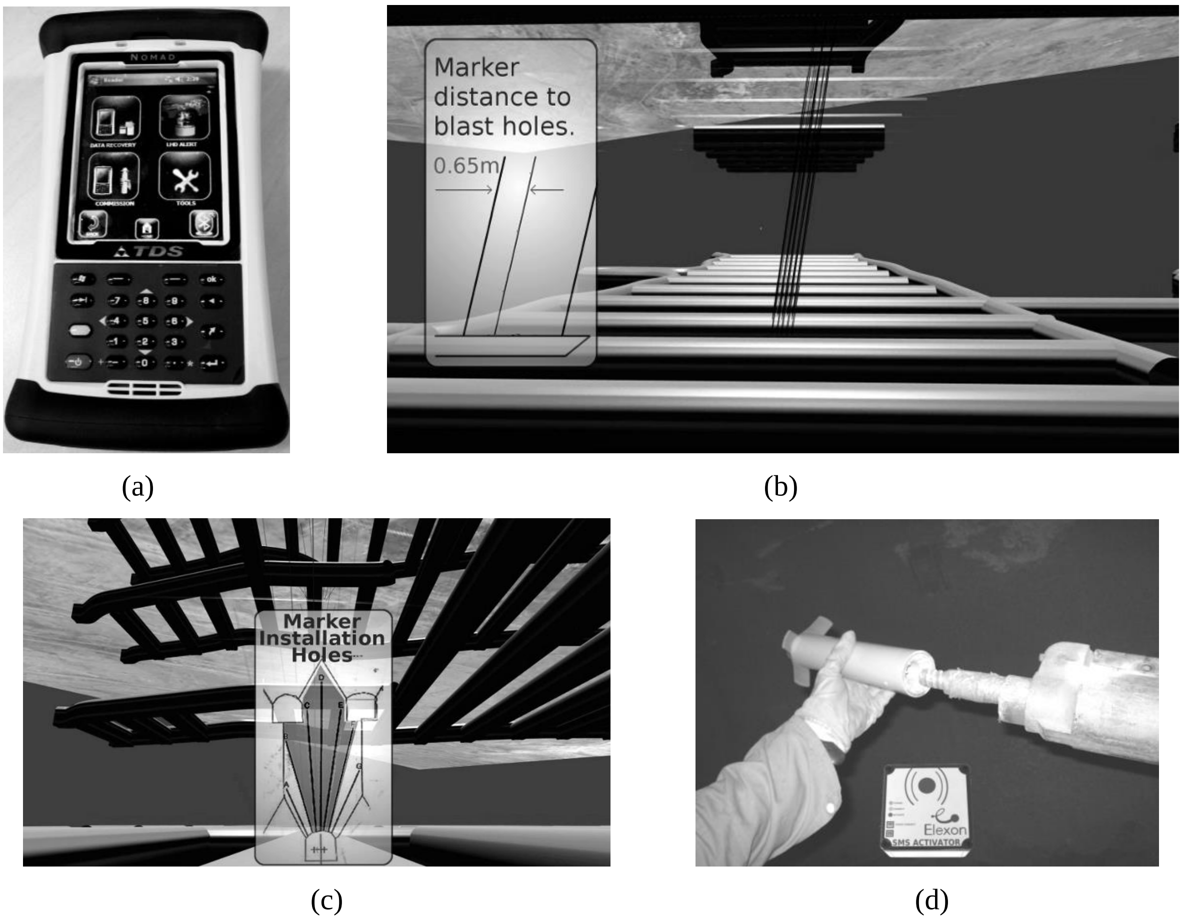


Figure 3 (a) The handheld Scanner; (b) and (c) markers are loaded into SLC installation holes drilled between the blast holes. In a block cave, markers may also be lowered into instrumentation holes; (d) Standard equipment is used to push the markers up into installation holes

Reader installation is reasonably straightforward. The process is as follows (see Figure 4):

- The Reader installation positions are selected. There should be enough Readers to cover the travel paths of the LHD.
- Power is wired to the area. The Reader operates from 'mains' voltage 110 V AC to 240 V AC.
- Bolts or rods are secured to the back of the drive to hold the Readers 'C-channel' frame.
- The Reader is bolted to the frame and the antenna is secured. The antenna is comprised of two 5 m lengths of wire, which are easy to deploy and transport. The Reader is constructed of stainless steel and is IP rated to exclude dust and water.
- The Reader is commissioned.

Commissioning takes between 10 and 20 minutes. It involves:

- Using the Scanner to initiate a Reader health check. This takes around 10 seconds.
- Walking along the drive, under the antenna, with a 'commissioning marker'. The Scanner checks that all the signal strengths are normal and that the reading process is functioning.
- Having an LHD drive under the Reader with markers and ore in the bucket. This checks that the installation has been successful.

Each Reader is equipped with a 'Check Marker', that wirelessly checks every five minutes that the Reader is functioning normally.

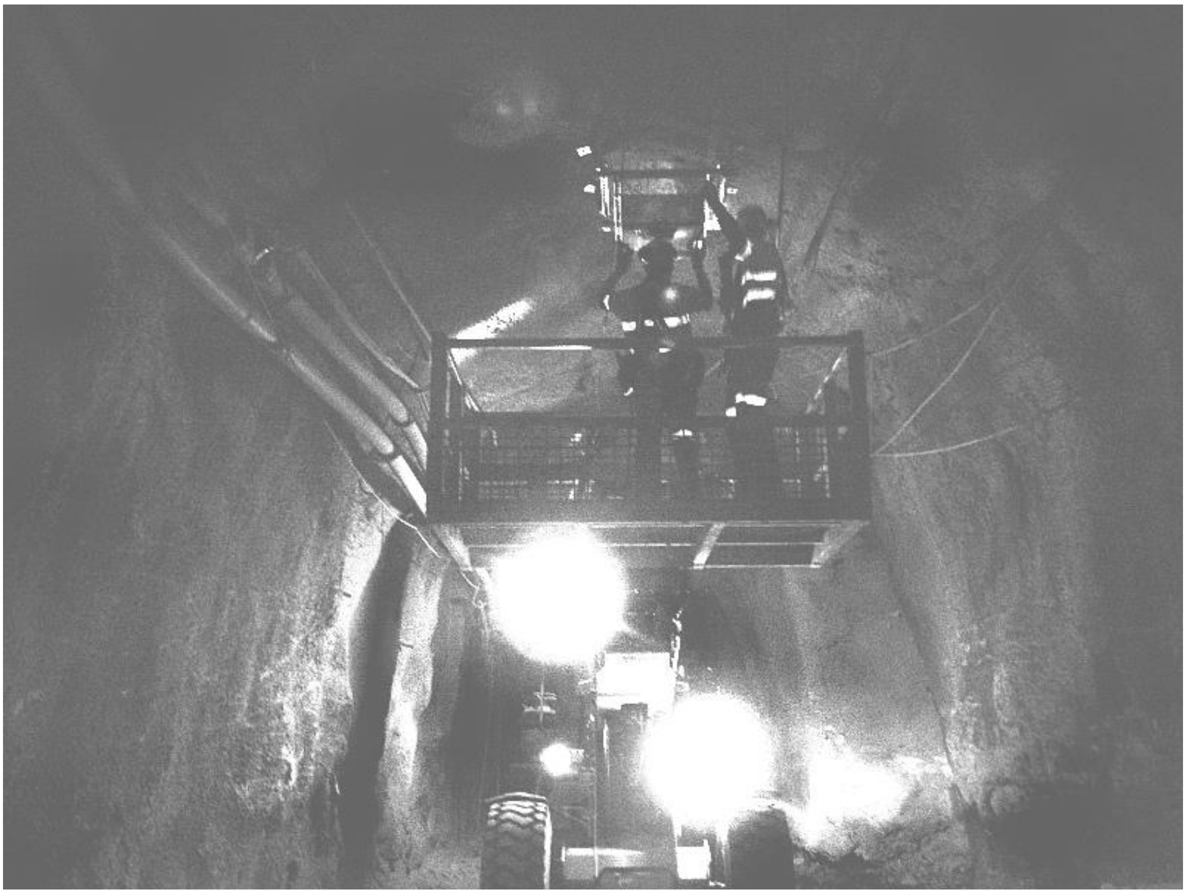


Figure 4 Reader is installed in the undercut level at RioTinto's Northparkes E26 block cave

4 Smart Marker system sublevel cave testing — 1 m blast results

Underground marker tests were carried out at Newcrest's Telfer SLC mine in Western Australia. The markers were installed in December 2008 and blasted in early January 2009, representing the first SLC production level test of the Smart Marker System.

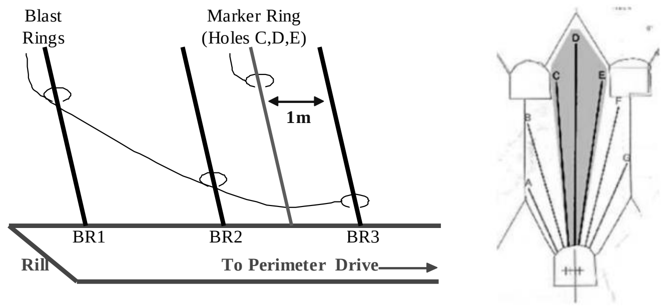
The set-up of the test is illustrated in Figure 5 below, along with a few photos of recovered markers in Figures 6 and 7.

For the first test, markers were grouted into three installation holes, marked as 'C', 'D' and 'E'. The marker ring was drilled 1 m from the blast ring. All hole sizes were 102 mm in diameter and the velocity of detonation (VOD) was approximately 4,800 m/s.

Smart Markers were spaced every 0.5 m inside their installation holes, with a passive steel marker placed after every second Smart Marker (see Figure 5). The purpose of the steel markers was to act as a 'control' during the test. By comparing the recovery of the steel markers with Smart Markers, success of Smart Marker recovery could be determined.

A strobe light was also fitted to the Readers for this test. The Readers could be set up by the Scanner to trigger the strobe light for a short time whenever markers were detected. When the strobe was seen by the LHD operator, the load was tipped into an adjacent crosscut so that the markers could be recovered. This was relatively easy using a Smart Marker location finder. Note it is not necessary to physically recover Smart Markers during normal use; however, it was important in this early test to physically recover as many Smart Markers as possible. This enabled the physical condition of the markers to be assessed following blast and extraction.

The results from this first test were excellent. The detected markers in the first 10 m of the holes 'C', 'D' and 'E' are shown in Figure 5 below. The first 10 m depth represents the area with the greatest blast energy.



Colour Key:		
Smart Markers	Steel Markers	Not Yet Detected

	Hole C			Hole D			Hole E		
Installation Depth (m)	ID number	Marker Type	Status	ID number	Marker Type	Status	ID number	Marker Type	Status
10.5	-	-	-	-	-	-	2146	Smart	DETECTED
10.0	1019	Smart	DETECTED	1161	Smart	DETECTED	4101	Steel	
9.5	4353	Steel		1034	Smart	---	1157	Smart	DETECTED
9.0	2039	Smart	DETECTED	4269	Steel		2182	Smart	DETECTED
8.5	1058	Smart	DETECTED	1152	Smart	DETECTED	4345	Steel	
8.0	4305	Steel		1022	Smart	DETECTED	2067	Smart	DETECTED
7.5	2054	Smart	DETECTED	4037	Steel		2155	Smart	DETECTED
7.0	1014	Smart	DETECTED	1160	Smart	DETECTED	4156	Steel	
6.5	4364	Steel		1089	Smart	DETECTED	2110	Smart	DETECTED
6.0	1034	Smart	DETECTED	4238	Steel		2149	Smart	DETECTED
5.5	1057	Smart	DETECTED	1167	Smart	DETECTED	4331	Steel	
5.0	4242	Steel		1038	Smart	DETECTED	2114	Smart	DETECTED
4.5	1010	Smart	DETECTED	4219	Steel		2143	Smart	DETECTED
4.0	1003	Smart	DETECTED	1171	Smart	---	4102	Steel	
3.5	4234	Steel		1064	Smart	DETECTED	2069	Smart	---
3.0	1147	Smart	DETECTED	4067	Steel		1042	Smart	DETECTED
2.5	1002	Smart	DETECTED	1118	Smart	DETECTED	2101	Smart	---
2.0	1070	Smart	DETECTED	1030	Smart	DETECTED	1013	Smart	DETECTED
1.5	1066	Smart	DETECTED	4119	Steel		2107	Smart	DETECTED
1.0	4240	Steel		-	-	-	4273	Steel	

Figure 5 Detection results for the successful first SLC Smart Marker test

Figure 6 Inspecting markers after the first test

When the automatically detected Smart Markers were extracted from the LHD (to assess their physical condition), it was noted that adjacent steel markers were sometimes also present. This indicates that these Smart Markers and the steel markers were moving with the rock in the same fashion.

An important feature of the system was also demonstrated with this first test: the detected markers shown in Figure 6 can be animated to show actual order of detection. It is not possible to reproduce this in a written format, however, the next section shows a series of images to illustrate the effect.

Figure 7 shows an operational Smart Marker from the test still embedded in a large rock in the LHD bucket.

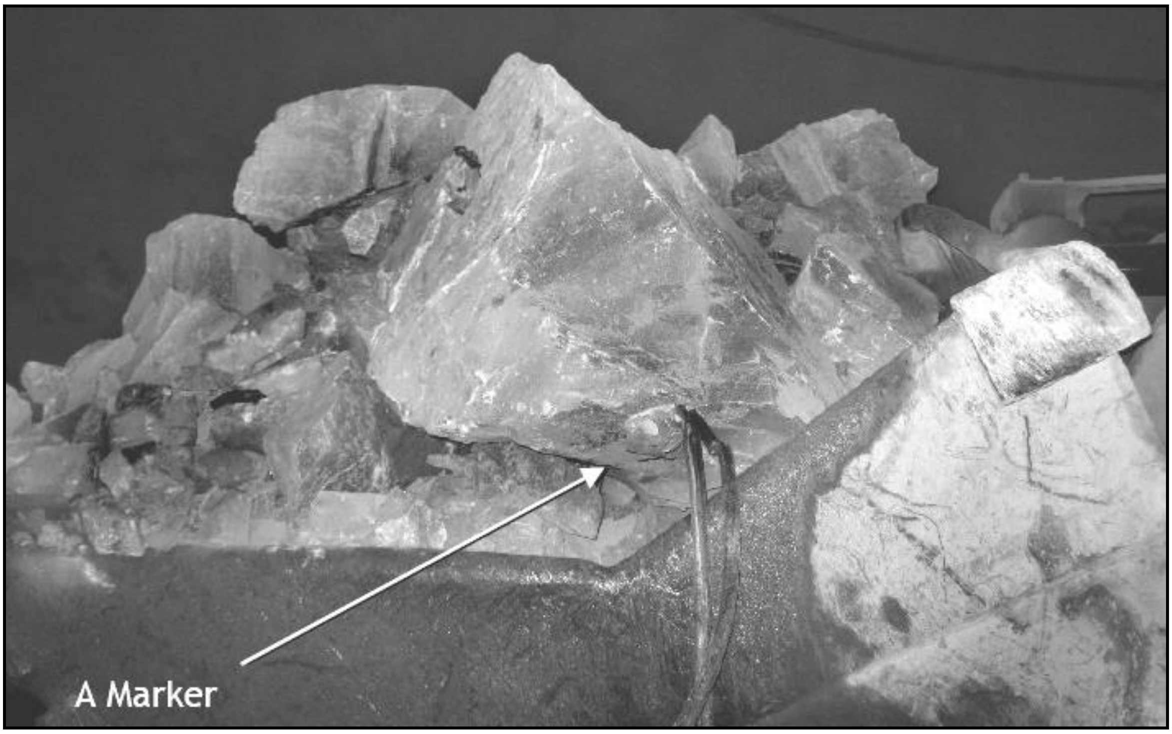


Figure 7 This Smart Marker was successfully detected while embedded in the rock

5 Smart Marker System sublevel cave testing — 0.65 m blast results and observations

Following the successful first SLC production level test with the marker holes 1 m from the blast holes a second test was carried out at a spacing of 0.65 m from the blast holes. While markers were detected during this test, the physical damage was regarded as too great and a hardening program was carried out. The hardening program tripled the strength of the marker. A third test was carried out in August 2009.

The set-up for the test was similar to that described in the previous section, with the exception that the marker ring was spaced (closer) at 0.65 m from the blast ring. Two extra marker installation holes, ‘B’ and ‘F’ were also drilled and loaded with markers (Figure 8).

The results from this test were excellent, with very good recovery over the full installation depth of 20 m.

The test results have been animated to reveal which volumes of the ring were extracted at what time. The estimated tonnage is also displayed. For this paper, the animation has been split into a few ‘stills’ so that the development of the extraction zone can be observed.

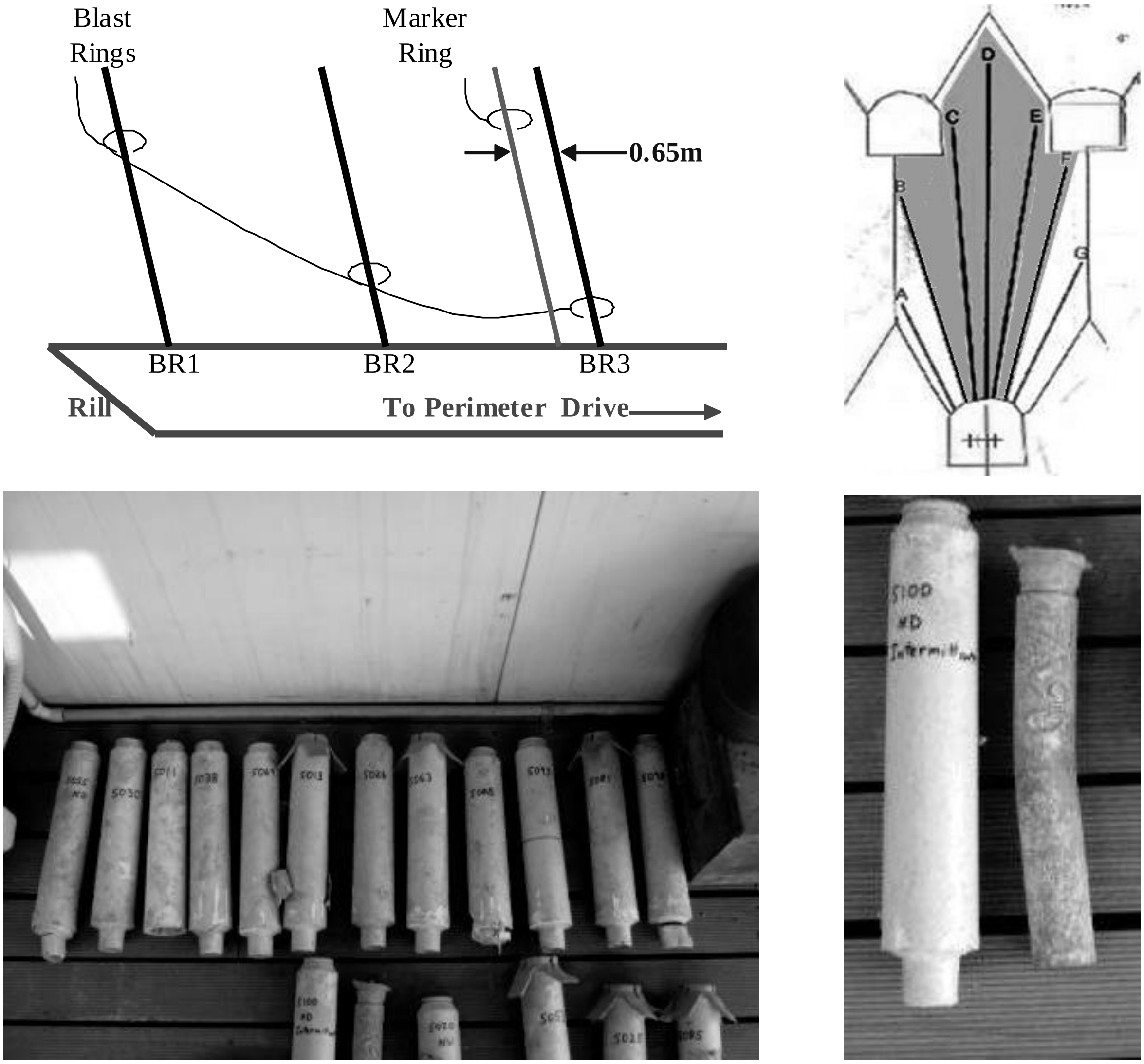
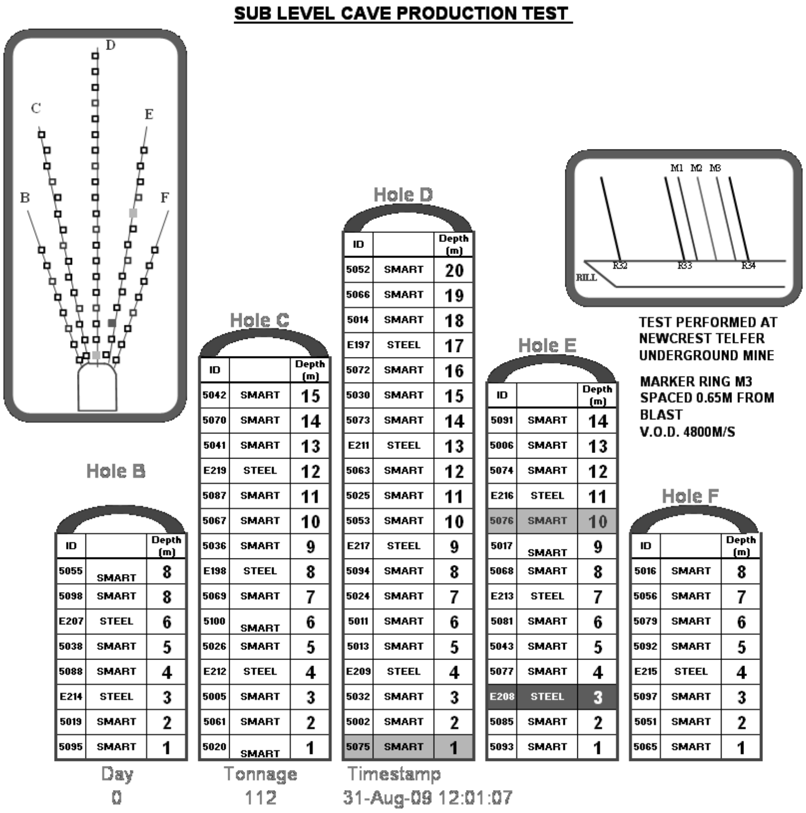


Figure 8 Top images show the test set-up. Bottom images show some of the recovered Smart Markers, including a steel marker

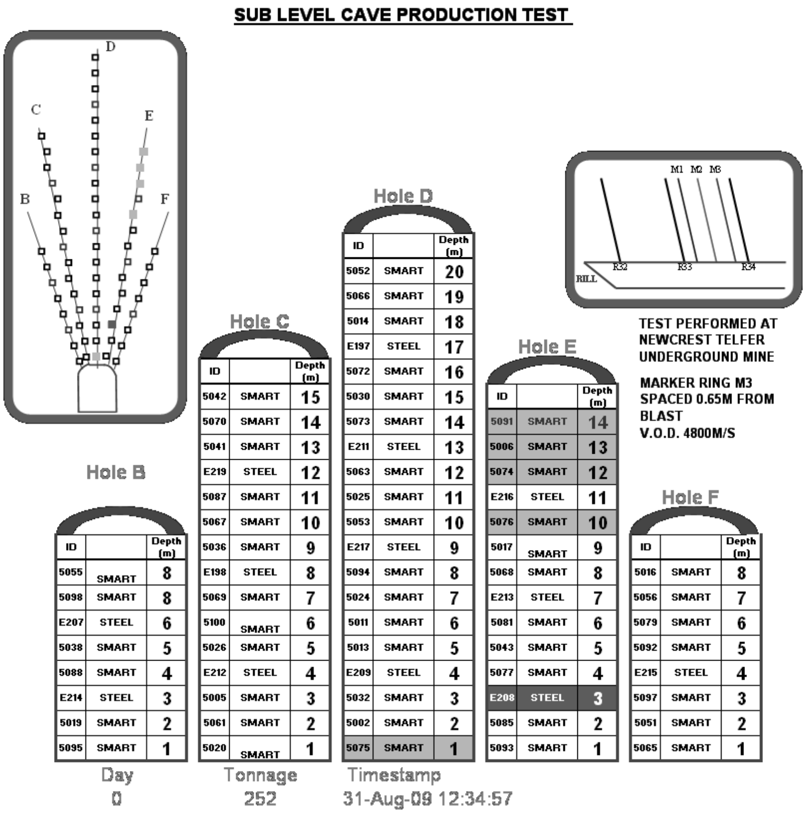
The frame sequence in Figure 9 below demonstrates how marker extraction from a blasted ring can be captured on a ‘per bucket’ basis without the need to pause production.

The eight images shown have been selected from a sequence of 30 images. An image is generated every time markers are electronically detected in the LHD bucket (note that some bucket loads contain more than one marker).

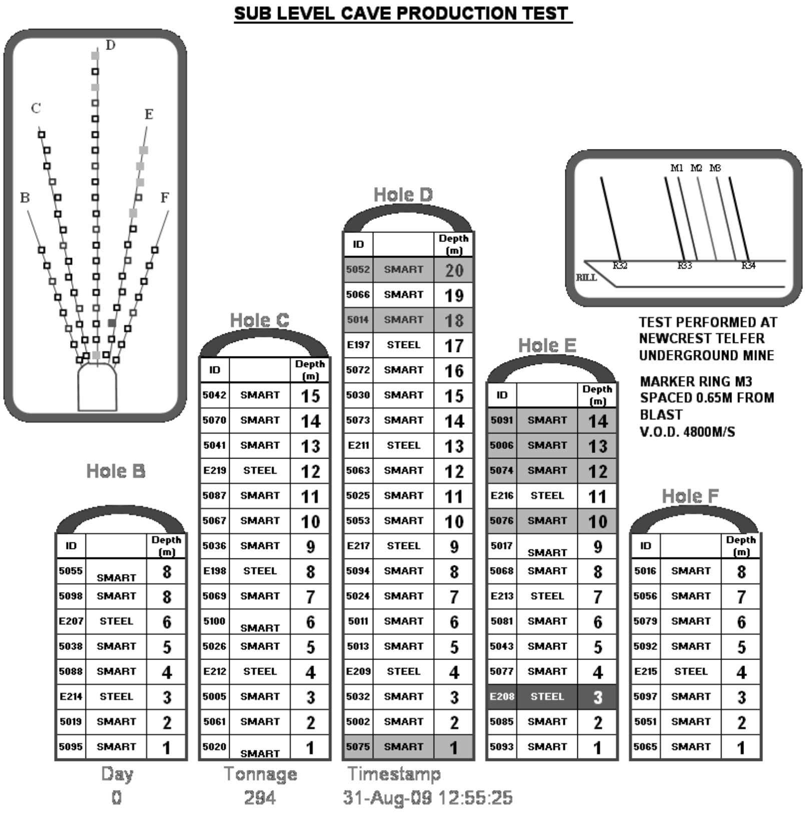
The results of this test show that the Smart Markers were successfully detected when placed in an installation ring spaced 0.65 m away from the blast ring.



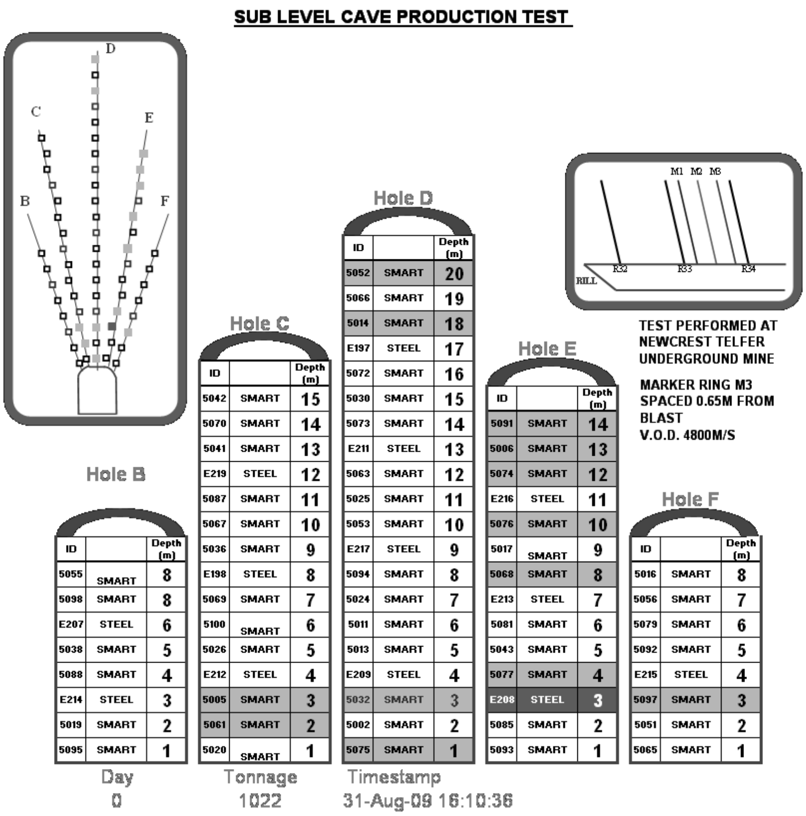
Frame 2/30: 112 tonnes drawn



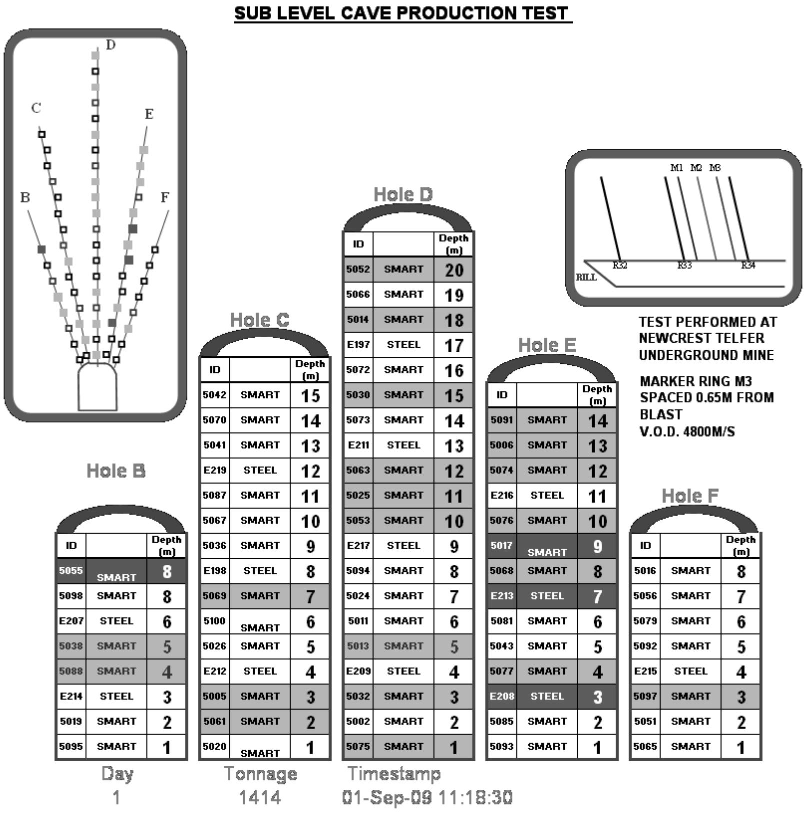
Frame 5/30: 252 tonnes drawn



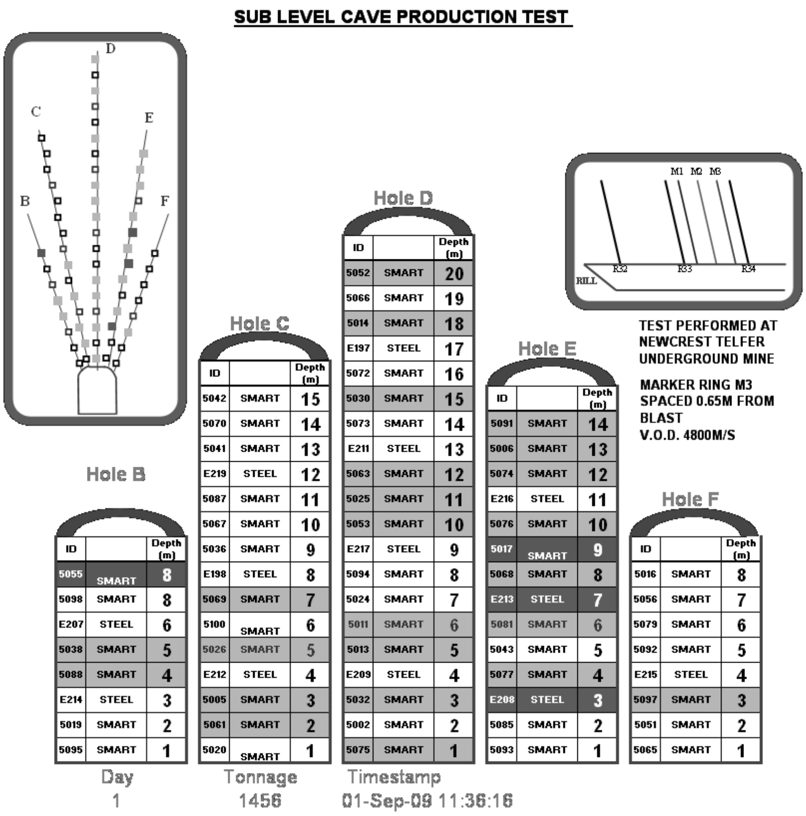
Frame 6/30: 294 tonnes drawn



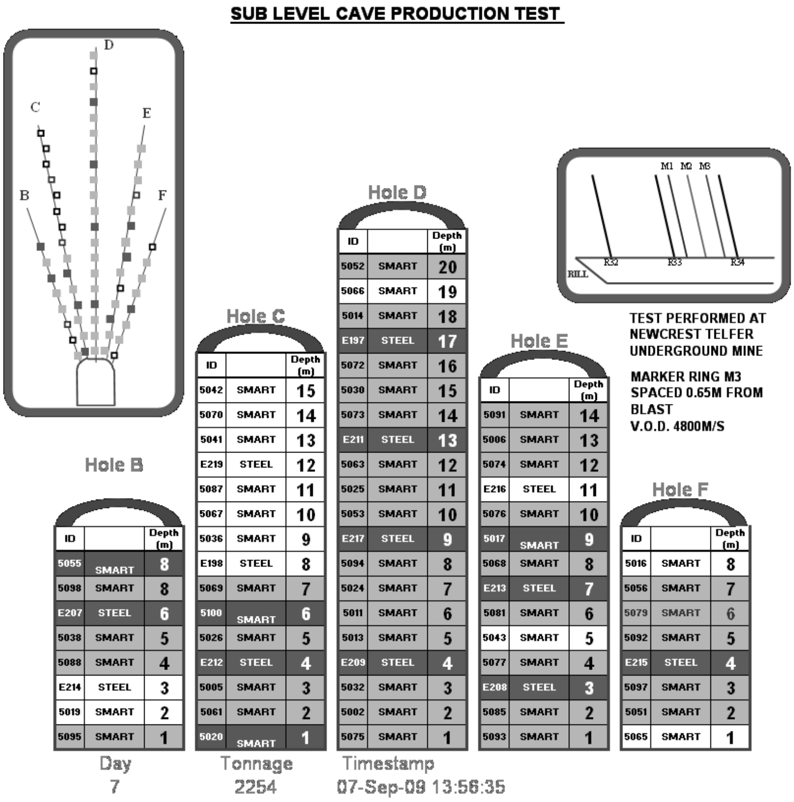
Frame 12/30: 1022 tonnes drawn



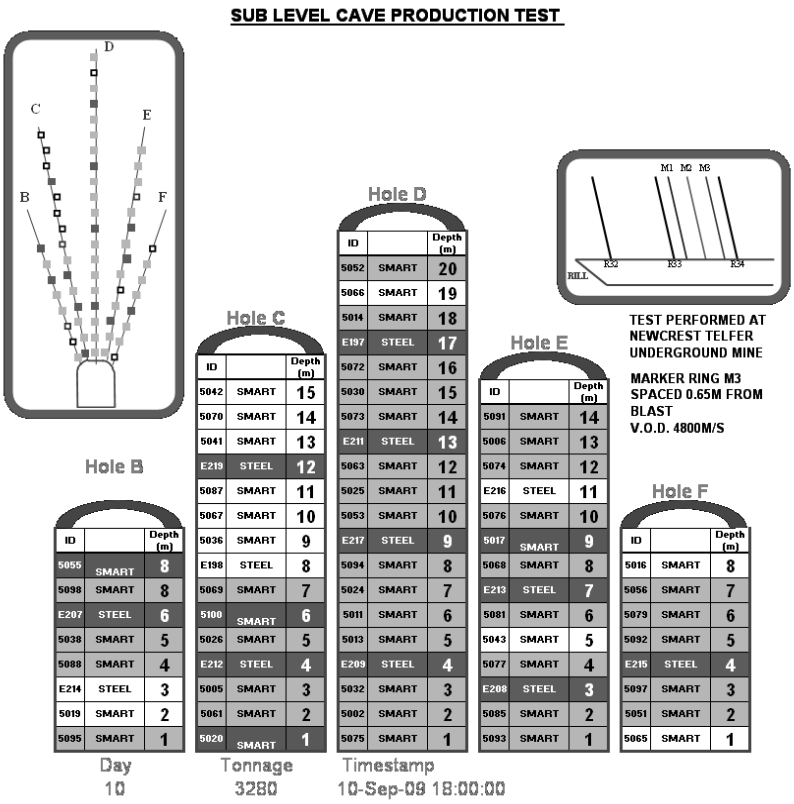
Frame 17/30: 1414 tonnes drawn



Frame 18/30: 1456 tonnes drawn



Frame 29/30: 2254 tonnes drawn



Frame 30/30: 3280 tonnes drawn

Figure 9 Light shaded cells in this data sequence represent detected Smart Markers. Smart Marker data resolution is down to the LHD bucket load

In Figure 9 detected markers are the lighter shaded cells. The darker shaded cells represent the steel 'control' markers. There was excellent agreement between the steel markers recovered and the Smart Markers recovered.

Although this marker trial was predominantly to test the Smart Marker system in a close range blast, the high tonnage resolution gave insight into which areas of the ring were extracted at what time. This generated much discussion among those who have seen the animation.

Note that some markers from 20 m up the hole were recovered after only 300 tonnes of draw. This highlights the fact that in the SLC environment, the underground rock movement is significantly affected by the blast and represents more than just 'simple' flow. A number of people have commented that early recovery of high-up material is not an uncommon event.

In addition to the ability to 'see' high resolution movement in a blast ring, and the automated ability to track primary, secondary and tertiary (etc.) recovery, the system offers immediate benefit in day to day operations. The occurrence of back-break is instantly detectable if markers are detected from in front of the blast ring. While it may be possible to visually detect back-breaks that affect the brow, the system offers the ability to detect the 'unseen'; and a chance to recover material left behind from the primary extraction during the tertiary extraction phase.

A possible benefit of the high resolution data is the potential to record hang-up events. When a hang-up prevents the flow of material, this is reflected in the marker recovery data, as markers are also 'held up'. When a hang-up releases, the markers are released with it. This should create a searchable data signature that could be used to analytically categorise hang-up events. An attempt may be made to correlate such events with various draw strategies.

6 Block cave testing

The Smart Marker System was also tested in a block cave environment, at Rio Tinto's Northparkes E26 mine in New South Wales, Australia.

A comprehensive paper detailing the E26 cave performance, including the testing of the Smart Marker System is given by Talu et al. (2010). A full analysis of the data provided by the E26 cave monitoring systems is given in that paper, along with the results gathered from the Smart Marker System. The information that is presented here will cover the background to the Smart Marker E26 block cave test and the overall system results.

Eight Readers were installed in the E26 cave. Seven of these were installed in the extraction drives, and one in the undercut (see Figure 10).

Markers were gradually 'fed' into open instrumentation holes in Northparkes E26 mine commencing September 2008. Because of the dynamics of block cave testing, markers can take 200 days or more to travel through the orebody to the drawpoints 835 m underground.

As a 'control' in this test, steel markers were introduced along with Smart Markers every time the cave was 'fed'. The success of the Smart Marker system was determined by comparing the number of physically extracted steel markers to the electronically read Smart Markers.

The overall results from E26 testing at time of writing were as follows:

- Smart Markers placed in E26 block cave: 88.
- Steel markers placed in E26 block cave: 57.
- Smart Markers detected in E26 block cave: 21.
- Steel markers detected in E26 block cave: 9.

A placement rate of 1.5 Smart Markers for every steel marker, and a detection rate of 2.3 Smart Markers for every steel marker indicates that the system is performing well.

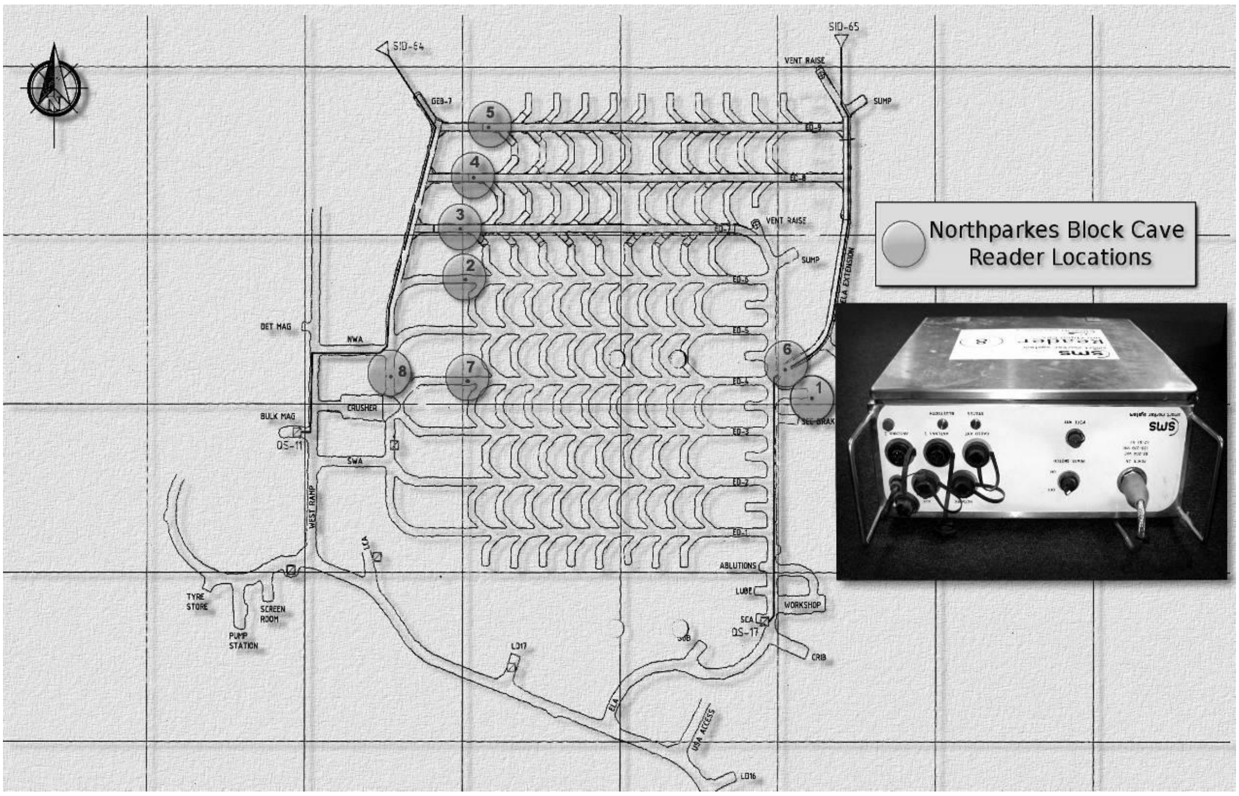


Figure 10 Smart Marker System Reader locations in the E26 block cave

Referring to the photos in Figure 11, this particular marker is of the design before the above-mentioned hardening program: the current design has three times the strength of the marker shown.

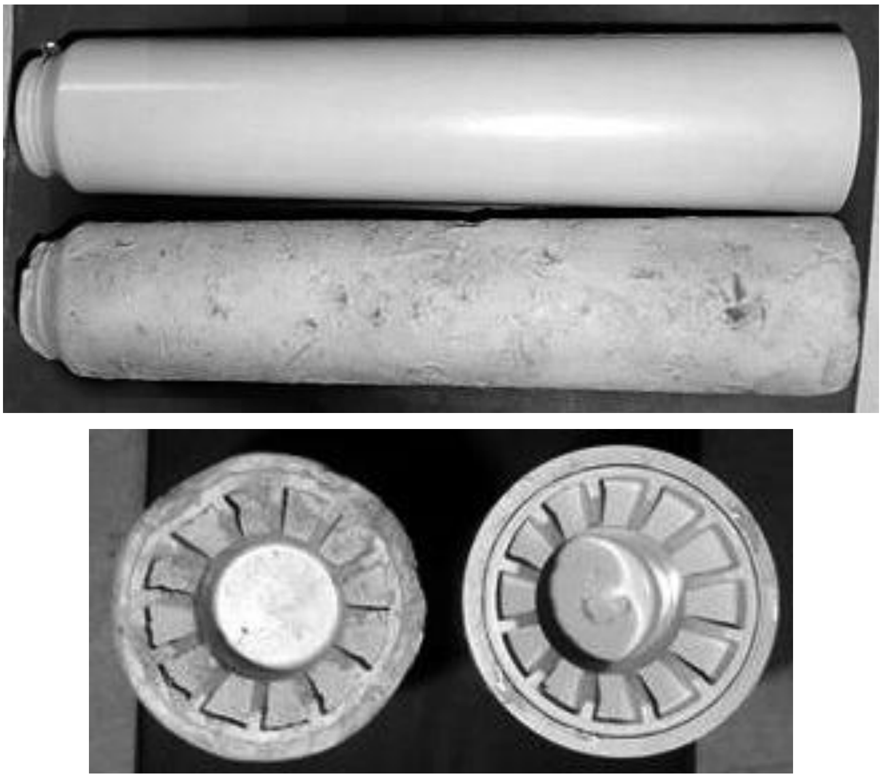


Figure 11 Comparison of a marker recovered from E26 with a new marker

The marker in the photo was physically extracted with the aid of a strobe light that flashes when a Smart Marker is detected by a Reader (as discussed in Section 4). The strobe alert feature is programmable, and can be enabled and disabled by the Scanner. As noted earlier, markers only need to be there physically extracted during testing of the system itself, not during normal operation.

The fastest time for a marker to travel to the extraction point has been logged at six days. The longest period that a marker has taken to travel to the extraction point is (so far) 176 days. The test is currently 25% completed, and ongoing.

The widely varying time for markers to present themselves at the drawpoint illustrates the usefulness of an automated system over long-term testing (many years) with thousands of markers.

As discussed in Talu et al. (2010), the markers along with bore-hole cameras have revealed surface rilling as a dominant flow mechanism. It is hoped that cave flow models can be updated in the future with further calibration data provided by the Smart Marker System.

7 Advanced features — alerts and feedback

Readers can be configured by the user to generate a chosen alert when specific marker IDs (or groups of marker IDs) are detected. Tens of thousands of markers may be detected and pass through the system without the need for any real-time alerts to be generated, however, specific markers may be 'tagged' to generate an alert as soon as they are detected.

The alert can be in the form of:

- A strobe light that is activated in the underground tunnel (visible to the LHD operator).
- An SMS test message that is automatically sent via the Marker Management System when it receives an alert from a Reader (the Marker Management System can connect to Readers via WiFi, LAN, Leaky Feeder, or via Scanner Downloads).
- An email message that is dispatched by the Marker Management System when it receives an alert from a Reader.
- An alert entry in a log file.

The alert concept is powerful. Here are some examples of how they could be used:

- *Dilution Entry Alerts:* Specific groups of markers (placed in areas of the mine that are of low ore quality, or in regions where movement and extraction is not desired) can generate special alerts. This information can be used by draw control officers to determine if extraction from a certain drawpoint should be terminated.
- *Back-break Alerts:* If the system is configured to set off an alert if a group of markers is recovered before a certain blast date, then this information is immediately useful in the analysis of the blast and in addressing reconciliation issues.
- *Flow Analysis Alerts:* Before Smart Markers were available, measuring flow velocity of underground ore was very difficult. Automated, real-time logging of Smart Markers makes this process simple. Groups of 'flow measurement' markers may be tagged in the system to generate an alert as soon as they are detected. When an alert is generated, the engineers responsible for the flow analysis can evaluate the results. Note that thousands of Smart Markers may be passing through the system where no alert is required or wanted. Flow velocity test markers may emerge anywhere between 10 days, 10 months, or 10 years after installation. The ability to single out a single marker, or groups of markers, to generate an alert reduces the overhead in daily monitoring of logged data.
- *Flow Propagation Alerts:* Without Smart Markers, it is difficult to gain an understanding of the flow patterns of a particular mine. Nevertheless, every mine has a model on what flow is expected to occur. Based on these models, if a marker is installed at a certain point inside the mine then, in most cases, it can be expected to be extracted somewhere below that point (allowing for some lateral drift). By having the Smart Marker System generate alerts (for example, if groups of markers are

extracted in unexpected zones), draw strategists can receive an early warning that their mine is not caving as expected.

In addition to alerts, the real-time measurement possibilities now make it possible to provide instant feedback to LHD operators.

8 Discussion and conclusions

The testing of the Smart Marker System in sublevel caves and block caves has demonstrated that it can be effectively used in the mining environment.

In sublevel caves: markers, installed 0.65 m from blast rings, survived production blasting and extraction by LHDs to be automatically detected, whilst inside LHD buckets, en route to the orepass.

In block caves: markers fed into open instrumentation holes were automatically detected during extraction from LHD buckets at a level of 835 m underground. Block cave markers to date have taken between six days and 176 days to travel from the installation point to the extraction point.

While demonstration of the system in the rigorous underground mining environment was an important milestone, the real importance of the testing has been to highlight the value of the data that was measured underground. The data falls into two categories.

The first category concerns the highly accurate time stamped marker detection data, which allows precise pinpointing of the marker extraction point. This type of data has never been available before in production situations, and hence the information it provides is invaluable in providing a new understanding of underground rock movement.

The second data category is related to the benefits of continuous, automated marker detection. Large steel marker trials, carried out over many years, require continual human effort to ensure that markers are regularly searched for. This is required to maintain data quality. Simplifying the marker detection process using an automated system allows larger trials to be undertaken with little effort. During block cave testing, the detection rate of Smart Markers was higher than the recovery rate of the steel markers.

To elaborate on the value of the automatically gathered, real-time marker data:

- It has not previously been possible to correlate ore fragmentation size with the ore's original underground position.

  With the automated system, this is made possible using the Scanner (a hand held computer). The Scanner identifies markers and their installation positions as they are detected by Readers from the LHD buckets. The fragmentation size of the ore in the bucket can then be assessed and correlated with its original underground location.

  It is also possible to carry out correlation work above ground, by matching time stamped ore fragmentation size evidence with marker detection times.

  Note: The only way to carry out this type of test with steel markers has required that every LHD bucket be searched before delivery of ore to the crusher. Carrying out a test in this manner requires a significant drop in the rate of extraction, which inturn may effect the rock movement and fragmentation being measured.

  During the testing of the system it was confirmed that the detections could be monitored underground in real-time with the Scanner.

  The system is ready for further mine trials to be conducted to try to determine the relationship between draw rates, LHD operation at the drawpoint, the effects of varying blast parameters and the resultant effects on fragmentation size.

- Real-time marker extraction data allows analysis to be carried out on rock movement inside an SLC ring, block cave undercut, or general orebody. Playing back the marker detection data as an animation allows rock movement and flow theories to be tested. This can be performed at any time with minimal impact on production.

Data gathered in the trials to date have generated a lot of discussion when viewed during playback. It can be seen in SLC primary recovery that the first marker detections are generally not from the very lowest markers in the installation rings, but from the markers several meters above. Markers from 20 m or higher in the two closest rings to a blast ring can also be seen in the early stages of extraction. This demonstrates that a ‘simple’ flow action, as represented by uniformly fragmented material in a hopper, is not taking place. The blast is a significant driver in subsequent rock movement behaviour and its effects should be included in computer simulation models.

Further trials will reveal whether there are parameters that establish rock movement patterns which can be fed into computer simulations.

- Evidence for the topological mixing of ore can be examined by looking for simultaneous marker detections in LHD buckets (up to 10 markers can be simultaneously detected in an LHD bucket). By looking at the installation locations of the detected markers, the originating location of the ore in the LHD bucket can be inferred and the spatial mixing of recovered ore established. Ore mixing can also be observed by examining sequential marker detections from one bucket to the next.

  It has been observed in SLC testing to date that clusters of markers are often simultaneously or sequentially drawn from similar areas in the ring. Detections in one area progress (or sometimes ‘jump’) to another area, however, there are noticeable events where markers are detected from widely separated areas.

- The immediate detection and logging of marker data allows for the real-time characterisation of back-break. Because the date of each ring blast is known, markers that are detected before ‘their’ ring has been blasted can be immediately classed as ‘back-break’ markers and highlighted in system’s 3D visualisation tools.

  Figure 12 shows how the RockView tool automatically shades back-break markers as red (dark gray in the image). Markers that are detected during normal ring extraction are shaded as green (white in the image). Markers that have not yet been detected are shaded yellow (light gray in the image).

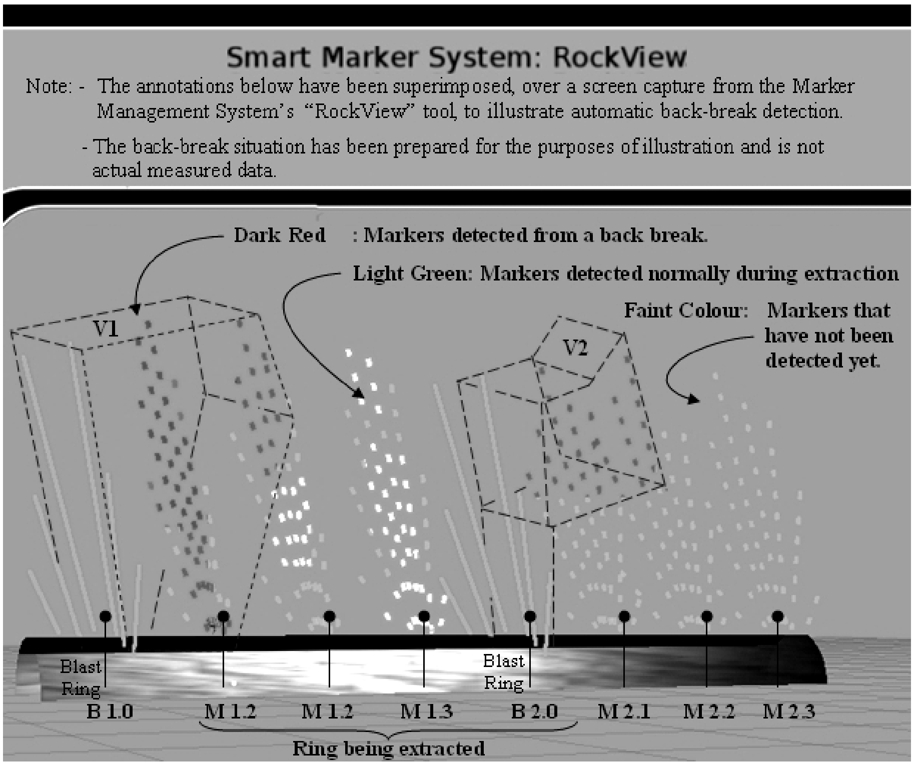


Figure 12 Back-break can be viewed in real-time either underground or above ground

Note: The data used in Figure 12 has been specially generated for the purposes of illustration, it is not an actual example of back-break measured from a mine (although the system is doing this at the time of writing).

Because Smart Marker data is gathered in real-time, it is possible to characterise the extent of any back-break in real-time. It can be observed underground, or in an office above ground as it occurs.

The volume of rock “V1”, shown in the Figure 12, represents back-break that originates from the brow. It would be possible to observe this break from the extraction drive, as the rill would be further along the drive than expected. However, the extent of the back-break would not be known; nor would the originating positions of the ore being extracted from the ring (i.e. material from the ‘B1.0’ ring may be left behind as material is pulled from the ‘B2.0’ ring).

With the volume of rock “V2”, shown in the Figure 12, it would not be possible to visually detect that back-break had occurred. With the automated system, the break can be detected and quantified. In addition, the spatial origins of the ore being extracted can be determined (in real-time) by observing the highlighted back-break markers with the 3D visualisation tool.

Informed with this knowledge, it may be possible to adapt draw and cutoff strategies to ensure that material is efficiently extracted from the mine. Ore that is left behind in the primary extraction phase may be targeted in tertiary extraction by ‘over-drawing’.

With real-time observation and categorisation of back-break it may be possible to tailor subsequent blasts, or be forewarned of the likelihood that a blast will not go as planned due to compromised rock.

- In the case of block cave testing, the ability to pinpoint marker extraction points with the real-time data made it possible to establish how many horizontal metres markers had travelled. Excessive travel can represent features such as rills that affect the flow of material in the cave. The horizontal distances travelled by markers during the trial were significant.

  The same techniques as already described are applicable to investigating rock movement in block caves (where evidence of interaction, or establishing height of interaction may be sought).

  Markers may be placed in the undercut, prior to blasting, and the effectiveness of the blast observed by the flow (or absence of flow) of markers to the drawpoints.

  The importance of access to open instrumentation holes (in which markers can be ‘fed’ to a block cave) has been established and pioneered by Rio Tinto. When developing new block caves, the continuing use (and positions) of instrumentation holes should be kept in mind from the earliest stages.

In conclusion, the Smart Marker System is a powerful tool for the measurement and analysis of rock movement in underground caves.

Much of the data that the system provides has never before been available and thus provides a rich opportunity to carry out trials to observe and characterise the inner workings of underground caves. Some of the areas of research and production interest are tabulated in Table 1.

The system is useful both as a research instrument and as a tool for production process control due to the fact that during extraction, Smart Marker data is continually and automatically detected in real-time and is available for immediate analysis.

Table 1 Some areas of interest for Smart Marker use

Block Caves	Sublevel Caves
Fundamental flow data	Fundamental flow data
Rill features	Development of the extraction zone over time
Height of interaction	Primary, secondary and tertiary recovery
IMZ, IEZ characterisation	Blast effectiveness and ring to ring dynamics
Air gap	Hang-ups
Automated flow rate measurement	Back-break
Geospatial flow patterns	Dilution entry
Reconciliation	LHD operator feedback
Dilution entry	Reconciliation
Effectiveness of drawbell geometries and spacing	Effectiveness of level and cross-cut spacing’s
Calibration and validation of recovery curves	Calibration and validation of recovery curve.
Calibration and validation of modelling tools	Calibration and validation of modelling tools

Acknowledgements

The author would like to thank Newcrest Mining and Rio Tinto for their support and assistance during the testing of the Smart Marker System in their caves, Telfer and Northparkes E26 respectively.

A very special thank you is extended to Nigel Clark and Markus Karlsson of Newcrest along with Andre Van As and Sami Talu of Rio Tinto for their considerable generosity with their time, knowledge, drive and their patience with our seemingly-never-ending questions.

Finally, I would like to thank Gideon Chitombo for his valuable assistance and the Mass Mining Technology project members for their support.

References

Hustrulid, W. and Kvapil, R. (2008) Sublevel caving – past and future, in Proceedings 5th International Conference and Exhibition on Mass Mining, MassMin 2008, H. Schunnesson and E. Nordlund (eds), 9–11 June 2008, Luleå, Sweden, Luleå University of Technology Press, Luleå, pp. 107–132.

Kvapil, R. (1965) Gravity Flow of Granular Materials in Hoppers and Bins, International Journal of Rock Mechanics and Mining Sciences, Vol. 2, pp. 35–41.

Power, G. (2004) Full scale SLC draw trials at Ridgeway Gold Mine, in Proceedings MassMin 2004, A. Karzulovic and M. Alvaro (eds), 22–25 August, Santiago, Chile, Instituto de Ingenieros de Chile, Santiago, pp. 225–230.

Talu, S., Van As, A., Seloka, W. and Henry, R. (2010) Lift 2 North extension cave performance, in Proceedings 2nd International Symposium on Block and Sublevel Caving (Caving 2010), Y. Potvin (ed), 20–22 April 2010, Perth, Australia, Australian Centre for Geomechanics, Perth, pp. 407–422.

van As, A. and van Hout, G.J. (2008) Implications of widely spaced drawpoints, in Proceedings 5th International Conference and Exhibition on Mass Mining, MassMin 2008, H. Schunnesson and E. Nordlund (eds), 9–11 June 2008, Luleå, Sweden, Luleå University of Technology Press, Luleå, pp. 147–154.