

# The mythology of full interactive draw in high column caves

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## ABSTRACT

As cave mining moves deeper, the production level layout must satisfy two competing design criteria when determining the drawpoint spacing: first ensuring the stability of the drawpoint apices, and second, addressing the impacts of drawpoint interaction between adjacent drawpoints.

The upfront selection of stability over recovery by planning teams is obvious, as it is imperative that drawpoints remain active over the life of mine (LOM). The actual underperformance of modern mines (Van As et al 2008, 2011) however, is becoming increasingly scrutinised by regulators in the light of substantial stakeholder losses. Consequently, current modelling tools used to evaluate recovery by simulating cave flow require greater scrutiny, particularly for high column caves where the recovery of ore high in the column is at risk, and results should be challenged to ensure that dilution and recovery forecasts are reliable.

To this end, a reliable forecasting model should be well calibrated and be able to accurately predict, not only grade but also the geological composition of each drawpoint. Van Hout et al (2023) describe how routine drawpoint sampling of grades and lithology monitoring can reliably inform the evolution of drawcone geometry and Height of Draw (HOD) for each drawpoint over time. This data is therefore able to assist in evaluating cave performance periodically and demonstrates whether isolated or interactive draw predominates so that more accurate forecasting takes place in studies and operations.

This paper elaborates on the importance of detailed drawpoint field data collection and analyses for cave reconciliation work and demonstrates that with real life examples of drawpoints that do (not) conform with forecast behaviour. It is supplemented with a novel analysis methodology for cave monitoring instruments, namely the Elexon Cave Trackers, that aid in the interpretation of the detailed drawpoint analysis.

## 1 INTRODUCTION

As cave mining moves deeper, the production level layout must satisfy two competing design criteria when determining the drawpoint spacing: the stability of the drawpoint apices and addressing the impacts of drawzone interaction between drawpoints.

### 1.1 Stability of the Drawpoint Apices

Cave mining operations at increasing depths, generally associated with high ore columns, expose personnel and infrastructure to elevated stress regimes that can exacerbate rock mass instability conditions, particularly around the

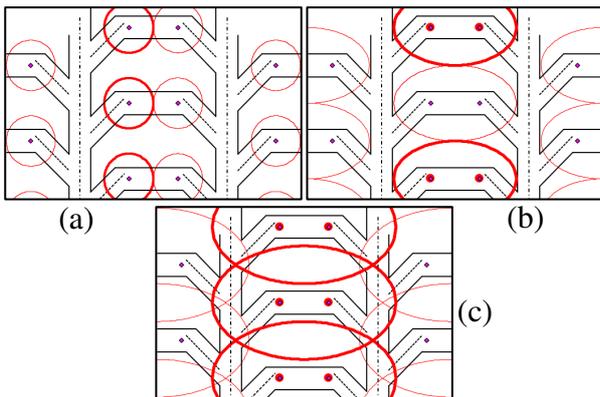
critical production level. Adequately sized and properly supported apices and drawpoint excavations, must ensure the overall stability of the extraction level. It is reasonable to prioritise rock mass stability over ore recovery initially, as it is crucial for drawpoints to stay open and active throughout the mine's lifespan.

The size of the minor and major apex pillars is affected by the excavation dimensions, but more so by the spacing of tunnels and drawpoints. Industry practitioners have published numerous papers on the topic of the drawpoint spacing, based on their interpretation of physical experiments, numerical modelling, empirical

studies of marker recoveries and other field observations (Kvapil 1965, Marano 1980, Richardson 1981, Heslop and Laubscher 1981, Laubscher 2000, Paredes 2022).

### 1.2 Isolated Draw versus Interactive Draw

Besides the overall excavation stability requirement to enable planned production rates, the extraction level design must also incorporate the objectives of achieving high ore recovery and avoidance of excessive dilution. These criteria rely on ‘interactive’ or ‘interaction’ draw conditions which improve with good draw control practice and decreasing drawpoint spacings (Laubscher 1994 & 2000), see Figure 1 (Van Hout et al 2004). The drawpoint spacing application developed by Van Hout in 2000, has seen widespread adoption in the caving industry but is frequently misapplied when the isolated draw zones (IDZs) within the drawbells fail to meet the requirement of touching, to satisfy the first interaction condition.



**Figure 1** Interaction modes (a): isolated, (b): interaction within drawbell and (c): interaction across minor apex.

Guest (2007) clarifies the distinction between interactive and interaction: *When two drawpoints are placed in very close proximity to each other so that their Isolated Draw Zones interact, they are said to be ‘interactive’.* *Drawpoints that have been moved some critical distance apart and yet mass flow is still seen to occur, this is called ‘interaction.’*

The authors acknowledge the distinction but as it is difficult to determine in the field which mechanism is at play during the flow of rock

under gravity, one can only distinguish between ‘isolated’ and ‘interactive’ draw. With the former, ore is deemed left behind in between the IDZs while the latter implies that the drawzones above the neighbouring drawpoints interact, resulting in mass flow and minimal ore losses.

There is currently no consensus in the industry on whether interactive draw conditions occur for widely spaced drawpoints, especially in deep, high-column caves. One prevailing viewpoint suggests that the empirical interactive draw theory, initially proposed by Laubscher in the 1970s, remains relevant for modern deep hard rock caves. This perspective advocates for maintaining limited drawpoint spacings and adhering to strict draw control practices. Contrary to this, another perspective argues that as depths and ore column heights increase, wider IDs and full interactive draw become more common. Consequently, this allows for more widely spaced drawpoints and less stringent draw regimes. Supporting this view is the notion that Laubscher's empirical rules are primarily based on data from sandbox models and experiences from shallow, soft rock cave mines with low ore columns. Therefore, they may not be applicable to deeper, harder rock caves.

## 2 THE NEED FOR ANALYSES ON THE DRAWPOINT SCALE RESOLUTION

Van As et al (2008, 2011) provide qualitative assessments of some high column cave mines with a poor track record of overall reserve recoveries. More recently, the actual under-performance of modern mines is becoming increasingly scrutinised by regulators and stakeholders in light of considerable financial losses. Consequently, current modelling tools used to evaluate recovery by simulating cave flow require greater scrutiny, particularly for high column caves and results should be challenged to ensure that dilution and recovery forecasts are reliable.

Forecasting of metal production for most caving projects and operations is conducted using software packages such as PC-BC (Diering, 2000). These sophisticated codes generally schedule the tonnages for each drawpoint during the first three to five years on a monthly basis,

thereafter in quarterly or annual increments for the remainder of their Life of Mine (LOM). The initial cave production scheduling effort is a complex process that incorporates many mining, geotechnical and practical considerations when converting the Mineral Resource to a Mining Reserve. Essentially, the software maps out ore tonnes (the drawpoint call), while also calculating and monitoring the corresponding metal content from numerous individual drawpoints positioned on the extraction level beneath the orebody to be mined. The orebody in the software is represented by an in-situ block model (BM), typically created by the Geology team. For communication with management and other stakeholders, the detailed drawpoint data output is typically summarised into graphs of annual metal or Net Smelter Revenue. It is important to realise that there is no extra effort or development required to access the high-resolution data set to forecast monthly drawpoint tonnes with their associated metal and rock types. The real effort lies in analysing the large data set, something that many engineers tend to shy away from when facing footprints with hundreds of drawpoints.

Production scheduling applications such as PC-BC, along with other widely used flow modelling software like PGCA (Power, 2024), CAVESIM (Sharrock, 2021), and REBOP (Pierce, 2010), are frequently employed for reconciliation analyses, where the actual metal production is compared with the forecast. It is imperative to accurately quantify the actual metal and lithology recoveries from each individual drawpoint. Without this information, there is no way to validate whether interactive draw exists in the overlying caved rock mass or not. Analysing the overall cave performance, based on global and/or temporal data trends, as reported by the mill or concentrator, cannot provide the necessary detail to inform whether interactive draw occurs between drawpoints. Drawpoint-by-drawpoint analyses are imperative for the evaluation of cave performance in terms of understanding the dominant cave flow mechanisms, identifying where the ore originated from and ultimately assessing metal/mineral recovery. Yet, with few

exceptions, current reconciliation assessments only focus on readjusting global cave ore flow parameters, resulting in a very general comparison between forecast and actual average ore grades across the entire cave footprint.

In today's caving operations, most drawpoints contain ore valued at millions of dollars and should be treated as valuable mine assets. Hence, they warrant individualised attention, as outlined in section 3.

### 3 A DETAILED DRAWPOINT METAL AND ROCK TYPE METHODOLOGY

A reliable forecasting model should be well calibrated and be able to accurately predict, not only grade but also the geological composition of each drawpoint. Van Hout et al (2023) describe how routine drawpoint sampling of grades and lithology monitoring can reliably inform the evolution of draw cone geometry and HOD for each drawpoint over time. Rather than just plotting monthly drawpoint metal grades and rock types against time (on the horizontal axis in **Error! Reference source not found.**), the same data can be presented to emphasise the variation of the drawpoint parameters based on the HOD, as demonstrated in **Error! Reference source not found.** Sections 3.1 to 3.3 below briefly discuss the three different curves shown in **Error! Reference source not found.** (b). More details are described by Van Hout et al. (2023), the concept of Area of Influence (AoI), used to convert the tonnes drawn from drawpoints into a height value, holds significant importance.

#### 3.1 *The actual drawpoint grade sampling and rock type monitoring data versus height*

The red curve depicted in **Error! Reference source not found.** (b) represents the HOD, on the y-axis, versus the composition of a rock type (RT2) from drawpoint monitoring on the x-axis, specifically for drawpoint P15-04W. The location of this drawpoint is shown in **Error! Reference source not found.** (a), which represents a vertical cross-section through the geological block model, running parallel to production tunnel P15. Besides rock types, the three-dimensional BM, which comprises of

fifteen-metre cubic blocks, stores additional rock properties such as in-situ density and metal grades, associated with the orebody and surrounding host rock. The BM forms the basis of all geological, geostatistical and geotechnical modelling, including for simulating cave growth

and cave flow. To best display the sampling and monitoring data, vertical cross-sections are created, these plots clearly illustrate the (potential) origin of the caved material reporting to the drawpoint.

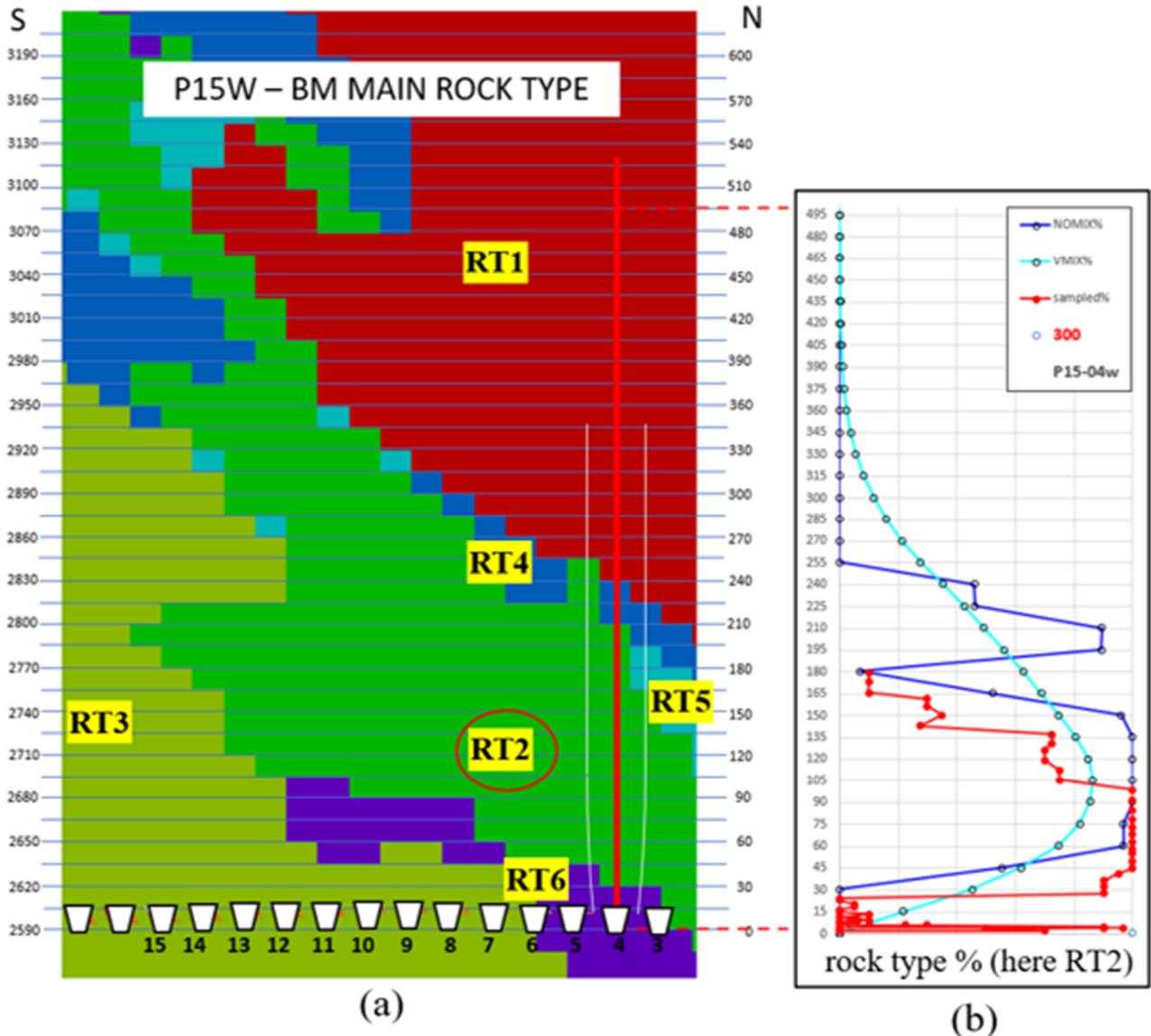


Figure 2 (a) A vertical North-South section of the geology BM, showing six different rock types above the cave drawpoints, indicated by the white troughs and drawpoint numbers at the bottom of the plot. The red vertical line represents the central axis of the (white outline) chosen PCBC draw cone geometry above drawpoint P15-04W. (b) the RT2 rock type profiles versus HOD for drawpoint P15-04W: the red curve represents that of the drawpoint monitoring program, the dark blue is associated with the geology BM and the cyan curve is the result of a standard pre vertical mixing algorithm. (Van Hout et al, 2023).

### 3.2 The forecast drawpoint metal and rock type data versus HOD

While this paper does not delve into the intricate details of grade forecasting for caving operations, it is important to emphasise that this process incorporates multiple cave flow mechanisms of which the inter-rock mixing process is arguably the most important. One of the least complex algorithms available to the mining engineers is that of the pre-vertical mixing (VMix) module offered in PCBC, which is based on empirical rules developed by numerous authors such as Marano (1980), Laubscher (2000), Heslop (2000) and Carew (1992). When applying this vertical mixing algorithm to the example shown in **Error! Reference source not found.**, it results in a forecast grade curve that is represented by the cyan curve. It should be noted that the VMix logic is usually only used for greenfield projects whereas the more advanced PCBC grade reconciliation analyses are used for brownfield caves (Khodayari and Diering, 2022).

### 3.3 The BM drawpoint metal and rock type data versus HOD

In addition to the actual (sample based, 3.1) and the forecast (mixing based, 3.2) grade profiles, there is another useful grade profile, rarely used in cave performance back analyses, and that is the unmixed (or NoMix in PCBC) grade profile, i.e., the dark blue curve depicted in **Error! Reference source not found.** The NoMix curve offers a representation of the quality of (undiluted) ore material that can be mined from a drawpoint and serves mainly as a reference curve for both the forecast and actual grade curves. The magnitude of the deviation of the actual curve from the NoMix curve can provide clear indications of what, when and how mixing mechanisms and caving mechanics, such as rilling underneath a stalled cave back, manifest themselves above a drawpoint. Employing the NoMix curve to compare all accessible metal grades and rock types, and analysing it in relation to the surrounding drawpoints, can reveal invaluable insights that will otherwise remain undetected when solely using the global mine forecast and actual grade profiles. It's

evident that the vertical cross-section through the block model, as illustrated in **Error! Reference source not found.** (a) provides valuable albeit qualitative and limited 2D insights into the 3D grade distribution. Conversely, the PCBC based NoMix profile (depicted by the dark blue curve) captures this 3D variability more comprehensively, offering a better means for quantitative analyses using the BM data.

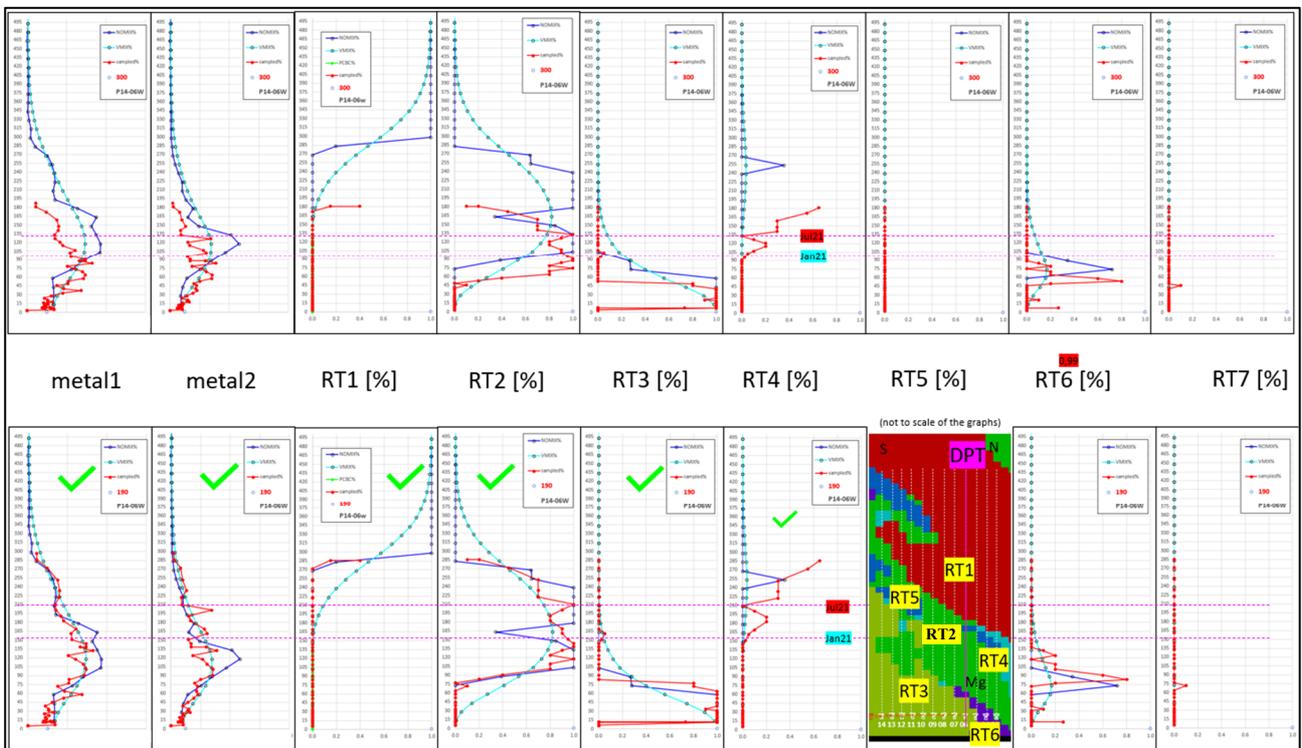
### 3.4 An example of a detailed drawpoint metal and rock type analysis

To demonstrate the value of undertaking detailed, individual drawpoint analyses, consider the example presented in Figure 3. The two most important metal grade elements and the seven relevant rock types at this cave mine are all sampled at regular intervals and combined to generate a monthly figure for each of the drawpoint observations, as represented by the red datapoint. In the upper series of graphs, the depicted curves correspond to a drawpoint AoI of 300 m<sup>2</sup>, with the tunnel spacing at 30 m and drawpoint spacing at 20 m, respectively. Some of the important observations include:

- 1) The actual (red) curves in the top graphs exhibit a noticeable lack of correlation with both the in-situ geology (dark blue), NoMix curve and the forecast (cyan) VMix curve.
- 2) The first appearance of rock type RT1 occurs at a considerably lower HOD than anticipated based on the NoMix curve and progressing at a rapid rate (too steep) compared to the VMix curve. This discrepancy may be attributed to the high fines content characterising RT1 material fragmentation.
- 3) To make more sense of the actual drawpoint sampling data, it should be noted that the actual curves (red) in Figure 3 are significantly influenced by the predetermined Area of Influence (AoI), initially set to cover the tributary area of one drawpoint (300 m<sup>2</sup>), as depicted in the top graphs. By varying the AoI, a better alignment between the actual curves and the NoMix and/or VMix curves can be achieved, as demonstrated in the bottom graphs. In this specific case an AoI of 190 m<sup>2</sup> proves to be the

best overall choice, representing a 37% reduction from the tributary area of the drawpoint.

Further details can be found in the paper by Van Hout et al (2023).



**Figure 3** Typical display of a drawpoint metal grade and rock type analysis whereby the drawpoint sampling and monitoring data (red, actual curves) of two metal grades and seven rock types is compared with the in-situ geology block model derived vertical profiles (dark blue, NoMix curves) and output from a simple pre-vertical mixing algorithm (cyan, VMix curves). The top series show the graphs when using a tapered PCBC cone size with a cross sectional area of 300 m<sup>2</sup>, while for the bottom series a cone with a narrower area (190 m<sup>2</sup>) was employed. The pairs of two horizontal dotted pink lines indicate two instances of large seismic events, in January 2021 and July 2021. (Van Hout et al, 2023).

### 3.5 Example of detailed drawpoint analyses across a caving mine footprint

As discussed by Van Hout et al (2023), detailed drawpoint analyses across a selection of the cave footprint revealed initial caving propagation issues in some drawpoints and demonstrated the temporal and spatial effects of some large seismic events. Most significantly, from an interactive draw perspective, the detailed drawpoint analyses across the mining footprint provided valuable insights into the spatial distribution of the optimal (best fit) value of the AoI for the individual drawpoints.

As depicted in Figure 3 above, the detailed validation analysis of Area of Influence (AoI)

encompassed nine grade elements for examination across 123 drawpoints in the study. Among these, seven grade elements were found to be pertinent and informative. In the case where the seven AoI values proved very different or where reducing the AoI did not result in better fits between the actual and the NoMix profiles, these drawpoints were highlighted on a map (orange cells in Figure 4).

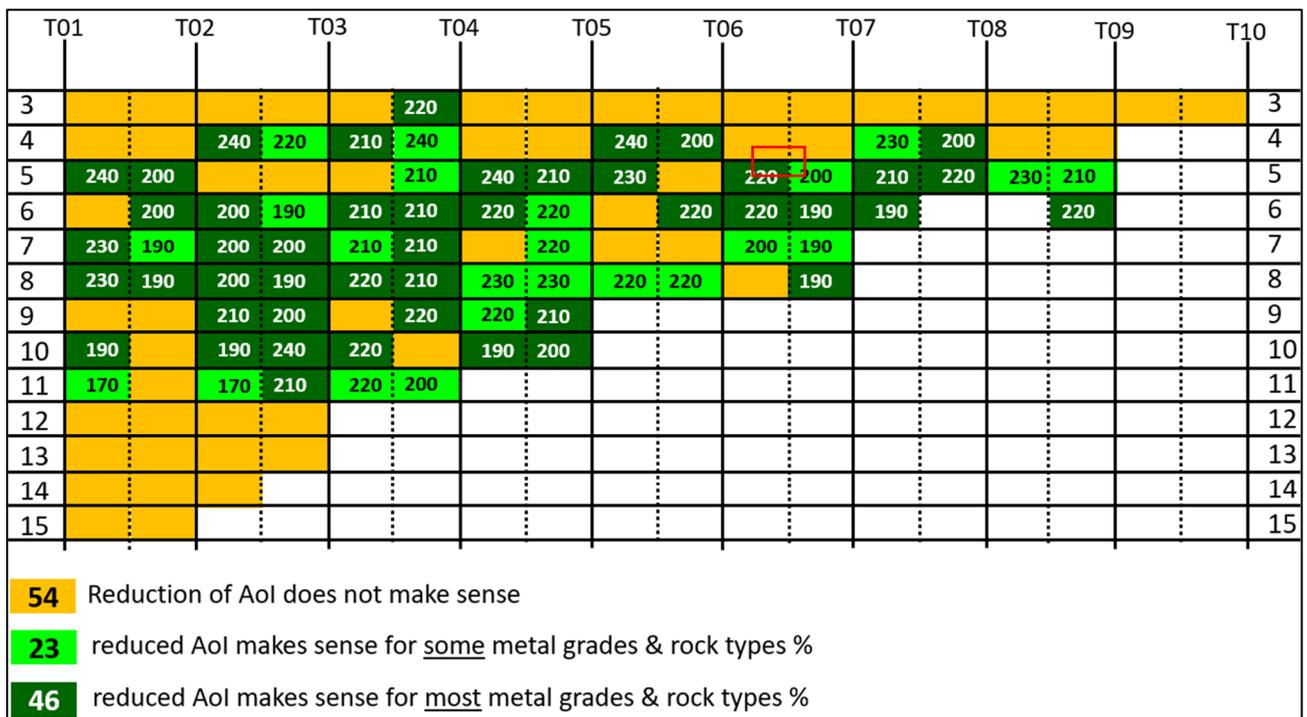
Conversely, when a uniform reduction in Area of Influence (AoI) is deemed sensible for all seven grades, the drawpoint is highlighted in dark green, accompanied by the specified common AoI value. For instance, drawpoint T07-6W, outlined by the red rectangle in Figure 4,

exemplifies this scenario. Its analysis in Figure 3 revealed that an AoI of 190 is more appropriate than the initially designated 300, which typically corresponds to full drawzone coverage or interactive draw. Drawpoints where three to five elements suggest that reducing the AoI is justified are denoted by light green cells.

Maps such as the one illustrated in Figure 4 offer valuable insights into the global cave flow behaviour and should serve as inputs, informing enhancements to draw cone dimensions for subsequent PCBC reconciliation analyses. Regarding the mine under scrutiny in the

mentioned study, feedback from the reconciliation engineers emphasised that, along with incorporating cave back surfaces to accommodate rilling, the reduction in PCBC drawcone sizes proved to be the main drivers in achieving improved metal reconciliation results.

It is hard to argue the case for drawzone interaction across a mining footprint when the detailed analysis reveals numerous instances of AoIs around 190 m<sup>2</sup>, equivalent to drawzones of around 15.5 m diameter, whilst the tunnel spacing and drawpoint spacing stand at 30 m and 20 m, respectively.



**Figure 4** A selection of drawpoints considered for the grade fitting procedure, indicating for which ones a reduction of the AoI was inconclusive (54, in orange), for which drawpoints it made some sense (23, in light green) and for which drawpoints it was appropriate (46, in dark green) up until that stage of production( February 2022). Note drawpoint T07-6W, highlighted by the red rectangle, its analysis is shown in Figure 3. (After Van Hout et al, 2023).

#### 4 CAVE TRACKER ANALYSIS

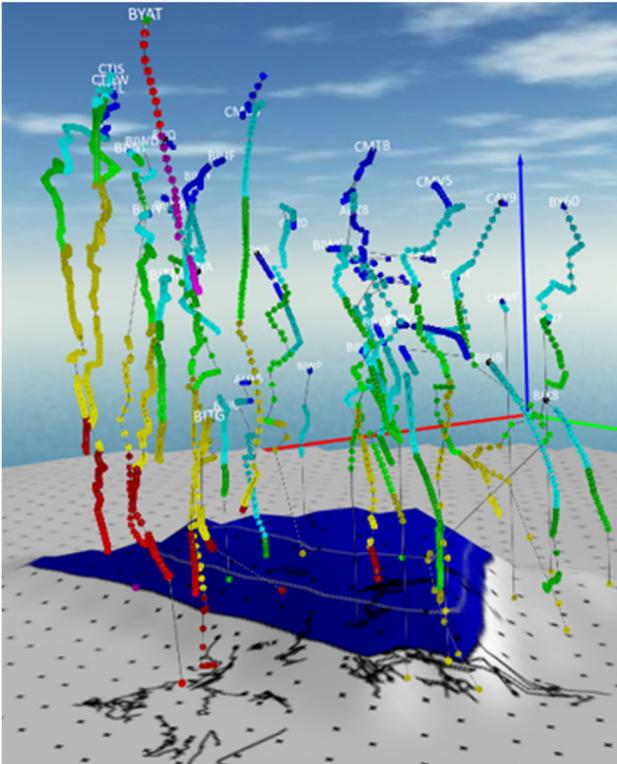
Rio Tinto was one of the first mining companies to undertake trials of cave smart markers at Northparkes Mines, collaborating with Newcrest, Mining3 and Elexon to develop the Cave Tracker technology (Elexon Mining, 2016) that enables spatial monitoring of markers inside the cave. The first successful trial of Cave Trackers (CT) was conducted at Argyle

Diamond Mine, subsequently other operations (e.g. Hocking et al, 2020) have followed suit.

##### 4.1 Visual analysis of raw Cave Tracker data

Mining companies lack access to the software necessary for processing CT beacon signals detected by the CT detectors. Elexon provides mines with reports and CT position data in csv format on a regular basis. Despite having CT data for beacons in motion since the last cave

back position update, the industry faces challenges in fully analysing and interpreting the results and thus are yet to unlock the tremendous value that these relatively new instruments can offer. There are various methods for visualising the 4D CT data, ranging from 3D animations illustrating the downward movement of CTs to isometric views displaying coloured CT trajectories overlaid by HOD surfaces, such as shown in Figure 5.



**Figure 5** Isometric view onto coloured 'spaghetti' CT beacon trajectories over a 6-month period (blue=start, magenta=end), above an intermediate HOD surface onto which the locations of drawpoints are indicated by black spots.

Whilst these visuals offer valuable qualitative insights into both the (non-)conventional or (un)expected pathways of the instruments, they fall short when attempting to answer pertinent questions, such as: *'Is the beacon moving under free bin flow conditions or is its movement associated with chimneying along a geological feature? How did the cave react to the recent change in draw strategy? Do the beacons display more uniform draw behaviour when the*

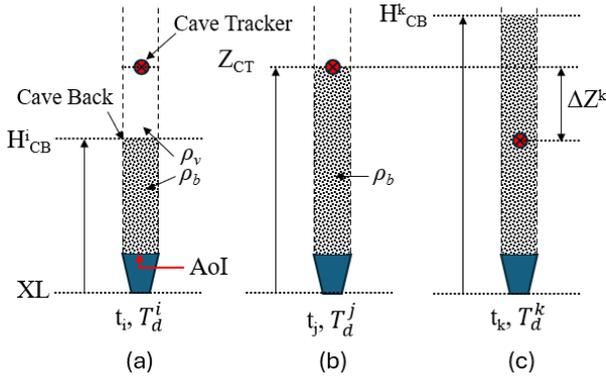
*load shedding was implemented?* To tackle these and many other questions, analytical techniques beyond merely visualising "spaghetti" or movies and relying on subjective assessments must be employed.

#### 4.2 Simplified Conceptual Models

Before delving into the specifics of analysis techniques crucial for flow model calibration and reconciliation, it is essential to introduce two highly simplified conceptual models upon which the analysis depends.

CT beacons are generally installed before the underlying drawpoints start mining and the units remain stagnant while the cave back approaches the instrument. The cave back is assumed to be a distinctive boundary between the muckpile and the solid rock above. The upward progression of the cave back, right above a drawpoint, is assumed to be only affected by draw from that drawpoint over its individual AoI. It is also assumed that the cave growth is controlled by an isotropic, homogeneous bulking process, associated with constant, though different, virgin and bulk densities. The models initially assume that there is no airgap, and that no significant horizontal movement occurs in the muckpile above the drawpoint.

Whilst these assumptions clearly oversimplify reality, they can easily be adjusted in subsequent phases of analysis. Nonetheless they facilitate the visualisation of cave back progression, as depicted in Figure 6. The model idealises a steady upward moving cave back under progressive draw from the drawpoint below. Once the cave back reaches the CT beacon, the beacon moves through the muckpile, which comprises a constant bulk density. The pace of the beacon is dictated by the instantaneous draw rate and the tributary drawpoint area. This approach allows for approximate calculation of key parameters, such as the Caving Ratio and bulk density.



**Figure 6** Simplified conceptual model of the cave back progression above a drawpoint before (a), at time of (b) and after reaching the position of the CT beacon (c) that travels towards the extraction level (XL). The terms are listed under equations (1) – (5) in the main text.

The Caving Ratio (CR) is defined as follows:

$$CR = \frac{HCB}{HOD} \quad (1)$$

with HCB = Height of the Cave Back  
HOD = Height of Draw

As the Block Caving Mechanics publication by Brown (2007) contains no description or definition for HOD, Van Hout et al (2023) defined it as: *The instantaneous drawpoint HOD represents the vertical height attributed to a given extracted volume of in-situ rock above a drawpoint that results from the accumulative tonnage drawn from that drawpoint up until that point in time.*

The HOD can therefore be expressed as follows:

$$HOD_i = \frac{T_d^i}{\rho_v \cdot AoI} \quad (2)$$

with  $T_d^i$  = tonnes drawn up to time stage  $t_i$   
 $\rho_v$  = (constant) virgin density  
 $AoI$  = Area of Influence of drawpoint

Substituting Equation (2) into Equation (1) when the cave back has reached the CT's installed position, as shown in Figure 6 (b), yields:

$$CR = \frac{Z_{CT} \cdot \rho_v}{T_d^i \cdot AoI} \quad (3)$$

with  $Z_{CT}$  = distance of CT above drawpoint  
 $T_d^j$  = tonnes drawn when cave hits CT

Equation (3) can thus be used to estimate the local CR when a CT beacon starts moving. The CR should not be confused with the caving rate, a term that is used by the industry to describe the average rate of cave propagation, expressed in mm per day (Brown, 2007).

The mass balance equation at the stage when the cave back reaches the CT, see Figure 6 (b), can be written as:

$$\rho_v \cdot AoI \cdot Z_{CT} = \rho_b \cdot AoI \cdot Z_{CT} + T_d^j$$

Therefore,

$$\rho_b = \rho_v - \frac{T_d^j}{AoI \cdot Z_{CT}} \quad (4)$$

Equation (4) can thus be used to estimate the bulked density when a CT beacon starts moving. It provides confidence in the value that site engineers use as input into various cave calculations, such as cave back height estimates and PBC forecasts.

The simplified conceptual model also facilitates the estimation of the bulking density during different intervals while the beacon steadily progresses at a constant rate towards the drawpoint. The mass balance equation, applicable at any stage subsequent to the mobilisation of the CT unit, Figure 6 (c), is:

$$\rho_b \cdot AoI \cdot \Delta Z^k = T_d^k - T_d^j$$

Therefore,

$$\rho_b = \frac{T_d^k - T_d^j}{AoI \cdot \Delta Z^k} \quad (5)$$

with  $\Delta Z^k$  = CT movement between  $t_j$  and  $t_k$

The reason for calculating bulk densities after the beacons start moving is twofold. Firstly, the progressive calculation over time might reveal a change in the muckpile density over the cave's LOM. Secondly, as it is calculated using the AoI, initially set as the entire drawpoint footprint area, back analysis may reveal that a reduced AoI is more appropriate.

Calculating the Caving Ratio for each beacon serves to assess how the draw on the extraction level and/or the presence of large-scale faults affect the initiation of movement for that specific beacon, an example thereof will be discussed in section 0. As for the bulking density, the Caving Ratio also depends on the AoI as illustrated in Equation (3), also making it a valuable tool for back analysis. While not elaborated on further in this paper, when combined with the detailed analysis of drawpoint metal and rock types discussed in section 3, it can lead to a deeper understanding of the cave performance.

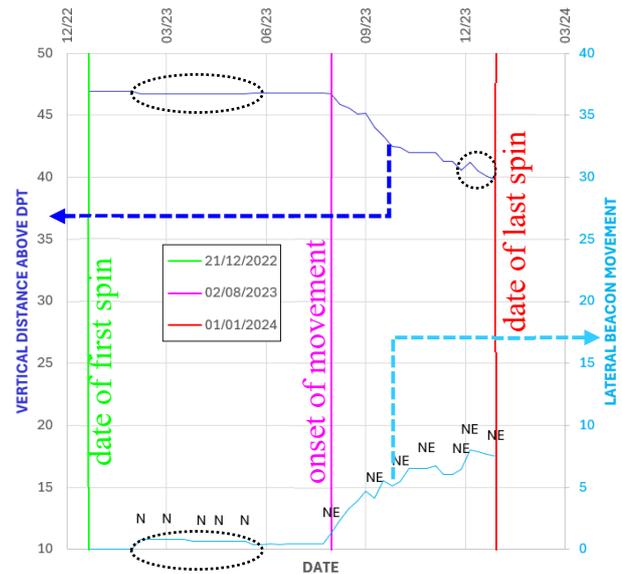
Note that bulk density can be calculated at any stage when the beacon is moving, the Caving Ratio can only be calculated once, at the onset of beacon movement.

#### 4.3 A detailed Cave Tracker Beacon Analysis

Each CT implementation in a caving mine requires extensive drilling, installation and maintenance of costly beacons and detectors, resulting in considerable cost. This undoubtedly warrants careful management, customised for each individual beacon. This commences with allocating a unique workbook to each unit, documenting its specific characteristics, past issues, initial QA/QC upon arrival on site, installation details, raw data registry and subsequent analysis.

Site engineers need to be diligent in sanitising the 'raw' data Elexon provides, as occasional unintentional errors (such as increasing z-values over time) do occur. This task becomes a challenge when solely examining the CSV files or the 3D spaghetti plots (Figure 5). However, it becomes more manageable when plotting the data as demonstrated in Figure 7. Here, a slight "uplift" of the beacon, as indicated by the black dotted circle, can be promptly identified. Additionally, the black dotted ellipses highlight a minor, yet consistent vertical and horizontal displacement occurring before the onset of movement (indicated by vertical magenta line), which are likely not genuine displacements. Consequently, the threshold of 1m is selected for identifying the onset of 'real' movement, preventing small incorrect displacements from

being mistaken for a passing cave back and the associated initiation of beacon movement.

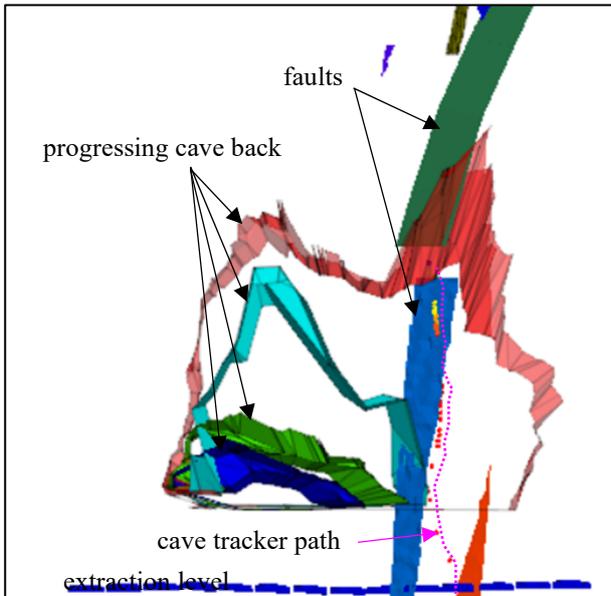


**Figure 7: The vertical position (dark blue curve) of a beacon and its lateral movement (light blue curve) versus time. Annotations above the bottom curve indicate the direction of lateral movement, relative to the beacon's original position. The black dotted areas show data errors.**

The graph above reveals valuable information, such as flow mechanism at play (bin versus intermittent flow, mass flow versus rat-holing) and beacon movement rates during draw down. However, it fails to demonstrate the cause-and-effect relationship between draw and movement. For this purpose, Figure 8 is more suitable as it depicts production from underlying drawpoints in correlation with the vertical movement of the same beacon versus time. Note that the forecast movement (can also be added on Figure 7), often based on interactive draw or complete drawzone coverage, is included in the graph as its trend and closeness with the actual curve hold clues to how interactive the draw really is. For the example shown in Figure 8, it is clear that there are strong indications that there is interactive draw at play around this beacon as the forecast is very similar to the actual draw down, the caving ratio is 5.4 and thus well within the 'bin flow' range (5-10). The bulk density, based on equation (4) is 2.2,



this unit's graphs & statistics, akin to those of Figure 7 and Figure 8, reveals that the unit exhibited faster flow than expected under bin flow conditions. Furthermore, the cave exhibited localised rat-holing along the faults (as also indicated by the red cave back profile): the unit commenced movement 7 months earlier than forecast, and the calculated caving ratio was 18, surpassing the range typically considered as bin flow conditions (5-10).



**Figure 9: vertical section showing a cave tracker's pathway, the progressing cave back and presence of large-scale faults.**

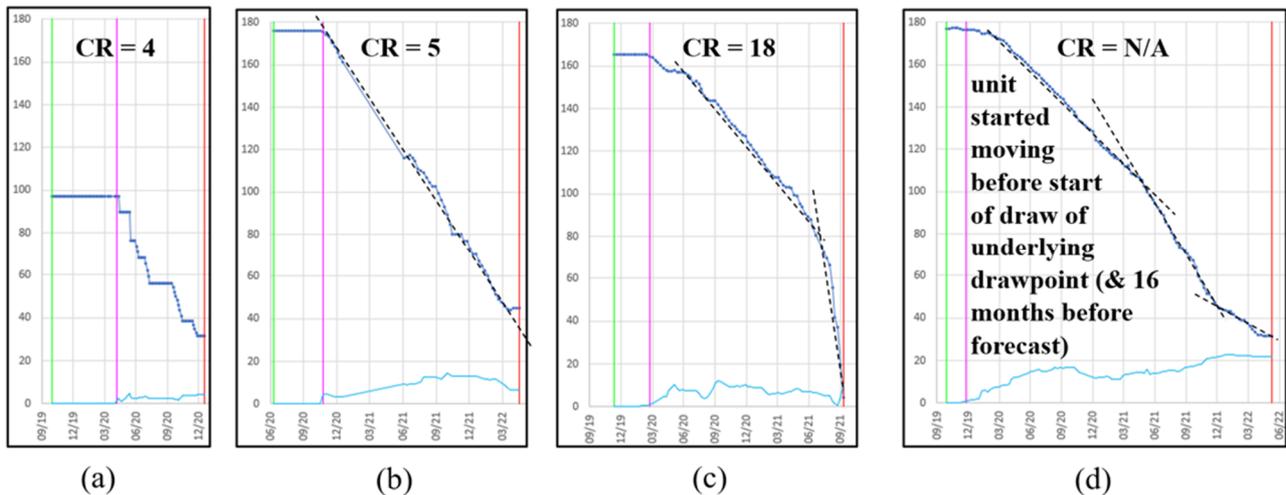
#### 4.5 Some distinctive Cave Tracker behaviours

Individual cave trackers offer valuable insights into local ore flow. However, to understand cave

behaviour on a broader scale and determine if interactive draw coincides with the mass movement, a larger number of appropriately spaced units are required. As observed at several mines, cave trackers exhibit varying behaviours as they descend towards the extraction level.

Figure 10 presents examples of distinctly different CT behaviours, similarly there are many other units on different mines that demonstrate comparable trends. The four examples depicted do not encompass all the possible unique behaviours within a cave. For instance, some units have distinctly demonstrated the presence of an air gap, evidenced by a sudden initial drop in the vertical position as the first movement. Additionally, there are beacons with significantly higher lateral displacement rates than those illustrated in these examples.

In the authors' experience, the data from the cave trackers alone does not reveal whether they are part of mass movement, isolated draw or rat-holing. This determination can only be deduced by considering the underlying drawpoint production, alongside a reliable forecast tool.



**Figure 10** Vertical position above the extraction level (dark blue curve) and lateral movement (light blue curve) vs time of four cave trackers, labelled with their Caving Ratio (see equation (3)). (a) a ‘stepped’ curve, potentially indicative of the ‘void diffusion’ mechanism (Heslop, 2010) or the ‘palm and fingers’ (Gustafsson 1998). (b) a ‘smooth’ pathway, at a constant rate towards the extraction level. (c) a ‘smooth’ pathway, at a constant rate initially and then accelerating at +/- 80 m above the extraction level until reaching that level (see also Figure 9). (d) a ‘smooth’ pathway, at a constant rate initially and then decelerating at +/- 100 m above the extraction level and even further around 50 m above the extraction level. Note that the Caving Ratio’s of (a) & (b) suggest ‘bin flow’ conditions while (c) and (d) strongly indicate that the cave growth in the vicinity of those markers is fault controlled.

## 5 CONCLUDING REMARKS

One of the foremost challenges facing cave engineers in the design of a cave mine is the determination of the drawpoint spacing. Stability concerns, often derived from numerical modelling, encourage design teams to widen the drawpoint spacing, thereby attempting to achieve more robust apices on the extraction level. However, it is not always recognised that larger spacings come with heightened risks of less draw interaction across the footprint, resulting in lower ore recovery and early dilution entry.

To quantify this risk and monitor a cave’s performance in terms of actual versus forecast metal, Van Hout et al (2023) developed the detailed drawpoint analysis, discussed in section 3. Figure 3 and Figure 4 clearly demonstrate that there are occurrences of narrow, isolated draw, indicating a lack of interaction across the footprint. Note that the analysis is based on routinely gathered actual drawpoint data. The importance of considering the high-resolution

data of drawpoints cannot be overstated; only then is it possible to identify areas that are under or overperforming, compared with the forecast. This, in turn, enables cave management engineers to adjust the flow parameters for specific areas, instead of applying an average correction factor to the entire footprint.

With the advent of Cave Trackers, there is now a new tool to monitor the flow of caved ore within the cave column to assess if draw interaction occurs across the footprint. A novel methodology for analysing beacon data is presented in section 4. These instruments can demonstrate that interaction occurs, as evidenced in Figure 8, where the beacon’s actual path closely matches the forecast (assuming interactive draw). However, Figure 9, Figure 10(c) and Figure 10(d) depict graphs from units that did not exhibit interactive draw but rather isolated draw or rat-holing, which appears more common in deep, high column caves.

The analyses presented in this paper were initially developed in Excel, but following the demonstration of their value, Taylor (2023)

converted them to Tableau dashboards to automate the process. More recently, an online application is being developed to replicate the initial work, incorporating machine learning enhancements.

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