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Marker design and calibration for Carrapateena sub level and block cave with a focus on fines migration and far field flow

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Abstract

Carrapateena is mined by the sub level cave method, with studies underway on its transition to a block cave. There is a large amount of weaker cover sequence at Carrapateena above the orebody, and the prediction of the flow of this material is extremely important for understanding the Ore Reserve. As flow modelling has increased in complexity, there has been little focus on how to calibrate flow models and how to set up the marker design within the cave to improve the knowledge of the material flow in cave mines, with a particular focus on Far field flow (>100 m from the draw points). This paper discusses the design of the monitoring at Carrapateena, which includes grade measurement, marker installation and observations in the field to give measurements that can assist calibration. It also discusses how this information can be used to assist flow model calibration and the ultimate understanding of the flow of this fine material. A scorecard method is suggested to use all measurements ranging from grade information to marker data, which can be tracked through the Life of Mine, forming a transparent calibration method. The aim of this work is to better predict fines migration and improve estimation for Carrapateena, where a strong focus is needed on flow.

1 Introduction

1.1 OZ Minerals

OZ Minerals is a copper-focused, global, modern mining company based in South Australia. Its growth strategy is focused on creating value for all stakeholders. OZ Minerals owns and operates the Prominent Hill and Carrapateena mines in South Australia, the Antas mine in the Para state of Brazil, is constructing the Pedra Branca underground mine also in the Para state, and has earn-in agreements with experienced exploration companies to create a pipeline of future potential growth opportunities.

The Carrapateena copper-gold operation is approximately 460 km north of Adelaide, and 160 km north of Port Augusta in South Australia's highly prospective Gawler Craton (see Figure 1). The project is located on Pernatty Pastoral Station and its supporting infrastructure is located within Oakden Hills Pastoral Station. The Kokatha People are the traditional owners of the land.

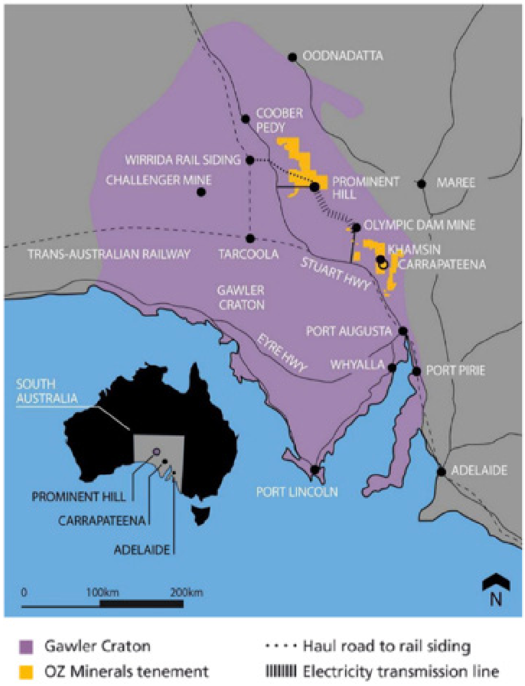


Figure 1 Carrapateena location map

The base case for the Carrapateena mine is planned as a sub level cave mine. An alternative scenario has been gated to feasibility study that looks at replacing the lower half of the sub level cave mine with a block cave mine, which allows increased throughput and better sequencing of the grade as shown in Figure 2. Above the current sub level cave, there is a substantial amount of weak cover material, of which two rock units, the lower Whyalla sandstone and the woomera shales, have been shown to break down more when liberated and so are expected to have increased fines migration.

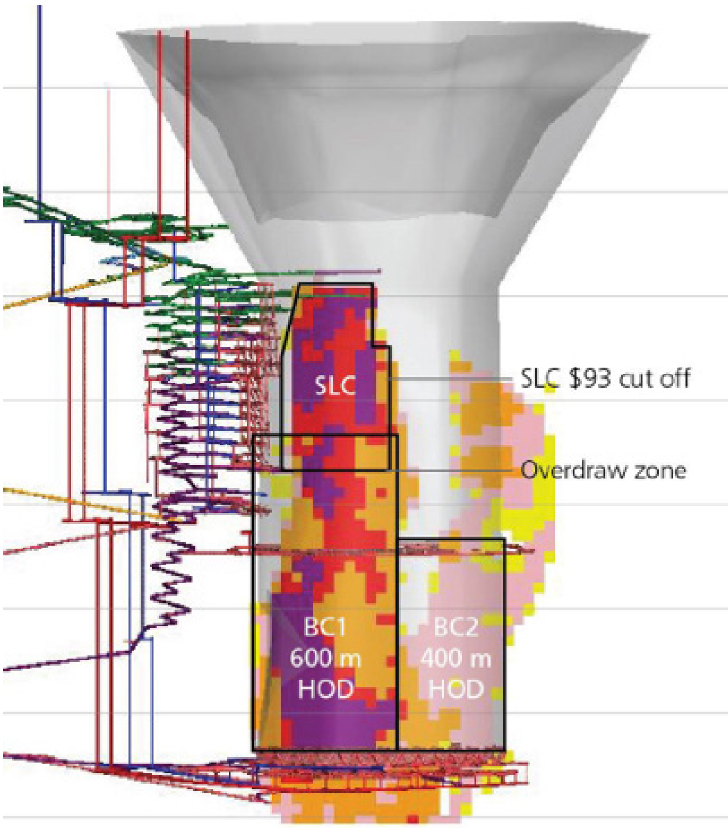


Figure 2 Layout of Carrapateena sub level cave (from Hocking & Masters 2020)

2 Outline of focus of calibration

The Carrapateena orebody is overlain by 500 m of sediment cover as shown in Figure 3, with the weaker units being the Woomera shales and the lower Whyalla sandstone. Some of these materials are mud forming, so their flow through the muck pile and understanding their behaviour is of utmost importance when estimating the likely ore recovered for the Life of Mine and ensuring the safety of the workforce. When the lower Whyalla sandstone is simulated to move at different velocities, different profiles are observed as shown in Figure 4. Understanding this behaviour will allow us to better predict the material flow. Estimation of the relative movement of material varies. Therefore, based on the Carrapateena rock mass and mining method, it will be important to measure the primary recovery in the sub level cave ring, and also estimate the migration of fine material from the cover sequence.

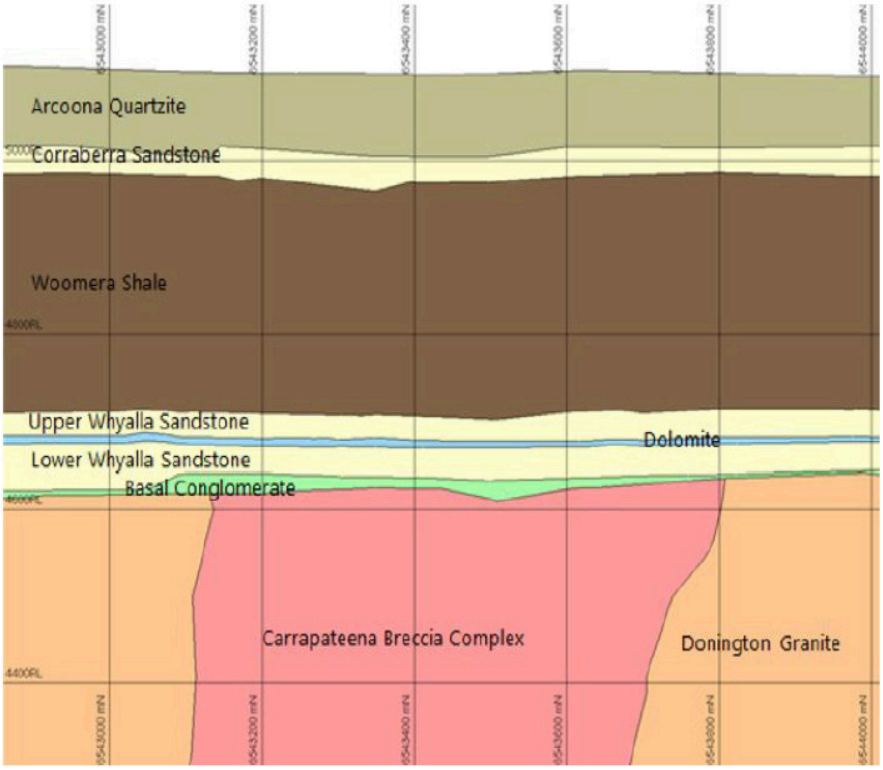


Figure 3 Cover sequence for the Carrapateena mine (from Hocking et al. 2018)

Calibration of the flow of the cave as well as the fines migration will have a big impact on the financial returns, but also a good calibration model will be foundational to further optimise the sub level cave, and potentially any further caves in the province. Therefore, establishing potential calibration methodologies and designing the cave markers around the calibration methodology will help improve understanding through time. Figure 4 shows the predicted amount of lower Whyalla sandstone with changes to the mobility factor in Power Geotechnical Cellular Automata (PGCA). The mobility factor is a parameter in PGCA that increases the movement rate of rock material relative to other material. In the Carrapateena reserves, this mobility factor is assumed to be 2 for the sub level cave (Hocking & Masters 2020), however sensitivities have been run to see the impact of increasing or decreasing the mobility factor (Figure 4). Understanding this variability and this factor will be key in optimising the draw strategy at Carrapateena, as well as understanding the risk from dilution to predict the grade better.

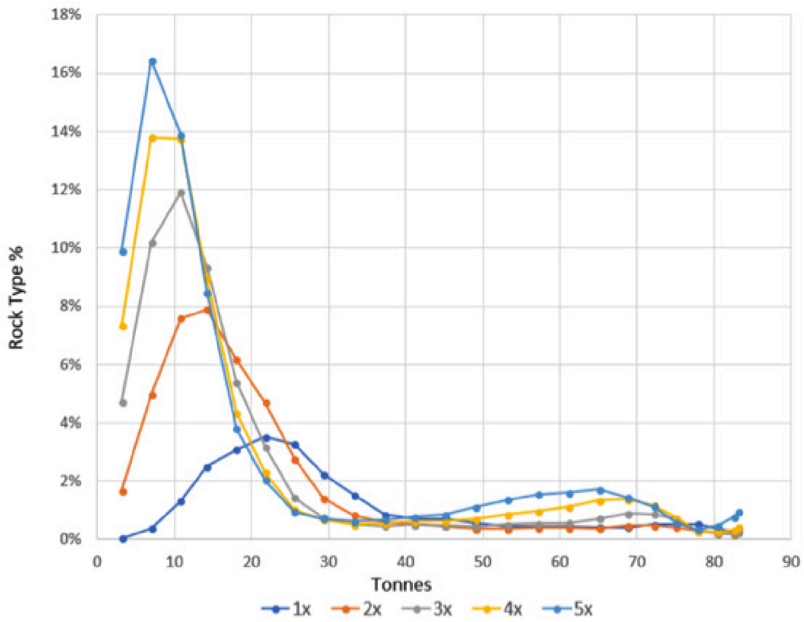


Figure 4 **Mobility of lower Whyalla sandstone with different mobilities assigned in PGCA code (from Hocking et al. 2018)**

Often calibration of flow models has focussed on the near field calibration. Within sub level caves, there is rightly a focus on maximising primary ring recovery. Typically, flow models are understood to be smooth and regular and easy to explain (Bull & Page, 2000) in comparison to the chaotic and episodic behaviour observed by Power (2004) at the Ridgeway gold mine, based on marker experiments. The chaotic nature of marker observations is also observed in the undercut of the Ridgeway block cave (Brunton et al. 2016) during and after the undercutting takes place, and also by Garces et al. (2016) in marker experiments in the El Teniente mine. In both instances, markers are observed to appear at a draw point, whereas markers next to those collected in a time period, take much longer to appear at the draw points. While this information is particularly useful for calibrating width of draw zones, it is also useful in showing the observed substantial variability. Therefore, a calibrating methodology needs to take into account this variability.

While detailed results of a sub level cave ring are important to understand, additionally important is the much more difficult to quantify far field flow for caving operations, where marker data is more sparse, but the importance of understanding the flow of fine material through the cave column cannot be underestimated. With a strong focus on extracting as much value as possible from orebodies through mathematical optimisation of Net Present Value (NPV) (Campbell & Power 2016), these optimisation models will increasingly rely on accurately describing the material flow, and thus accurate flow calibration is essential for the modern caving operations.

2.1 Sub level and block cave near field calibration

Since the work of Power (2004), substantial work has been done observing the chaotic nature of material flow in sub level cave rings (Figure 5). Power was able to create a sub level cave recovery curve based on the average recovery in each sub level cave ring. Repeated sub level cave experiments using markers demonstrate that similar results are observed, showing that flow is chaotic and difficult to predict in the near field. Power observed primary recoveries of sub level cave blast rings of approximately 60%, a result similar to that observed by Brunton (2008) and later Campbell (2018). Campbell observed no correlation between primary and secondary recovery, whereas Brunton et al. (2010) showed a weak correlation between primary and secondary recovery. Within a block cave environment, Brunton et al. (2016) did substantial work with markers in both the near and far field (Figure 4). Brunton et al. (2016) designed marker experiments at both Ridgeway and Cadia East mines, using steel markers at Ridgeway and Elexon smart markers at Cadia East. The markers were recovered using either steel magnets for the steel markers over the conveyor belt or using the active RF source for the Elexon markers. In both cases, it was observed that there was substantial variability and chaotic nature of markers appearing at the draw points for the undercut markers, and not the typical behaviour expected by rule-based flow codes. As large amounts of variability are observed in the near field for flow calibration, it is expected that this variability would increase as heights of draw increase. Therefore, it is not the specific movement of a single marker in isolation that is important, but rather the description of movement based on the groups of cave markers. Therefore, this probabilistic nature of groups of markers needs to be set up as part of the calibration process.

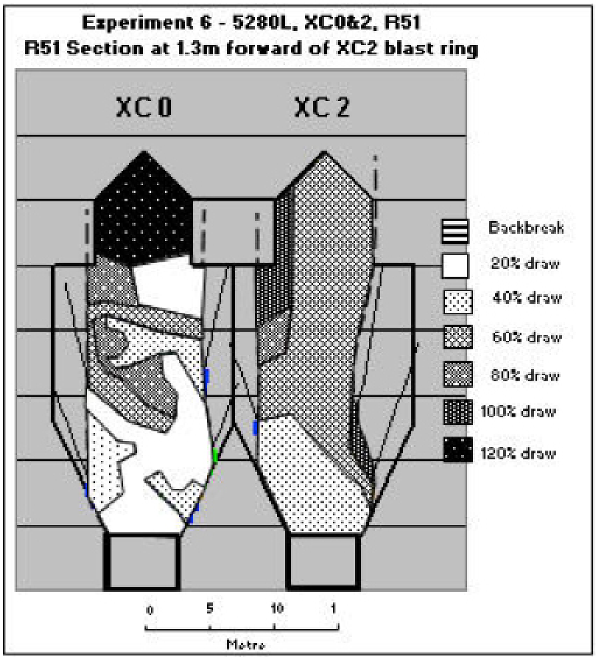


Figure 5 **Marker results from Power (2004) showing chaotic behaviour**

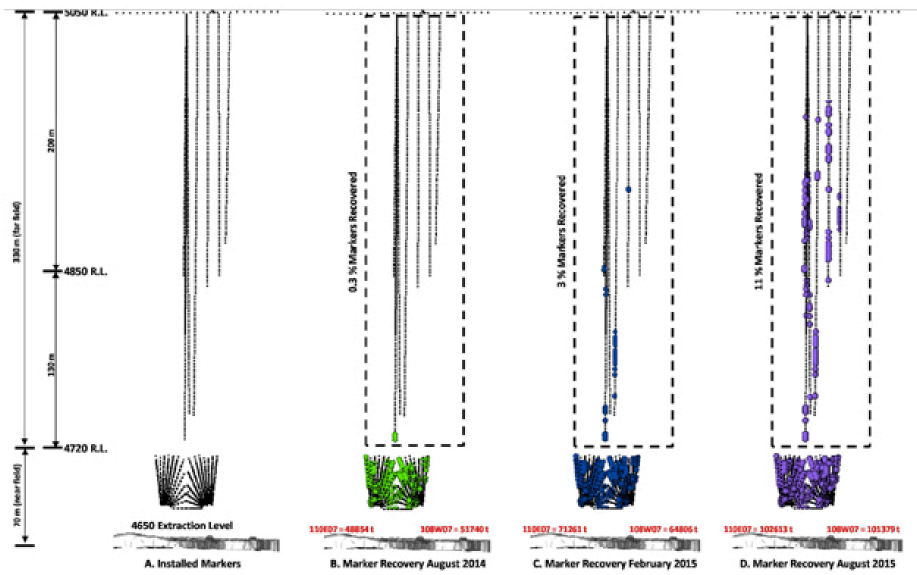


Figure 6 **Far field flow calibration at Cadia East PC1 (from Brunton et al. 2016)**

2.2 Block cave near field calibration

Pierce (2010) looked at calibrating Rapid Emulator Based on PFC (REBOP) to observations at Henderson mine. Pierce changed the fines content in REBOP to get closer to the observed behaviour. This method seemed to work for predicting grades on a draw point by draw point basis and shows the importance of sampling so that these models can be calibrated. It is also impractical to match the correlation of each draw point or apply different variables to different draw points.

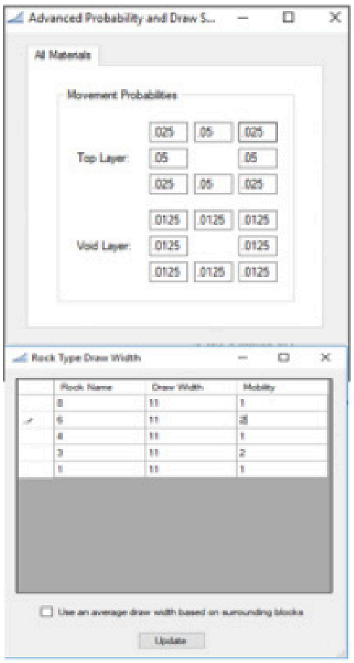
2.3 Block cave far field

Far field flow calibration has been completed using primarily average grade predictions over time. For instance, Diering (2018) used PCBC to explain the contribution of the pit failure at Palabora to the contribution of overall metal. PCBC has also been set up to utilise a tool to use least squares minimisation to better predict the average grade (Diering, Richter & Villa 2010), and this can be used to better predict cave flow. Other observations around far field flow is the flow of fines from the Argyle subsidence zone using passive RF markers (Wilson, Van Hout & Dean 2018).

3 Flow code parameters

Flow codes allow parameters to be changed to facilitate the calibration of the data. These parameters allow you to change both the near field and the far field behaviour of the models, as shown in Figure 7 for both PGCA code and PCBC. It can be seen that there is substantial variability available to change within flow models. Regardless of the marker results observed to date, there are a number of different flow packages on the market that can be used. All of them require a series of inputs around the block size, the fragmentation or the material movement. Of the tools available, there are cellular automata tools such as Cavesim (Sharrock et al. 2004), PGCA (Power 2012) and Flowsim (Castro et al. 2016). These codes rely on flow following a series of statistic rules where material will flow to replicate that removed using a matrix (Figure 7 (left)). These settings can be influenced by settings within the flow code PGCA, with variables such as relative velocity or draw width at a certain tonnage drawn (Figure 7 (right)).

Having a relatively large number of parameters to alter can become a problem for calibration.



Variable	Value	Description
HMIX_FACTOR	1	Hmix adjustment (0 - 1)
VMIX_FACTOR	1	Vmix adjustment (0 - 1)
TOPPLE_SLOPE	37	Topple slope angle (degrees)
RILL_SLOPE	37	Rill slope angle (degrees)
VMIX1	0.6	Vmix control 1
VMIX2	0.3	Vmix control 2
VMIX3	0	Vmix control 3
HMIX1	0.02	Hmix control 1
HMIX2	0.005	Hmix control 2
HMIX3	0	Hmix control 3
MIX_HORIZON	180	Mixing horizon
DEF_DENS	2.2	Default density of caved material
!DEBUG		Enable debug reporting
!SPECIAL		System
PLOT	0	Min plotting, max speed
!REPLENISH		System
DUMP_AIR	1	Report info for air gap calcs (rilling)
!EROSION	0.02	Rate of erosion
FINES	0.6	Fines probability (0.5 to 0.7)
!BASE_FROZEN	0.5	Fraction of base frozen at start (0-1)
!HT_FROZEN	120	Height in column where frozen stops
ISOLATED	0	Switch for Cone shrinkage
!AREA_TONS		XY Curve for shrinkage rate

Figure 7 Examples of parameters that can be changed in PGCA code (left) and PCBC (right)

For a sub level cave, Villa (2012) varied the parameters in PC SLC to calibrate a model of the Ridgeway mine, changing the frozen parameter to control relationships between primary and secondary recovery.

While there are other more complicated flow codes such as PFC 3D, the ones mentioned above are used widely in the industry and are also used for estimating Ore Reserves. They are typically used because they are commercially available and have been shown to replicate the flow of material. Regardless of the method or software, there is an infinite number of possibilities of different draw cones, mixing rates and fines migration rates, meaning that calibration can be difficult as the amount of data used to calibrate these variables is limited.

3.1 Available markers for caving

In order to calibrate empirical models (Cellular Automata and PCBC type models are both empirical) where variability is assumed within the model and the model represents the flow of material through time. This form of calibration is both the most pertinent and also the most difficult. "Fundamental models" may be useful, however they typically have long run times and do not capture the complexity (variable fragmentations) and cave shapes to calibrate the flow. One method to look at calibrating models is to calculate the chi – square of the model through time, this will allow you to model the variability in time and determine if there is a strong statistical correlation, where chi – square has n-1 degrees of freedom:

$$X_i^2 = \sum_{i=1}^{n} \frac{(o_I - E_I)^2}{E_I} \quad (1)$$

(n-1 degrees of freedom)

X_i^2	*Chi - Squared*
o_I	*Observation (i)*
E_I	*Estimation (i)*

Within the market and within the ore deposit, there are a number of markers that can be used. For a marker to be useful to the calibration of a full scale mine flow model, it needs to be something that can be measured as well as something that can be modelled (i.e. put inside the block model and then tracked using a flow code). A method of modelling the propagation of a marker is to 'seed' the block model with the marker density as shown in Figure 8. The marker that is collected in the draw point can then be compared to the model with the desired different model parameters to determine goodness of fit between the model and what was observed in the file (as shown by Figure 9).

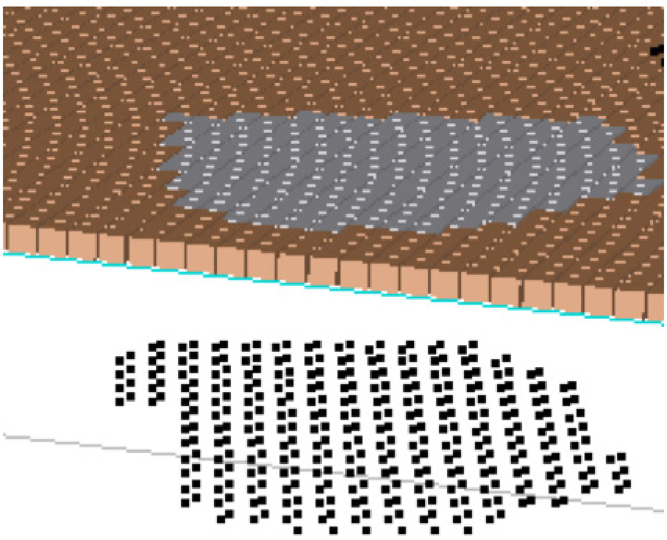
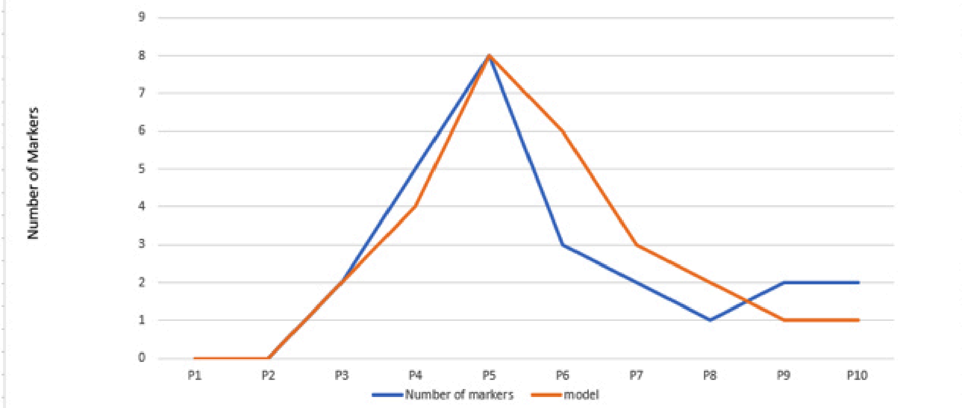


Figure 8 A layer of markers put inside the block model to run through the flow model

Once the marker data is collected, the flow models can be run with multiple parameters, such as varying the mobility of fines material using PGCA, and the results can be compared for the different model runs. An example of this is shown in Figure 9. In the case shown in Figure 9, both scenarios are viable at a 95% confidence (chi – squared is below the critical value of 12.6, with 6 degrees of freedom). However, the mobility of 3 fits the data better based on this metric and can be scored in a way to show this.



	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	sum
Number of markers	0	0	2	5	8	3	2	1	2	2	
model	0	0	2	4	8	6	3	2	1	1	
critical chi (95% 8 df)											15.50731
Chi 2	0	0	0	0.25	0	1.5	0.33	0.5	1	1	4.58

Figure 9 **An example of a comparison between actual and predicted markers, through periods of time**

3.1.1 Grade markers

Grade markers will always be of interest, as ultimately the Reserve reported is the representation of tonnes and grade through time. Therefore, grade is an important parameter to track. The grade through time for both block caves and sub level caves will be heavily biased by the block model. One problem with solely using this approach is that there can be a substantial difference through time, which can either be due to the block model, or the flow model, as shown in Figure 10. In the case shown in Figure 10, there is a large variability between predicted and actual grade results, which can either be due to the block model or the flow model. This difference will be important for the business to understand but without additional information on top of average grade data, there will be limited confidence in the flow model. In many instances, the grade will not vary substantially by level or tonnes drawn, making this parameter less useful for calibration of flow models.

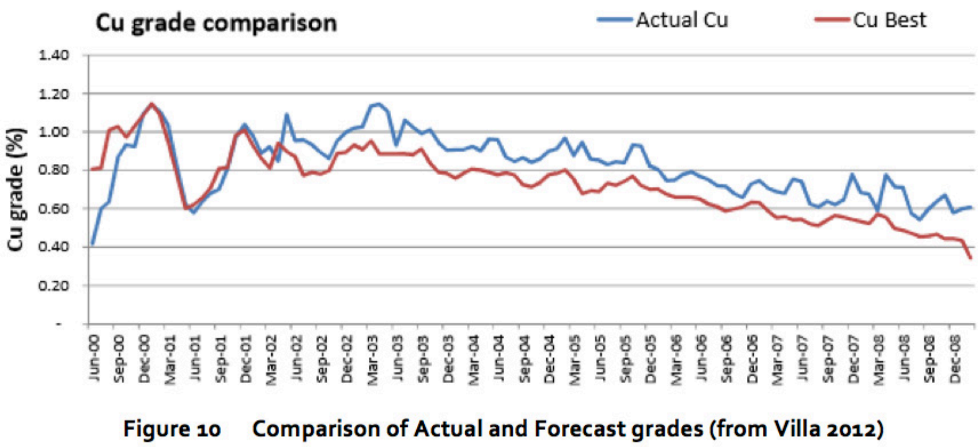


Figure 10 **Comparison of Actual and Forecast grades (from Villa 2012)**

3.1.2 Using distribution of markers across an extraction level

The distribution of the grade across the level at different tonnes taken through time is something that can also be looked at, which would be particularly useful if there was expected to be cave arch or highly variable flow through the sub level cave or block cave. Firstly, the level can be divided into zones as shown in Figure 11, and the grade that is measured at specific increments can be compared to the modelled grade for different parameters. The correlation between the model and actual can be calculated (Figure 9) and this correlation can be tracked through time (or levels) to act as a good score card input for the cave (as shown in Figure 12). The significance of the R value can be calculated using Equation 2 (Napier-Munn 2002). Generally, the R value can then be plotted through time for a given amount of tonnes removed from a sub level cave ring, and this correlation can be compared with a number of different models (as shown in Figure 13) that can be run in various flow codes.

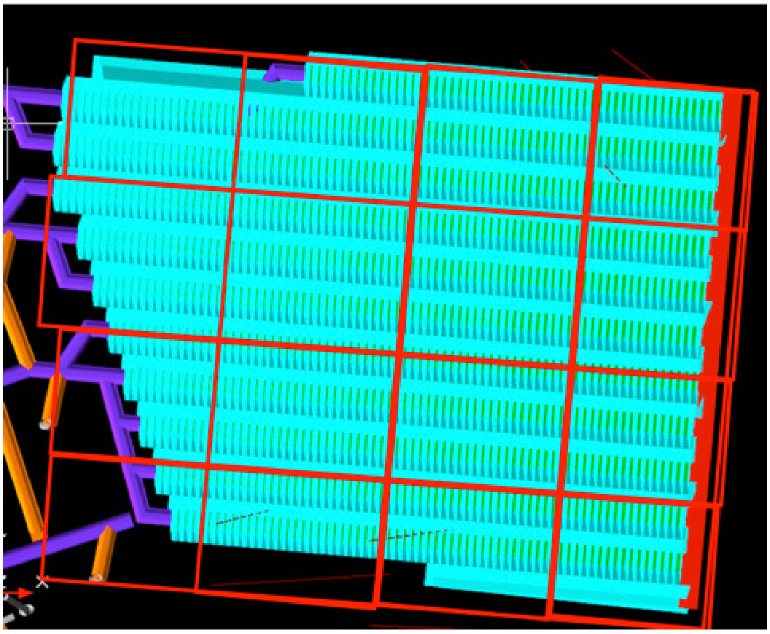


Figure 11 The level can be split into zones so the data between modelled and actual grade can be examined

$$t = r\sqrt{\frac{n-2}{1-r^2}} \text{ (n-2 degrees of freedom)} \quad (2)$$

t *Student t distribution*

n *Number of observations*

r *Correlation coefficient*

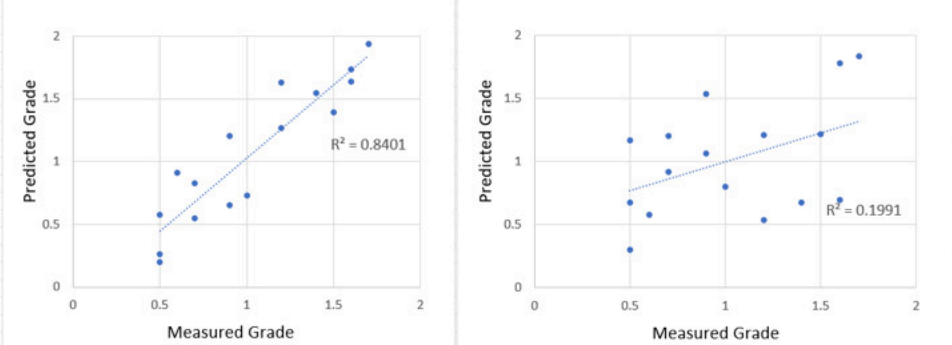


Figure 12 Correlation of grade marks in zones, left good correlation, right poor correlation with little statistical significance

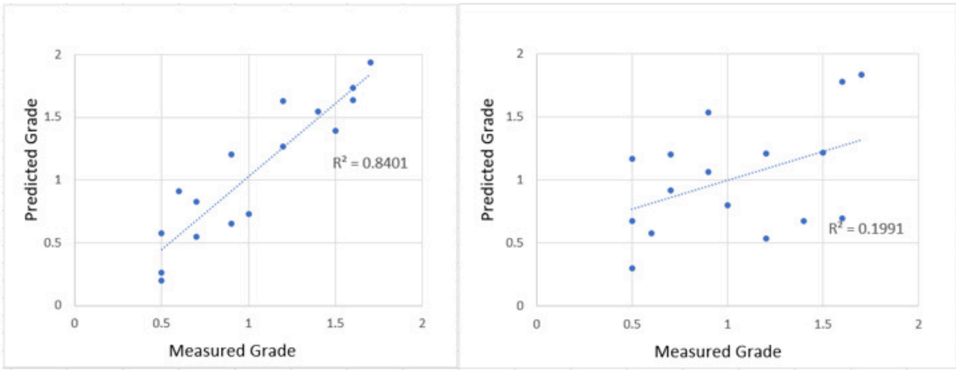


Figure 13 Correlation of grade through time using regressions significance (dummy data)

4 Marker design at Carrapateena

An understanding of the caveability and cave flow risks to the safe and economic delivery of the Carrapateena sub level cave defined the monitoring design.

Spatially, as mentioned previously, flow monitoring can be split into referred to as near field and far field. The initial marker design at Carrapateena was designed and executed with a focus on the cover sequence to capture early calibration of material mobility. Each address different risks to recovery and are initially independent of each other prior to cave maturity, where the systems overlap. Measurements in both systems enhance the accuracy in the calibration of flow models by minimising the delta between input assumptions and the actual behaviour of material in a chaotic system. By systematically defining each of the inputs against multiple marker sources, a score card can be developed, enabling operations to produce a defensible planning tool to predict forecasted metal output, dilution/waste and give early indication of risks such as material movement. In addition to this, a scorecard coupled with mine-to-mill reconciliation processes can provide an understanding to grade variability and guide Reserve and Resource depletion, which accounts for broken stocks in a mixed state.

The following design philosophy was adhered to in the design of both near field and far field monitoring systems at Carrapateena; monitoring purpose, monitoring quality and monitoring system as shown in Figure 14.

4.1 Near field purpose

The near field purpose was to determine what material is being extracted from each fired production ring. These measurements from primary, secondary, tertiary and quaternary sources capture ore movement across multiple levels. Data assists in measuring the performance of production drill and blast activities and ring geometry, and acts as a feedback loop to validate the right material is being mobilised and drawn through the Draw Control Strategy as planned in the medium- and short-term planning horizons. Marker populations on a more granular level enables confidence in the reconciliation and resource depletion during Life of Mine planning.

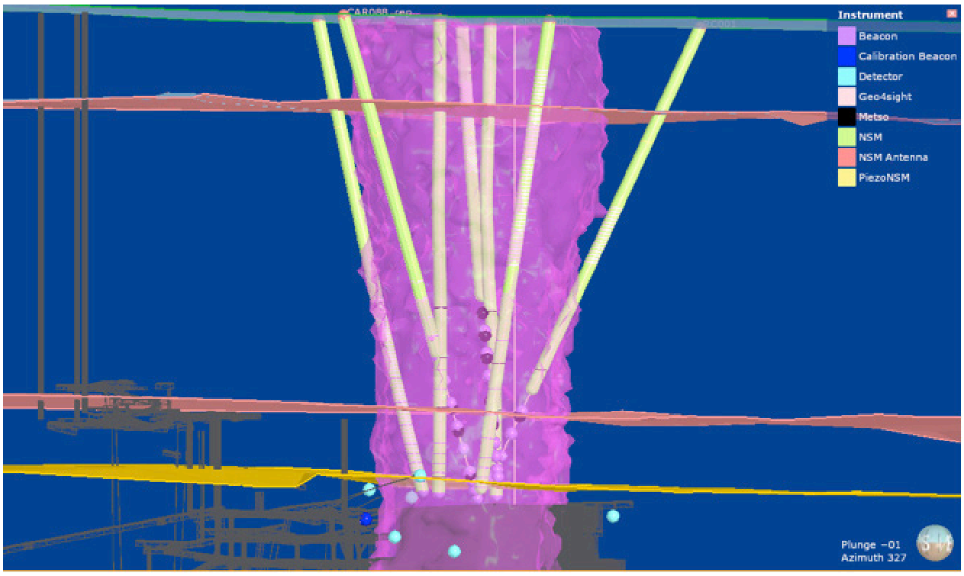


Figure 14 Oblique view of holistic design for both near and far field systems

4.2 Near field quality

Retrieving draw point accurate data with a spatial resolution representative of the fired material was the goal. The early calibration of the monitoring system and evolution of required monitoring resolution over time was predicted to decrease as orebody knowledge, material flow behaviour and production parameters were learnt.

4.3 Near field monitoring systems

Three marker systems were proposed:

1. RFID marker tags
2. Grade
3. A trace geochemical signature

4.3.1 RFID marker tags

Both active and passive RFID markers were planned to be used. In-ring experiments using active RFID markers, such as those conducted at Ernest Henry (Campbell 2018) are planned for a later date in levels where draw is determined by in-situ value, rather than the fixed draw percentage strategy deployed for cave establishment, where tonnage is less than in-situ tonnes. There are significant amounts of published data on the performance of rings through using this style of marker and there is no indication that the results at Carrapateena would be grossly different to the chaotic nature previously observed.

The passive RFID marker system is design by Metso and is an existing system used predominantly in an open pit production cycle. Passive RFID markers are installed in the bench prior to firing. As the material is moved, placed in primary crushers and conveyed to the mill, an antenna is placed beneath the belt which activates the markers as the material travels across it, thereby receiving the marker ID and time stamp of retrieval. Through understanding material resonance time in the underground production system, a back calculated method can be used to find the likely timing of marker retrieval from its primary source and then linked back to the origin of in-situ placement, making this marker system appropriate for a sub level cave. The benefit of using this marker system is that the size of marker, discussed in Hocking (2018), is more representative of Carrapateena ore fragmentation.

4.3.2 Grade

Grade is sampled at 500 t increments and is an important calibration measurement for understanding and generating the base line in flow model error as the grade error attributed to the Resource Model input. It is assumed that the first three samples taken at 0 t, 500 t and 1,000 t are representative of the in-situ resource grade and that all samples beyond that are subject to mixing and are calibrated against flow model outputs. The number of samples to achieve a statistically meaningful data set is substantial and wet lab assay costs are high. This promoted the trial of an alternative sensor technology which is continuing to be assessed but has so far shown reasonable success. It is expected over the next 12 to 18 months, all samples for flow calibration will be performed using this analytical technique, thereby reducing significantly the operational costs associated with sampling.

4.3.3 Geochemical marker

An elemental assessment of all rock types identified an element in which the orebody and cover sequence were depleted. Fortunately, this element could be purchased in pure (99.9%) form and had a high response to Prompt Gamma Neutron Activation Analysis (PGNAA) and Pulsed Fast Thermal Neutron Activation (PFTNA), the technology which had already been planned as a cross belt analyser. Although this marker has not yet been deployed, the elemental material will be distributed in areas of the levels to track mobility of fines.

4.4 Far field purpose

The far field purpose was to determine the mobilisation and migration of the waste cover sequence. These measurements provide a calibration tool for flow modelling through the calibration of inputs relating to material mobility, cave boundaries and flow width to forecast the timing, quantity and location of dilution during Quarterly and Life of Mine planning. It should be noted that there are significant amounts of overlap in technologies that track cave propagation and flow in the far field and that until break through, the monitoring systems serve as multi-dimensional in their data sets.

4.5 Far field marker design

The minimum requirement was to retrieve data with a spatial resolution representative of all lithologies within the cave column and define the expected cave boundaries. This was to be achieved in a time horizon that allowed the project to be proactive rather than reactive to dilution and cave propagation risks, and be applied to the calibration. Historic learnings in the deployment of markers and their detection systems were adopted, i.e. install monitoring early, as there is a single window of opportunity (at pre-cave initiation) to install the project far field monitoring requirements.

Far field monitoring system:

1. Cave tracker – Beacons
2. Metso passive RFID
3. Networked smart markers – being used for cave back tracking and final cave shape geometry due to size are unlikely to be representative of the fines mobility.

4.5.1 Cave tracker

Nominal 25 m spacings of beacons up to 200 m above the sub level cave undercut level, reduced to 10 m spacings across modelled higher risk lithological contacts (defined by competency and litho-strength) and greater density in the centre of the cave where higher amounts of draw are forecasted.

4.5.2 Metso smart tags – passive RFID

There were 6,000 medium tags and 3,000 micro tags installed in 20 sleeved and punctured poly pods (Figure 15). This ensures the survival of poly tubes under head pressures at depth and that markers will be liberated at mobilisation. Marker installation was concentrated at the interface of litho contacts, particularly the shale that is forecast to be a dominant litho-risk to the sub level cave. The markers will be tracked as populations for calibration purposes.

Figure 15 A mixture of 450 medium and micro smart tags installed in sleeved and perforated PVC pipe

The systems proposed in the near and far field enable four sizes of markers to be tracked, which is important for understanding the relationship between particle size and mobility. This data, coupled with fragmentation and grade measurements, positions Carrapateena in a strong position for understanding flow challenges and making proactive decisions for managing associated risks.

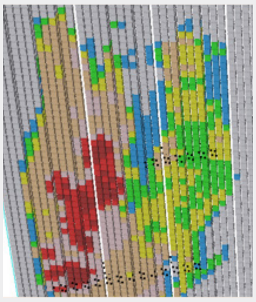
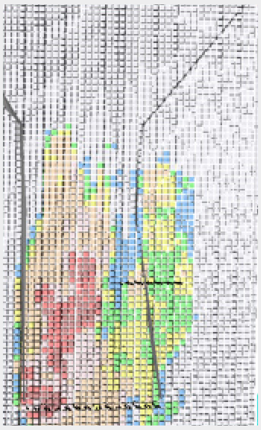
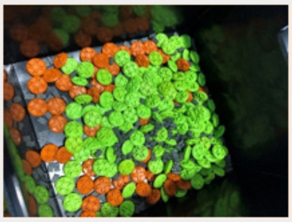
4.5.3 Lithology markers

Lithology markers are good if they are distinct from the other rock masses in appearance and can be modelled in the block model, and they can be treated in the same manner as grade markers. Within the Carrapateena dataset, logging the amount of the dilutant material in the draw points will be important so that it can be a key attribute in the model.

4.6 Creating a scorecard

Foundation to the creation of a scorecard is comparing a model across a number of variables, which include the measured grade, the lithology and the marker data across the Life of Mine of the orebody, as summarised in Table 2. As many as possible grade parameters should be selected, as long as they are independent of each other.

Table 1 Foundations of creating a scorecard

Model Givens	Markers	Mine Site Measure	Use within scorecard
Resource model 	• Grade information	• Reconciliation • Sampling	• Grade variability across draw point • Grade information through time
Cave Interpretation  Multi-platform monitoring system	• Lithology Markers	• Lithology Logging at Draw Point • (manual or automatic)	• Lithology Correlation through time
	• Installed markers • Geochem markers	• Marker logs • PGNAA	• Correlations through time

An example scorecard that will be used for calibration at Carrapateena is shown in Table 2. In this example, different grade copper and cobalt are selected as grades as they have a low covariance. The variability of the grade at 3,000 t drawn across the levels is used to see if there is different variability across different areas of the orebody, and the marker data is also logged through time. This method of calibration is independent of the flow code chosen and can be used for sub level and block caving mining methods.

Table 2 An example of a scorecard based on grade data (dummy data for illustration purposes)

		Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Score
Raw Grade										
Cu Predicted		1.4	1.5	1.6	1.5	1.6	1.6	1.7	1.8	
Cu Actual		1.3	1.6	1.5	1.4	1.5	1.6	1.7	1.8	
Score /10		5	5	5	5	5	5	10	10	55
Co Predicted		100	125	150	120	120	115	120	115	
Co Actual		110	120	140	120	120	130	140	110	
Score /10		8	9	8	10	10	7	6	9	67
Spatial Grade Relationships										
Cu sampled (@ 3000 t drawn)	R2	0.8	0.75	0.72	0.6	0.4	0.2	0.1	0.1	
Score		8	7.5	7.2	6	4	2	1	1	37
Co sampled (@ 3000 t drawn)	R2	0.65	0.6	0.55	0.3	0.2	0.1	0.5	0.2	
Score		6.5	6	5.5	3	2	1	5	2	31
Lithology Observations										
Sandstone Observed		0	0	1%	2%	6%	4%	8%	6%	
Sandstone Modelled		0	0.10%	0.50%	2%	6%	15%	13%	12%	
Score / 10		10	9.99	9.95	10	9.9	9.2	9.8	9.7	79
Markers										
Predicted Markers		0	0	1	2	5	6	8	6	
Modelled markers		0	0.3	0.6	1.5	3.2	5	7.5	5	
Score / 10		10	7	7.3	8.3	0	8	9.7	8	58
Total										327

5 Conclusions and future work

With a large amount of finer material overlying the orebody, substantial focus is required to model the behaviours of this material. With the increased amount of data available, cave mines need a systematic way of using the data so that flow models can be calibrated and improved, allowing better decisions. While some authors have looked at one variable in isolation, the number of variables that can be changed is generally in excess of the number of data points, making these simple calibrations difficult to replicate across orebodies. A method of calibration is described here which is independent of the flow code and will no doubt be added to with the invent of improved computing power to better our understanding of flow modelling.

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