Caving 2022 - Y Potvin (ed.)

doi:10.36487/ACG_repo/2205_67

Interpreting cave tracker beacon data at Carrapateena mine

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Abstract

Carrapateena mine is an underground sublevel caving (SLC) operation in South Australia. An array of Elexon Cave Tracker Beacons was installed in the barren sedimentary cover sequence overlying the vertical orebody. Within this array, a small-scale trial area of Cave Tracker Beacons was installed in the undercut of the northwestern area of the cave. The aim of the installation was to understand the extent of interaction of near-field and far-field cave flow in three dimensions in a sublevel cave. Elexon Cave Tracker Beacons contain a magnet which is spun at programmed intervals. An array of detectors installed outside of the cave allow the location of the beacons to be tracked with each spin as they move with the broken rock. The beacons can show semi-real time changes in material flow and movement within the cave. The proximity of the small-scale trial to the SLC rings allowed for the observation of material movement through primary, secondary and tertiary draw stages.

Keywords: *sublevel caving, cave flow, marker trials*

1 Introduction

Carrapateena mine is an underground sublevel caving (SLC) Operation 160 km north of Port Augusta in South Australia. The site produces copper concentrate containing gold and silver using a conventional crushing, grinding and flotation processing method. The SLC orebody is within the Carrapateena Breccia Complex and is situated beneath ~500 m of barren sedimentary cover sequence as shown in Figure 1. It is a vertical orebody so hangingwall draw constraints have not been applied in the flow models.

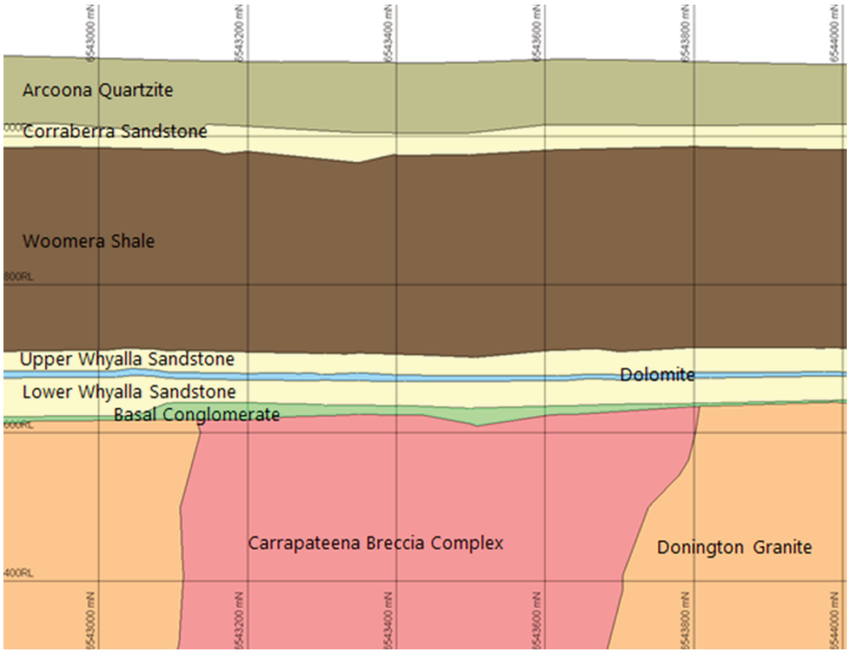

Figure 1 Carrapateena cover sequence

Several monitoring systems have been installed in the cover sequence to monitor cave propagation. The Elexon Cave Tracker Beacon System is the monitoring method used for measuring both far-field and near-field cave flow. The focus of this paper will be on the near-field flow experiment installed in the undercut of the northwestern area of the cave.

The aim of the near-field flow experiment was to determine the draw width and extent of interaction of flow in three dimensions in a sublevel cave. Several full-scale flow trials have been conducted in SLC Mines using markers made from steel-pipes (Power 2004; Brunton 2008) or smart-markers that contain radio frequency identification devices (RFIDs) (Campbell 2018). The install positions of these markers were confined to the ring geometry and were not installed above the undercut level of the SLC. Steel pipes used by Power (2004) and Brunton (2008) rely on visual inspection or magnetic retrieval at the crusher. RFID markers used by Campbell (2018) could be collected closer to the source of the ring through the use of electronic readers installed in crosscuts. Previous marker trials have explored primary, secondary and tertiary recovery through the material that is extracted. As Brunton (2008) described, results from past maker experiments have provided details on the extraction zone (ellipsoid of extraction) of an SLC ring but have not been able to describe the movement zone. The ellipsoids of extraction and loosening are shown in Figure 2 and are based off the gravity flow models of Kvapil (1982).

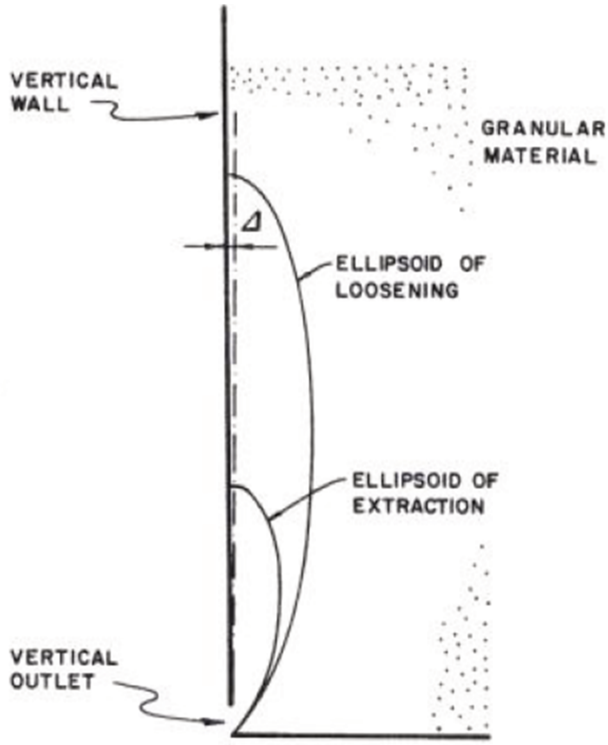

Figure 2 Gravity Flow Model – Ellipsoids of loosening and extraction at the brow of an SLC ring (Kvapil 1982)

The marker trial at Carrapateena aimed to learn more about the movement zone or ellipsoid of loosening around an SLC ring by using markers that can be tracked while they are still within the cave. Elexon beacons contain a magnet which is spun by an electric motor at programmed intervals and known frequency. Each spin is recorded by a detector containing a magnetometer. An array of detectors installed outside of the cave allow the location of the beacons to be tracked as they move with the broken rock. These beacons have been used in block cave mines (Whiteman et al. 2016), but this is the first time they have been installed in the undercut and upper levels of an SLC mine.

2 Methodology

Beacons were installed in horizontal arrays across three elevations to measure near-field flow in three dimensions. These elevations include 4555 Level, 4580 undercut level and 4615 RL, 35 m above the backs of 4580 Level, as shown in Figure 3. The third sublevel 4530 was the location of the centre ring that would have the best opportunity to mobilise the beacons. A total of 37 beacons were installed alongside nine detectors which are used to locate the position of the beacons.

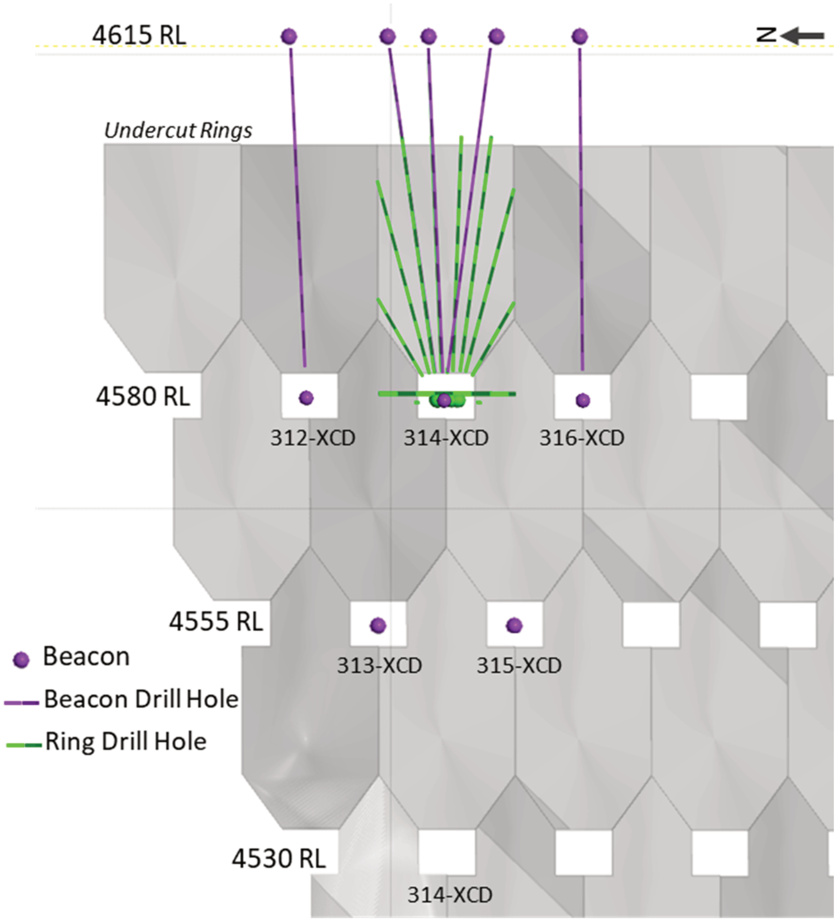

Figure 3 Cross-section showing beacon locations with respect to crosscuts and ring designs

The location of the flow width trial was towards the edge of the cave on the northwest side of the orebody as shown in Figure 4. This was to position the trial away from the edge of the cave to reduce edge effects or material rill causing false cave column material flow results.

Figure 4 illustrates the horizontal array of 19 beacons installed in 4615 RL. The position of each beacon was chosen to account for different draw width scenarios. According to Kvapil (2008), if the extraction height of an SLC ring is large, the ellipsoid zone of loosening becomes a cylindrical shape. Based on four fragmentation types, Kvapil (2008) plotted extraction widths of 11–20 m for extraction heights of 25–60 m. In this trial, the beacons are set up to measure three sublevels and the undercut which equates to 90 m. To understand the draw widths at the additional height of draw, the empirical chart by Laubscher (1994) for block caving was used which suggests the width of draw can be between 6 and 25 m depending on the fragmentation size of the blocks. The minimum distance between beacons was 5 m to minimise magnetic interaction. The largest distance was 15 m radially and to ensure the draw widths described by Kvapil (2008) and Laubscher (1994) were captured, each radial draw cone of 1 m from the ring centre had beacon coverage.

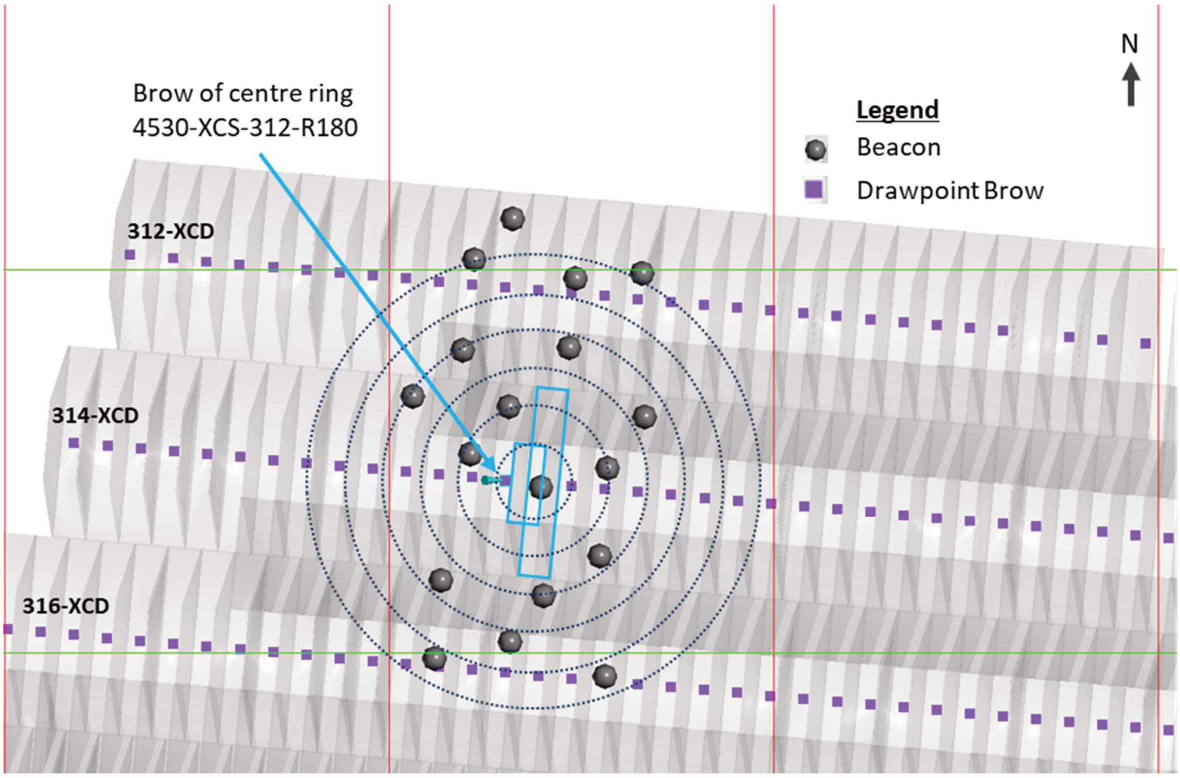

Figure 4 Plan view of 4615 RL beacon locations with respect to 4530 XCD 314 Ring 180

The beacons installed at 4615 RL were installed above the firing horizon as illustrated in Figure 5. The drill holes in the undercut rings are drilled to a height of 25 m. Holes were drilled between the undercut rings to a height of 35 m to allow for the beacons to be installed at the end of the holes as shown in Figure 5.

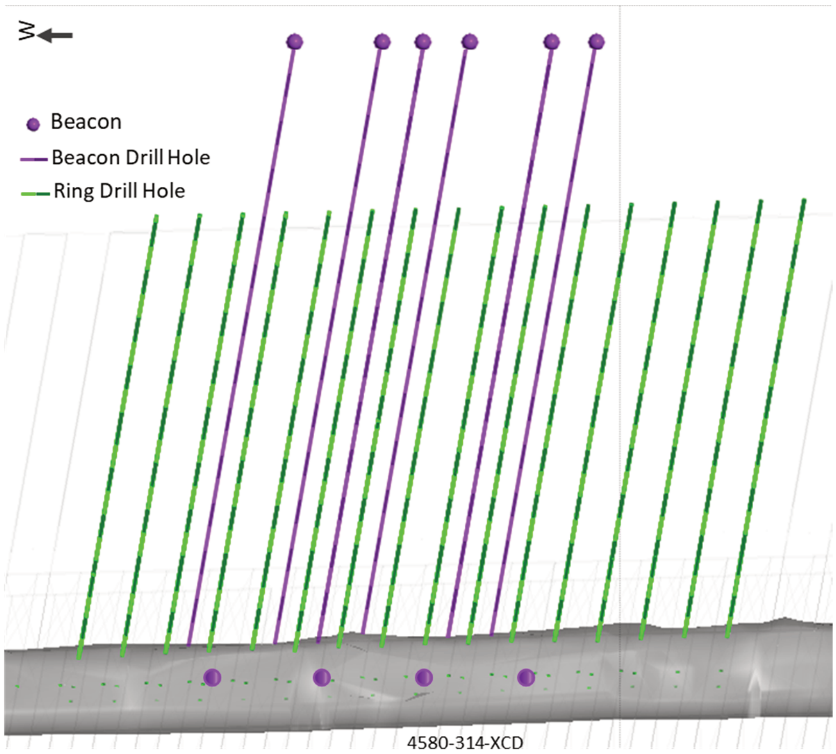

Figure 5 Longitudinal view of beacon locations in 4580-314-XCD

A beacon weighs 4.3 kg with dimensions of 450 × 76 mm. The installation of the beacons at the end of a 35 m uphole had to consider manual handling and falling object risks. To install the beacon at the end of the hole, it was first placed in the collar of the hole by a team in an IT basket and held in place by three red caps as shown in Figure 6. A scaling bar was used to push the red caps until they were ~0.5 m into the hole.

Figure 6 Placement of beacon in the collar of the drill hole

From the IT basket, the cable bolter speed rod, without the bit, was guided into the hole until it contacted the red caps as shown in Figure 7. The cable bolter steels were slowly fed up the hole. The number of steels were counted until the installation depth was reached. Once the beacon was pushed to the end of the hole, a bolt plate was installed using four galvanised screws to cover the hole to prevent the beacon from becoming a falling object hazard. The detector system is sensitive enough to register a beacon fall of 35 m to track whether any beacons dropped during adjacent firings. No beacons were monitored to have dropped from the holes during adjacent firings.

Figure 7 Position of cable bolter speed rod to push beacon to end of hole

A total of 18 beacons were placed in crosscuts in 4580 and 4555 during the firing of each ring. Each beacon was placed on a completed drawpoint rill by the charge-up crew and the subsequent ring fired on top of them. Figure 8 shows the location of the beacons with respect to the flow model simulated in Power Geotechnical Cellular Automata (PGCA) for a draw width cone of 11 m.

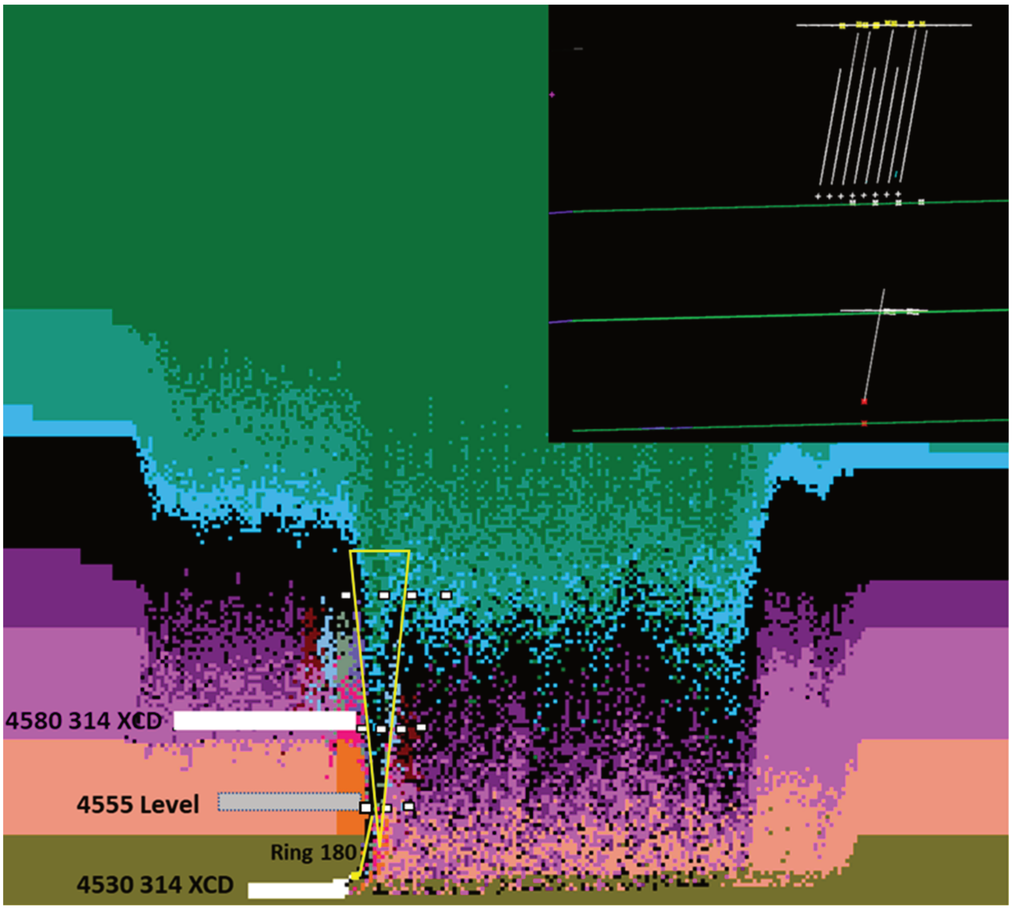

Figure 8 Long section of beacon design overlaid onto PGCA draw model to illustrate beacon location with respect to an 11 m draw width cone

The location of the beacon near-field trial ensures six detectors are always within 150 m of the beacons as shown in Figure 9. During the trial, one detector went offline. This reduced the confidence in interpretation for a period of time until it was replaced. When the detector was replaced, there was a shift in the beacon positions as their 3D positions were recalculated. This caused the apparent upwards movement of some beacons.

To calculate the frequency the beacons would need to relay their position via the detector system, it was assumed that the beacons would need to survive for 2.5 years. The more spins a beacon completes to communicate its position, the faster the charge is depleted from the battery. The beacons installed on 4615 and 4580 RL began in heartbeat mode to conserve their battery life for their first months of delivery, storage and install. Once installed for a month, the beacons were programmed to commence on a three-day spin cycle for one year while the 4580 and 4555 Levels were depleted. After one year, the spin cycle frequency reduced to one day to capture daily movement as the tertiary draw on 4530 commenced. 4555 rill beacons would be in the cave for less than two years so commenced on a one-day spin cycle. The spin programming of the beacons considered several mine schedule scenarios as the programming must be set before the beacon is installed and cannot be changed during their movement in the cave.

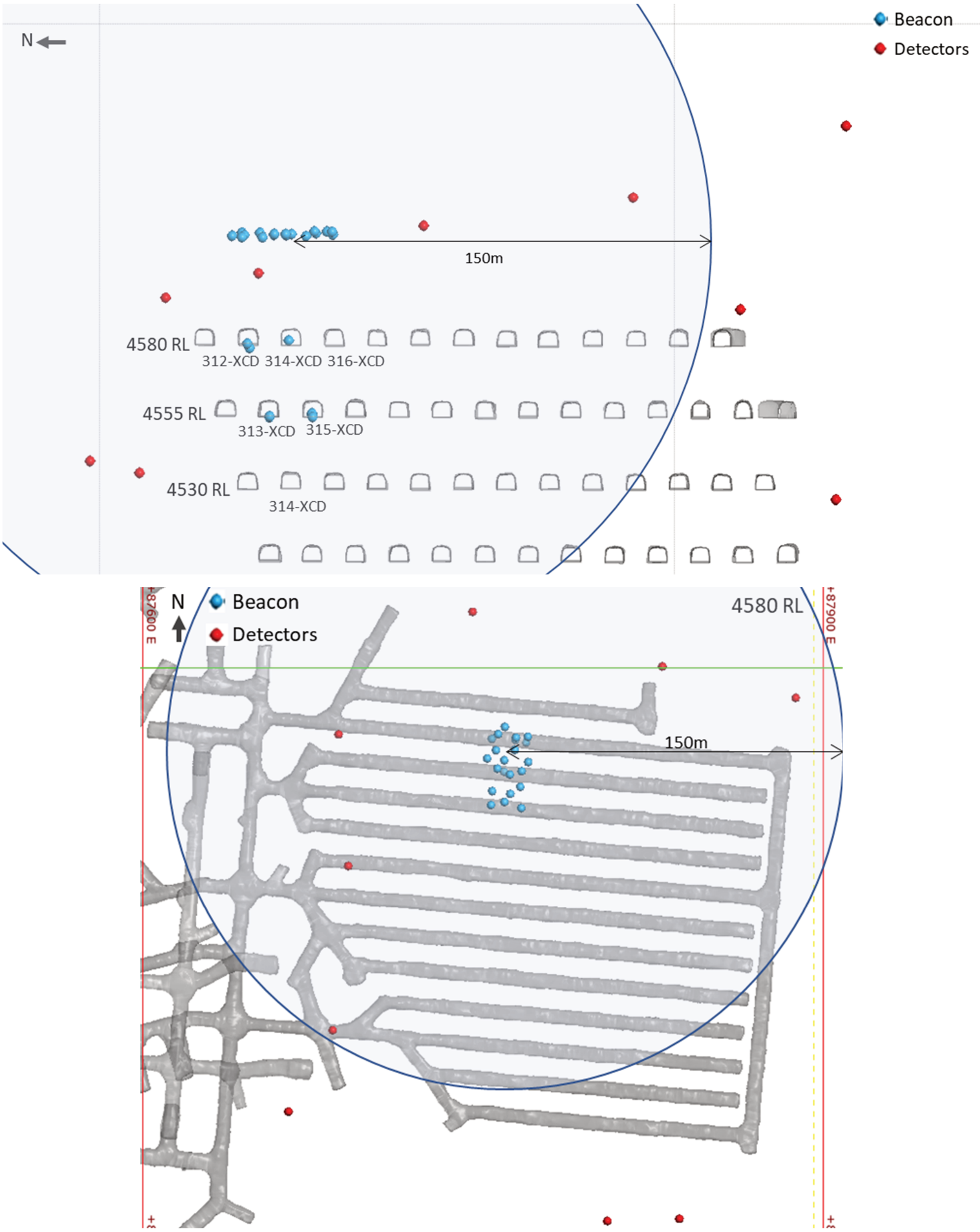

Figure 9 Transverse and plan view of detector array installed within 150 m of beacons

The position of the experiment at the top of the orebody dictates that the draw must follow the draw control rules to manage dilution and air-blast. The top three levels, 4580, 4555 and 4530 have draw constraints respectively of 40%, 60% and 90%. The fourth level, 4505, is the first level to operate on a non-fixed draw ratio based on Net Smelter Return (NSR) predicted by the PGCA cave flow simulation.

At the time of the experiment design, the aim was to bog the ring at the centre of the cone on 4530 (4530-XCD-314-R180) to 300% draw, above the planned 90% of adjacent rings, to mobilise tertiary flow of

~90 m height of draw. Based on Kvapil (2008) it was thought the flow ellipsoid would become more cylindrical or conical and by tracking the horizontal displacement of the beacons, the draw width at different extraction heights could be inferred. Referring to Figure 10, for a draw width of 11 m, it is anticipated that beacons in 4615 RL will have moved at 9000 t of draw (the equivalent of three rings) and potentially be recovered at the drawpoint. This is shown by the larger grey bubbles representing the proportion of material drawn assuming an 11 m draw width. If the draw width is larger than 11 m, additional tonnes would need to be extracted based on the small blue dots representing the 15 m draw width proportion.

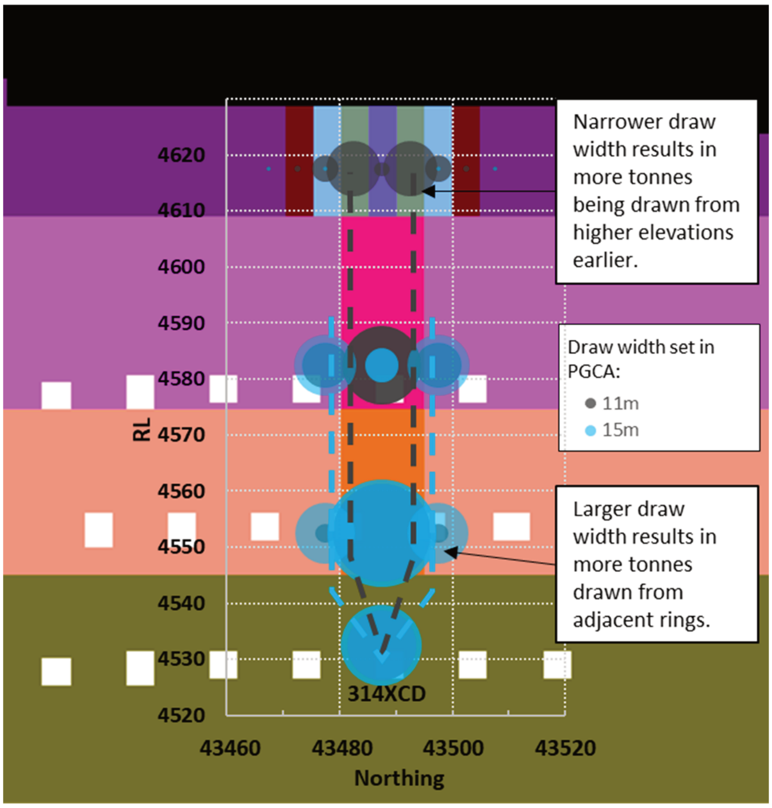

Figure 10 Tonnes location distribution for a single ring of 9000 t. The graph bubbles represent the percentage of production tonnes obtained from different locations as specified by the material colour the bubble resides in

The results from bogging the second sublevel, 4555, challenged the design of the experiment and the methodology for the draw on 4530 changed. This is explained in Section 3.2.

3 Data

The raw data from the detector system is processed by Elexon using their Cave Tracker software. The beacon data contains the spin date and corresponding position of the beacon. The number of detectors affects the location accuracy of the results. An interpolation field denotes which beacons had interpolated detector information in the position calculation. To represent the data in 3D, some data was filtered from the results. Date ranges 18–28 February 2021 and 2–12 September 2021 were time periods where detector upgrades/replacements were completed. As a result, false movements were recorded. As the beacon is 450 mm long, total 3D movements less than 500 mm have been removed from the visuals.

For the 3D visuals, points representing the brow of the fired ring have been coloured based on the date they were fired, and points representing the beacon position have been coloured based on the date they spun to communicate their position. To declutter the images, each level draw image only displays the movement that happened during that period and removes beacons that lost connection (OFFLINE). For example, the 4555 draw shows the final position of the beacon after 4580 draw but does not show the beacon installation positions. Removing beacons that have gone offline during the bogging period prevents the appearance of stationary beacons. For beacons installed in the SLC undercut, Table 1 summarises the points of the trial where the 10 beacons became offline.

Table 1 Beacon records going offline based on the level being drawn

4615RL beacon ID	Offline 4555 draw	Offline 4530 draw
bcn_DMDC		Yes
bcn_DMDP		Yes
bcn_DMDQ		Yes
bcn_DMDS	Yes	Yes
bcn_DMDV		Yes
bcn_DMDZ	Yes	Yes
bcn_DME5		Yes
bcn_DMEH	Yes	Yes
bcn_DMEN		Yes
bcn_DMEW		Yes

3.1 4580 bogging results

4580 Level is the undercut of the SLC with draw set at 40% to accommodate swell. The beacons were installed 10 m above SLC rings as shown in Figure 11. It was theorised that the first movement of the beacon would represent the first cave growth above the undercut. Sixteen out of 18 beacons experienced displacement of ~10 m, the height they were installed above the undercut firing. Two of the beacons travelled approximately two thirds of the way down the fired ring. Power & Campbell (2016) found zones of high and low mobility indicating possible uneven distribution of blast energy. Power (2004) described the consolidation on the waste side of the ring which would cause early dilution from the ore side of the ring. At this stage in the trial, the beacons were spinning every three days so there can be a lag between when the beacon moved to when it communicated its position. Reviewing the cross-section in Figure 11, beacons did not always move with their corresponding fired ring. Some beacons were observed to move after five proceeding rings had been fired.

Key observations from 4580 undercut draw were:

- Vertical movement was generally 2–15 m due to the low draw percentage.
- Two beacons had significant vertical movement which is like observations made by Power & Campbell (2016) and Power (2004) where markers from the top of some blast rings were recovered very early.
- Lateral movement across the apex from west to east rather than the draw direction of east to west could be due to rilling at the top of the muckpile due to the low cave height of the undercut.

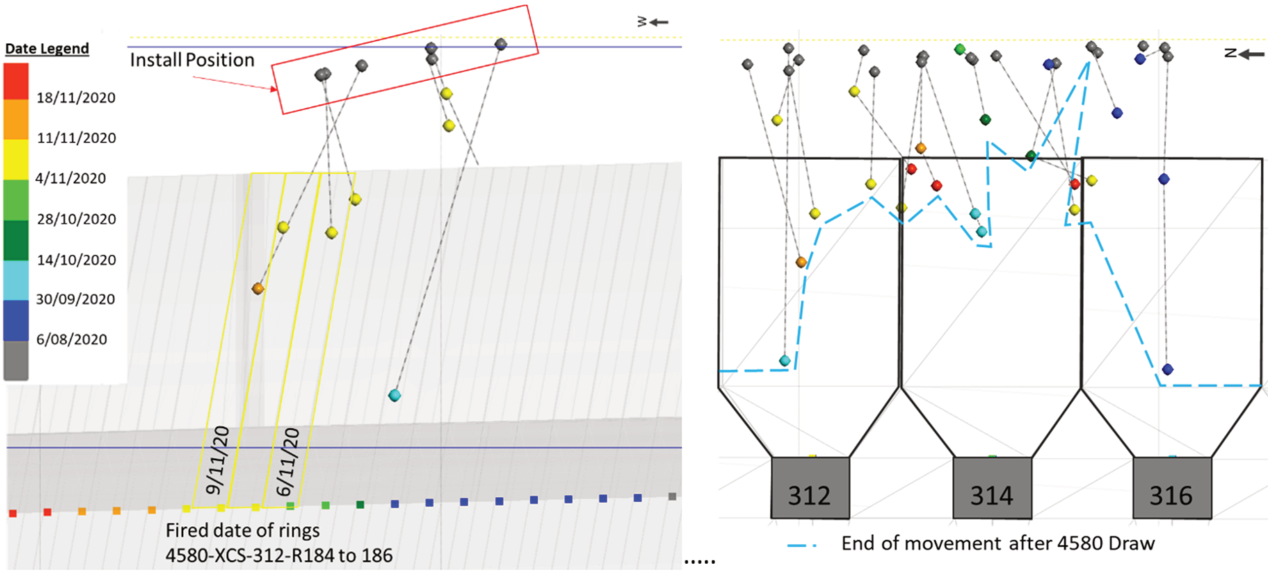

Figure 11 Longitudinal (312-XCD) and transverse sections of beacon movement during 4580 bogging

As the fired rings progressed, the 12 beacons for the 4580 array were placed on the rills of completed rings. Only five beacons successfully recorded spins underground. Most went offline early. The cause is unknown but likely reasons are due to interaction with metallic ground support or damage from blasting.

3.2 4555 bogging results

4555 Level is the second operating level of the SLC with draw set at 60% across the level. Figure 12 displays the beacon movement that is associated with 4555 draw. Movement that occurred during 4580 draw has been removed. The blue dotted line shows the final positions of the 4580 beacons.

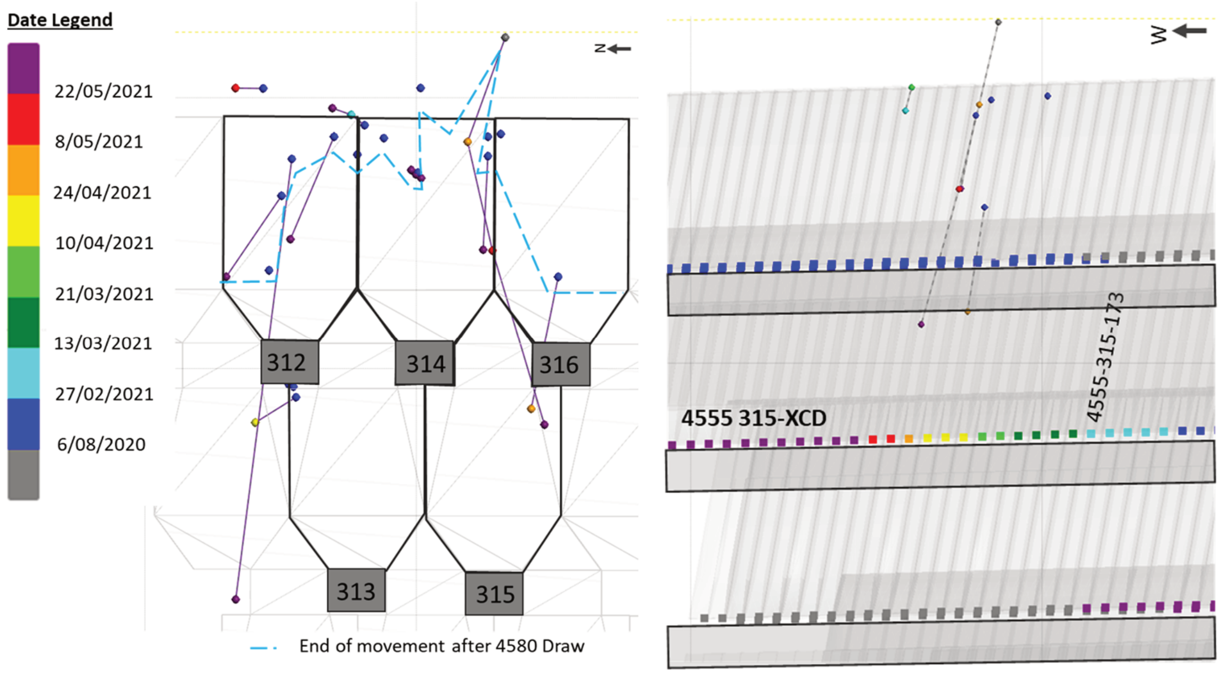

Figure 12 Longitudinal (315-XCD) and transverse sections of beacon movement during 4555 bogging

Shown in Figure 12 without flow lines, there were a number of beacons that did not move during 4555 draw. Of the 19 beacons that were online and could move, only nine did. As the trial progressed, it was theorised that pillars/low flow zones between the 4555 rings may have contributed to the stationary beacons.

However, beacons positioned over the centre of the 4555 drives were also shown not to move. It is plausible that the 60% draw on 4580 was not sufficient to mobilise beacons from that height. This will need to be confirmed with calibration models comparing draw width. Drill and blast performance has a large influence on the flow of material (Power & Campbell 2016; Brunton 2008). Power & Campbell (2016, p. 7) attributed unrecovered markers at the tops of rings to 'episodic flow patterns in full scale SLC flow'. The causes of these different zones of mobility were credited to drill and blast design, geotechnical conditions in the ring, unloading practices and how well the blast design is implemented. The formation of bridges or unfired apexes would stall the movements of the beacons.

From the longitudinal section in Figure 12, it was observed that the dip of the beacon movement was between 10–20°. This is similar to the ring dip of 10° showing the beacons had a preference to flow along the ring dip rather than vertically. Campbell & Power (2017) showed a widening draw zone above the ring geometry as shown in Figure 13. This was not evident in the beacon flow lines; however, it could be that the spin frequency in communicating the beacon position was not frequent enough to show the change in flow direction.

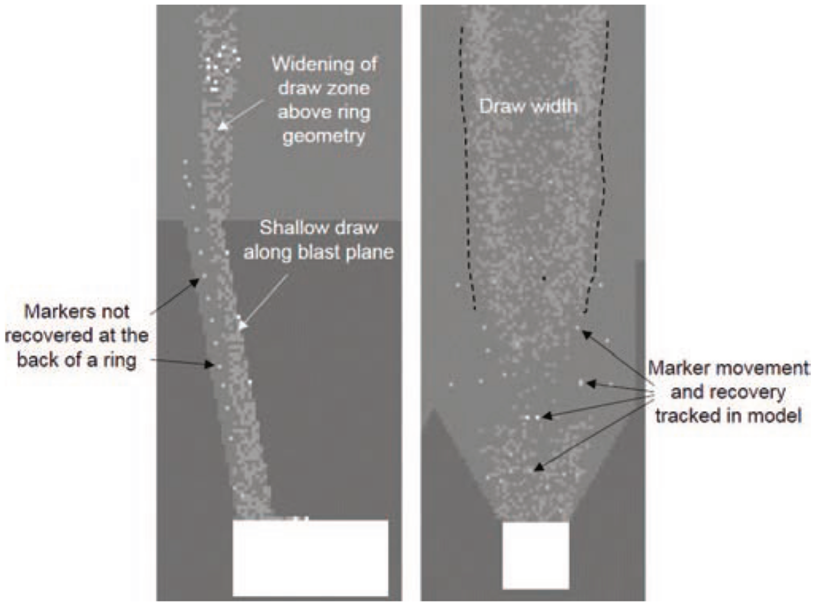

Figure 13 Markers simulated in PGCA showing zones of widening (Campbell & Power 2017)

The original trial methodology was based around drawing one ring on 4530 to 300% draw. Reviewing the end position of the beacons and the dip of their vertical movement, it was decided to draw three rings on 4530 to 150% draw rather than a single ring at 300% draw. This was to ensure that beacons that entered the flow cone of adjacent rings could be monitored and to review whether the stationary beacons during 4555 draw could be mobilised by the draw on the level below. The three overdraw rings were: 4530-XCS-316-R184, 4530-XCS-314-R184 and 4530-XCS-312-R184.

There was greater success with the rill beacons on 4555 with five out of six beacons recording spins underground.

3.3 4530 bogging results

4530 Level is the third operating level of the SLC with draw set at 90% across the level. Large vertical movements were observed during this period as shown in Figure 14. Interactions also began to occur with 4505. Some beacons were observed to move towards the centre of the cave front above the 4505 draw regions rather than maintain a 10° dip to align with the ring geometry as observed on the levels above. This movement can be attributed to the larger draw ratios (>100%) applied to 4505 Level and the maturity of the cave in the centre as the cave draw progresses from east to west. This supports the widening of the draw zone as presented by Campbell and Power (2017). Two beacons that were higher in the cave column were observed to move horizontally.

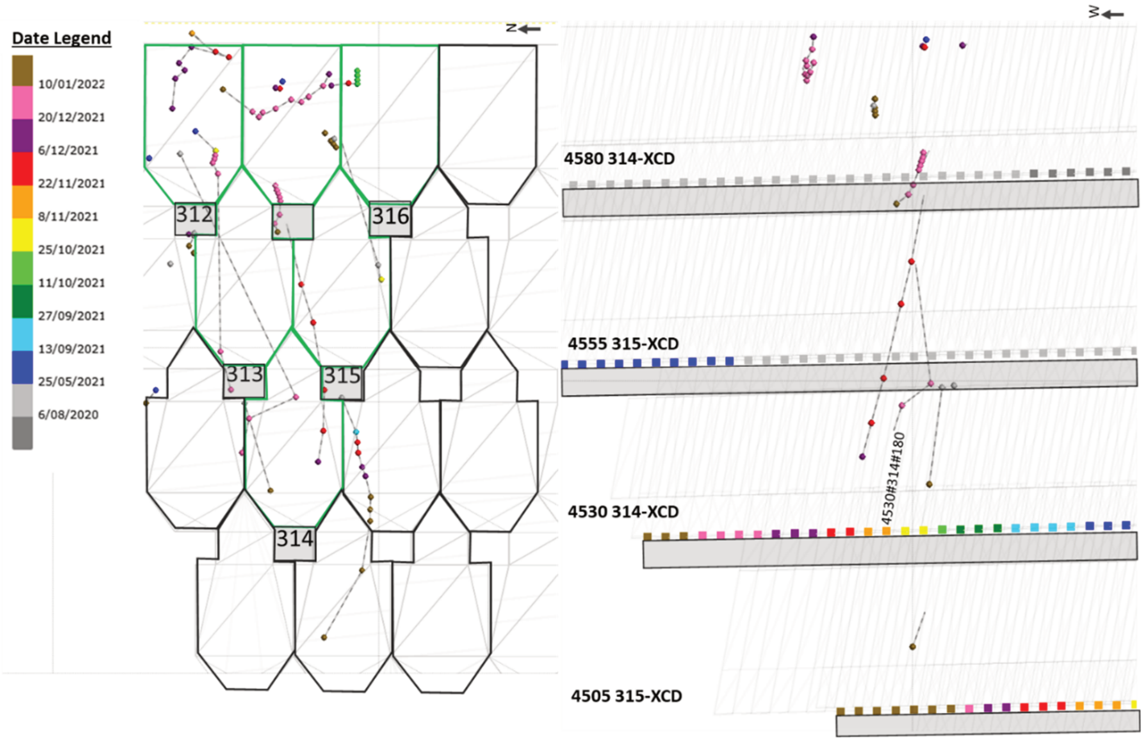

Figure 14 Longitudinal (314-XCD) and transverse sections of beacon movement during 4530 bogging

4 Results

The data presented from the near-field flow width trial has illustrated the different directions and heights that material was mobilised at Carrapateena. A component of the data that was not explored in this paper was the confidence of the beacon position. The factors that influence the confidence in a beacon position include the detector distance, the number of planes of triangulation from the detector system, the number of detectors online and available for analysis and the proximity of beacons to metallic objects. The unanswered question is whether the accuracy of the beacon position is suitable for small-scale trials where draw width increments of 5 m are noteworthy. Campbell (2020) on his review of current marker technology did not recommend the Cave Tracker system which uses beacons due to the detection accuracy relative to the scale of the marker spacing and ring geometry for SLC.

From the data presented, there are three main takeaways:

- Vertical dip in the longitudinal plane aligns with the dip of the fired rings until interaction occurs with the centre of the cave when draw percentages are above 100%.
- Draw greater than 60% is required to mobilise beacon movement of ~50 m or the height of two rings.
- Large horizontal movements are possible.

To validate the points presented above, future near-field trials should consider a square array pattern above the undercut to track cave growth and the effect of drawpoint offsets. Temporary detector installations underneath the trial region should be considered to improve the confidence in the beacons Z position. Installations within the SLC rings are not recommended due the survivability of the beacons.

While the influence of far-field and near-field interactions have been visualised, the calibration of draw width in the onsite models has not been completed. The beacon data presented will be run alongside flow models of varying draw width to determine whether 11 m is a suitable assumption.

5 Conclusion

Near field trials using beacons are useful to visualise draw in 3D. They held up against the forces of blasting installed 10 m away from ring firings and could be installed at a vertical height of 35 m with the assistance of the cable bolting rig. For the rill beacons that survived blasting and interaction with metallic objects, they added to the dataset to compare draw percentage vs draw height; however, the importance of that information would need to be weighed up against cost as the survivability of the beacons may not justify the data. If it were possible to keep beacons operating in close proximity to metallic objects, this could change the way flow is measured and calibrated.

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