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Assessing the risk of a sublevel cave–block cave transition using dynamic decision tree analysis overlain with Monte Carlo analysis

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Abstract

Depleting global copper resources and declining discovery rates are driving a step-change in the copper mining industry as open pit mines transition underground and exploration for new deposits moves deeper. The need to exploit deeper, larger and lower grade copper deposits has resulted in the emergence of a technically challenging underground mass mining method called block caving. To improve shareholder returns, mining companies rising expectations for block cave mines are currently pushing the limits of existing knowledge and positioning larger and deeper projects in uncharted territory from a geotechnical risk and cost perspective. This paper addresses unconsidered geotechnical risks in discounted cash flow (DCF) analysis by introducing Monte Carlo simulation and decision tree analysis into a DCF model for the feasibility stage Carrapateena block cave expansion, currently being advanced by OZ Minerals.

As a brownfield block cave development project expected to transition from sublevel caving to block caving, the ability to pivot the production strategy in response to downside risks encountered during block cave development and ramp-up was the focus of this paper. Dynamic modelling of geotechnical uncertainty was conducted to provide insight into how uncertainty can be resolved through time, as management decisions are made in response to uncertain events during the development and ramp-up of a block cave project. A dynamic DCF model was created to help assess the risks around the schedule, including the ramp-up and the undercutting phase of the project, while also using a decision tree to determine the best decision for the project overall.

The results from the simulation demonstrated an average recovery of approximately AUD 20 million to the valuation for Carrapateena and increased the minimum incremental net present value to be greater than zero, confirming based on the model assumptions and probability distributions that OZ Minerals should decide to pursue the expansion. An additional simulation, focusing on the value of the decision tree itself, indicated that management decisions could minimise the downside risks of delays by up to 15% on the base NPV, supporting the use of decision trees in DCF analysis.

Keywords: *block caving, Monte Carlo analysis, decision tree analysis, mine planning*

1 Introduction

OZ Minerals is a copper-focused, global, modern mining company based in South Australia. OZ Minerals owns and operates the Prominent Hill and Carrapateena mines in South Australia, the Antas mine in the Pará State of Brazil and is constructing the Pedra Branca underground mine.

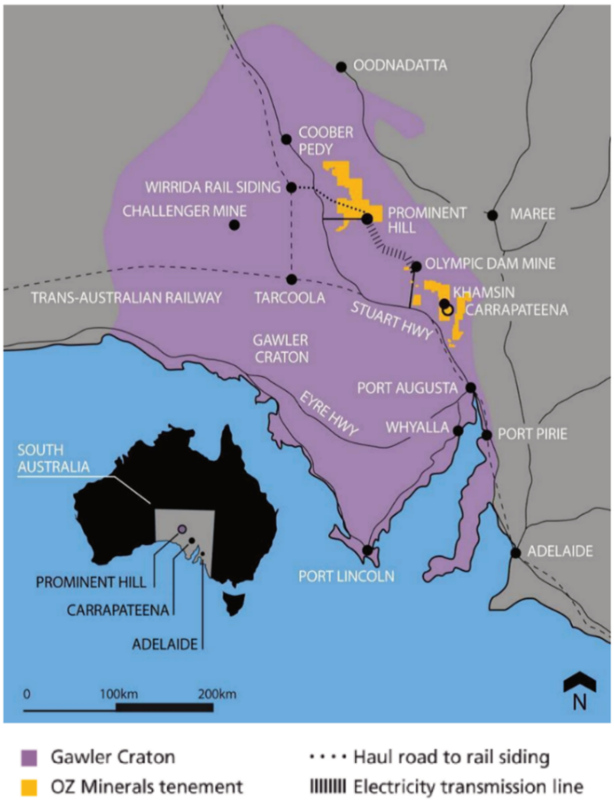

Figure 1 Carrapateena location map

The Carrapateena copper-gold mine is approximately 160 km north of Port Augusta in South Australia's highly prospective Gawler Craton (Figure 1). The project is located on Pernatty Station, and its supporting infrastructure is located within Oakden Hills Station.

In 2020, OZ Minerals released a pre-feasibility study (PFS) for a block cave expansion at Carrapateena, demonstrating the conversion of the lower portion of the sublevel cave (SLC) to two block caves. With sublevel caving as a top-down method, the PFS envisions an SLC operation to continue into 2025, at which point block caving, as a bottom-up mining method, would be undertaken to mine the lower section of the orebody. Figures 2 and 3 demonstrate the additional value of changing the mine plan from SLC only mining (Figure 2 – left) to the PFS design envisioning SLC mining until 2025 before transitioning to lower-cost block caving (Figure 2 – right), which has the potential to nearly double metal production by mining two lower grade block caves 1 (BC1) and 2 (BC2).

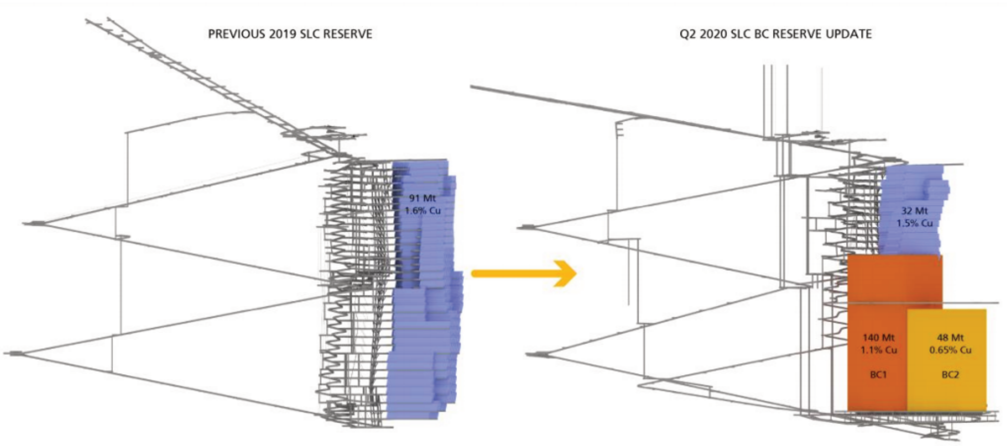

Figure 2 Simplified representation of the 2019 sublevel cave reserve to the updated 31 May 2020 sublevel cave to block cave reserve (OZ Minerals Limited 2020)

	Sub-Level Cave[2]	Block Cave 1[3]	Block Cave 2[4]
Production	2021–2025	2026–2037	2038–2045
Final Investment Decision	Operational	~2023	~2036
Construction Capital ($ real)		~1.25b	~90m
Production Rate (Mtpa)	4.25–5	12	8
Avg Copper Produced (ktpa)	~70	~110–120	~45–55
Avg Gold Produced (koz)	~85	~110–120	~45
Net Undisc Cashflow ($b)		~6	~1
C1 (USc/lb)	~50	~45–55	~1.20–1.40
AISC (USc/lb)	~75	~75–85	~1.60–1.80

Figure 3 Production parameters for sublevel cave and subsequent block caves (OZ Minerals Limited 2020)

2 Valuation of mining projects

2.1 Discounted cash flow model

The most common metric used for project valuation in the mining industry is net present value (NPV), described by Equation 1, derived using a discounted cash flow financial model with NPV equal to the sum of net cash flows discounted at a chosen discount rate (Buchanan 2016).

$$NPV = \sum_{t=0}^{n} \frac{NCF_t}{(1+r)^t} \qquad (1)$$

where:

NCF = net cash flow in period t.

r = the discount rate.

t = the time of the NCF.

The second most common valuation metric is the internal rate of return (IRR), which reflects the expected rate of growth from investing in a mining project corresponding to the discount rate giving an NPV of zero. Also included in economic studies for mining projects, IRR is another useful valuation metric to compare and benchmark mining projects. However, the valuation metric to be focused on in this paper is NPV.

2.2 Modelling uncertainty

A sensitivity analysis, frequently included in economic studies in the form of a spider graph (Figure 4), is conducted by flexing major input parameters, such as metal price and cost, to demonstrate the sensitivity of the base case NPV to deviations in input assumptions.

A Monte Carlo analysis, used less frequently by mining companies, is conducted to flex several of the parameters in Figure 4 simultaneously, an advantage over the traditional one-point sensitivity analysis while introducing probabilistic analysis to incorporate the influence of random behaviour in project parameters (Wypych 2011).

The limitations of the above approaches are twofold for the SLC to the BC transition for Carrapateena. Firstly, they do not fully analyse the risks associated with the ramp-up of the block cave, as some of the key geotechnical risks and operational risks, such as undercutting rate, equipment availability, and development rate are not considered as part of a typical Monte Carlo analysis. Secondly, the mine plan, in this case, can pivot as a delay to the block cave can mean additional tonnes can be extracted from the SLC at different grades, or conversely, if the block cave is developed more quickly, then less material can be extracted from the SLC at a higher grade. Therefore, there is a need to include mining method-specific value drivers in modelling and consider that decisions can be made to pivot strategy in response to unexpected events.

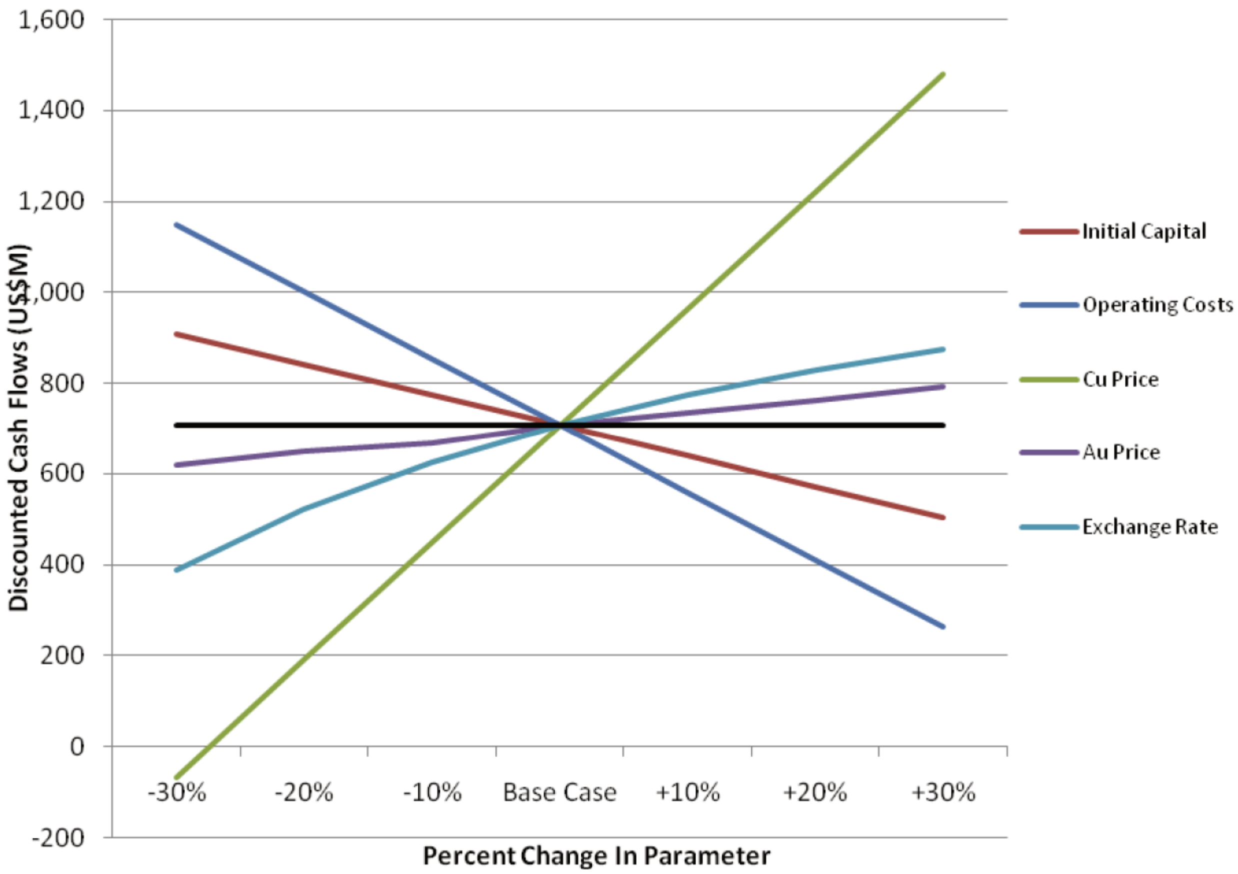

Figure 4 Example of a spider graph for a copper-gold project (Wypych 2011)

3 Modelling uncertainty at the Carrapateena block cave expansion

3.1 Incorporating flexibility into the model

The PFS has integrated optionality into the mine design, which, from a financial modelling perspective, allows the development and ramp-up plan to be divided into the development phase (2022–2025) and ramp-up phase (2026–2028). The primary value driver during the development of a block cave has been identified to be the development rate (m/month), and the primary value driver during ramp-up is the undercutting rate (m^2/month) (Ross 2018).

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
FS Stage 1		Declines								
		FS Stage 2		BC1 Setup and Underground Infrastructure						
				FS Stage 3		Process Plant and Surface Infrastructure				
						BC1 Ramp Up			12 Mtpa	

Figure 5 Indicative sequencing of potential Carrapateena expansion (OZ Minerals Limited 2020)

3.2 Development rate

Development rate can be defined as the time taken to complete the lateral development of the block cave. If there are delays or this is done quicker than predicted, then the SLC production can be adjusted as a buffer to production. As seen in Figure 2, with significant lateral development required to reach the cave footprint followed by additional lateral development to develop the undercut level (UCL) and extraction level (EXL), keeping the project on schedule and under budget represents a substantial risk to the viability of the expansion. Integrating a development schedule in the mine model incorporates flexibility for fluctuations in development rate (m/month), which allows the representation of operational and geotechnical uncertainty into the NPV calculation. Figure 6 illustrates the impact of positive and negative deviations from the base case development rate resulting in reaching design capacity one year ahead of schedule and one year behind schedule, respectively. This paper looks at ways of evaluating the buffer that can be added through additional SLC production to improve the NPV by adding additional material.

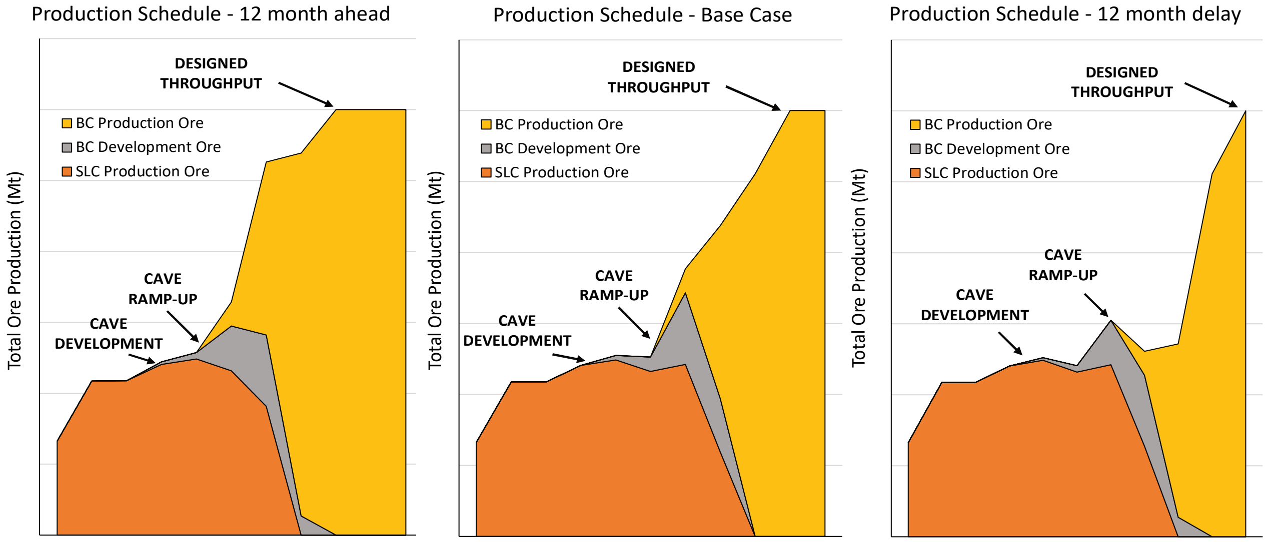

Figure 6 Modelled indicative annual production schedule with different lateral development rates

The impact of fluctuating the development rate on the mine plan was modelled by defining decision rules in the development and production schedule, whereby a defined lateral development milestone acts as a trigger value for block cave development ore, and a subsequent lateral development milestone triggers block cave production ore (Peter 2012). The major contributors to financial losses were found to be the deferral of revenue from the production delay with minimal losses from capital cost overruns due to the built-in optionality in the PFS design. As the PFS design allows for a decision in 2025 on the plant expansion, the progress of decline and cave development from 2022 to 2025 informed this decision in the model, which prevented the early construction of the plant and the high cost of an idle plant.

3.3 Undercutting rate

Following the development of the block cave, cave ramp-up commences by undercutting the orebody to initiate the caving of BC1. As the undercut front advances across the orebody, cave abutment stress loading is expected to result in elevated seismic risk in the vicinity of the undercut front and EXL. A slower than designed undercutting rate can allow the abutment stresses to damage the EXL, and a faster than designed undercutting rate could trigger seismic events (Ross 2018).

Undercutting rate (m^2/month) is an important value driver representing the rate of ramp-up for a block cave. The base case mine plan at Carrapateena envisions approximately 2.5 years to undercut the entire cave footprint and achieve a steady-state production capacity of 12 Mtpa.

3.4 Monte Carlo simulation

With the added flexibility of a development and undercutting schedule, probabilistic analysis can be introduced to incorporate the influence of random behaviour and geotechnical uncertainty inherent to cave mining at depths of 1,500 m. Additionally, random behaviour associated with other technical and economic value drivers, such as those seen in Figure 4, can be incorporated into the simulation to compute a more representative risk-adjusted incremental NPV for the Carrapateena block cave expansion. The additional value drivers at Carrapateena include metal price, metallurgical recovery and mining rate. The mining rate can be added to the simulation to reflect resource loss and the risk that the actual mining rate can either fall short or exceed expectations of 12 Mtpa depending on cave performance. Resource loss and lower than expected mining rates can be common during ramp-up due to convergence at the EXL, the loss of drawpoints and the sterilisation of the above ore.

Major technical and economic value drivers at Carrapateena:

- Lateral development rate (m/month).
- Undercutting rate (m^2/month).
- Mining Rate (Mtpa).
- Copper Price (USD/lb).
- Gold Price (USD/oz).
- Copper Recovery (%).
- Gold Recovery (%).

A risk-adjusted incremental NPV can be produced by simulating the abovementioned variables based on defined probability distributions. A triangular probability distribution was used with the minimum and maximum values chosen based on the technical and economic uncertainty reflected in the PFS. The most likely value corresponds to an approximation of base case assumptions in the PFS.

3.5 Decision tree analysis

Given the technically challenging nature of block cave mining combined with the limited existing knowledge of cave performance, unexpected future events are common and require the ability of managers to pivot their strategy on the fly to minimise losses in value (Winkelmann 2018). Whilst cave projects are at a disadvantage compared to other mining methods, anticipating uncertain future events in cave valuation and risk analysis can help mitigate these risks. Recognising that the feasibility study design is likely to experience inevitable variation and that project performance is not static implies that the current practice of basing investment decisions on traditional DCF analysis can be improved (Gui 2013).

Figure 7 demonstrates the impacts of slower than expected lateral development and undercutting rates leading to a one-year production delay and resulting in a significant loss in value. This assumes no management optionality and nothing can be done to minimise the financial losses resulting from a development delay.

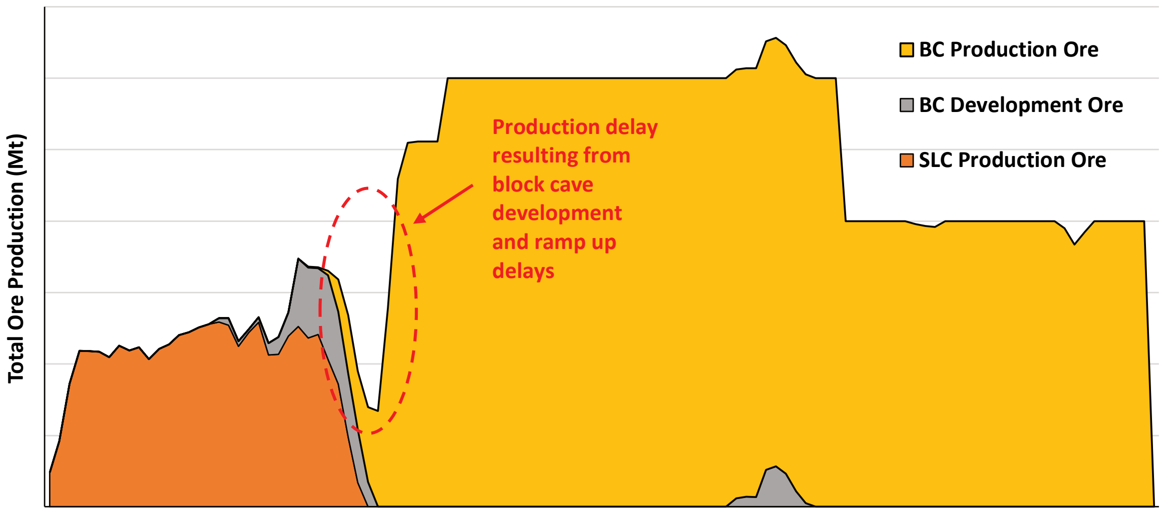

Figure 7 Modelled indicative quarterly production schedule for the Carrapateena project with slower than expected lateral development and undercutting without additional feed from the SLC

By recognising that the Carrapateena mine design is likely to experience inevitable variation during the six-year development and ramp-up phases, with potential upside and downside to the base case plan, dynamic modelling of this uncertainty can consider management's ability to change production strategy in response to a delay by mining additional sublevels. By incorporating 10 production schedules for the sublevel cave into a model, including the SLC only scenario (Figure 2 – left), a simple decision tree can be produced to represent the incremental NPVs for each mine plan in Figure 8, to determine the best outcome based on changes to the mine plan.

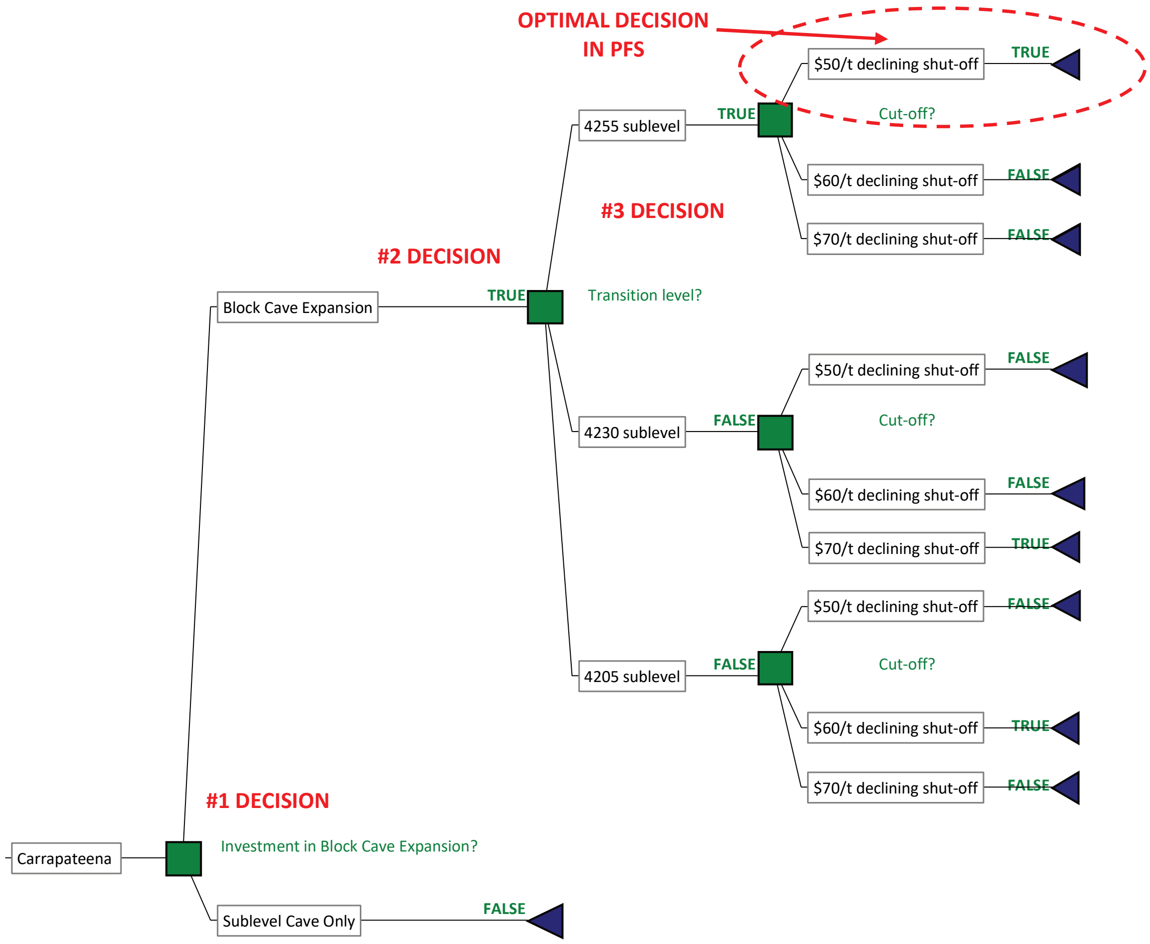

Figure 8 Decision tree with incremental NPV for 10 SLC production schedules

As seen in Figure 8, the optimal path in the tree is based on three management decisions, including the investment decision in the expansion, the decision on the transition level and the decision on the declining shutoff approach for the last levels.

In the PFS, the optimal path envisioned by the PFS involves the SLC operating until the 4255 level with a declining shut off of AUD 50/t (base case), where the declining shutoff approach is applied to the bottom four levels using AUD 80/t, AUD 70/t, AUD 60/t and AUD 50/t. The shutoff value, similar to the cut-off value for conventional projects, refers to the point when mining will cease from a drawpoint. For example, a lower shutoff of AUD 50/t on the last 4255 level allows the extraction of lower value ore to achieve a higher production rate from the sublevel until the value of the ore being extracted falls below AUD 50/t, at which point mining will cease.

For a one-year production delay seen in Figure 9, the optimal path selected by the decision tree would be to mine both the 4230 and 4205 sublevels, increasing the transition depth by 50 m and adding one year of

SLC production, which can partially fill the void left by the block cave delay (Figure 9) with tonnes from the SLC, resulting in an improvement in the returns for the project. Conversely if the block cave is delivered early, less levels are needed in the SLC and a high grade can be achieved.

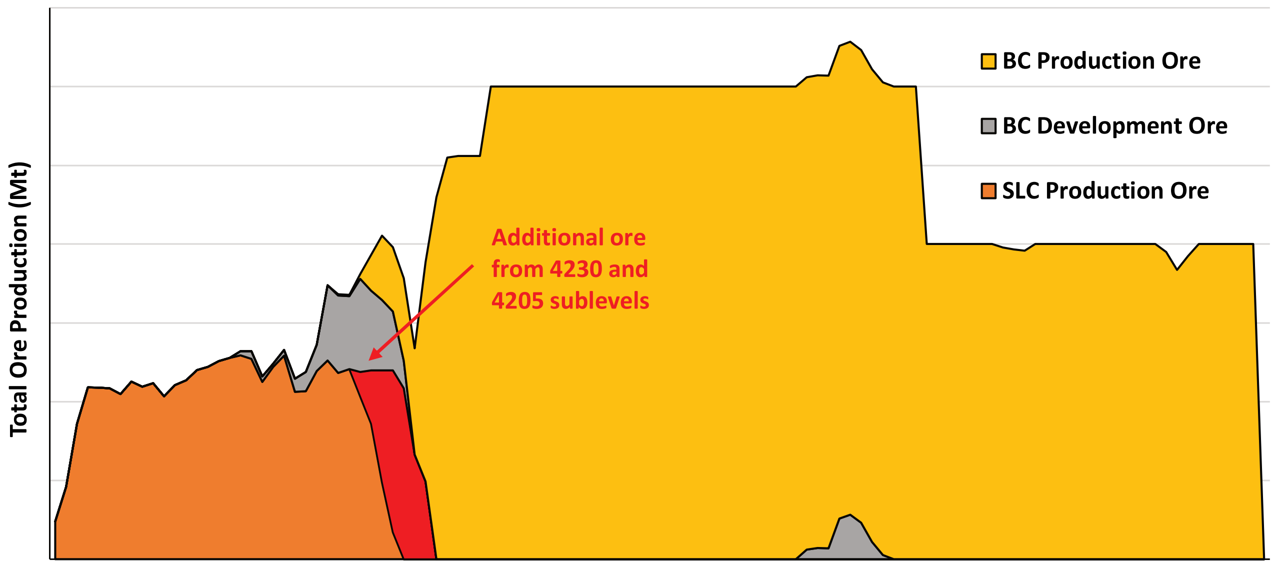

Figure 9 Modelled indicative quarterly production schedule for the Carrapateena project with slower than expected lateral development and undercutting with additional feed material in red added to improve NPV

Given the eventual connection between the block cave and the sublevel cave above, a constraint was applied in the model to account for safety, whereby the entire sublevel caving operation is shut off once the block cave ramp-up reaches 6 Mtpa.

When used in conjunction with a Monte Carlo simulation, each of the 1,000 iterations selects an optimal mine plan in the decision tree based on three decisions made in response to technical and economic conditions (e.g. undercutting rate, development rate, metal prices, recoveries). The results demonstrated a reduction in downside risk and recovery in value through a higher mean NPV and a significantly higher minimum NPV over the 1,000 iterations conducted.

4 Conclusion

This study addressed the technical challenges of block caving and how traditional DCF analysis can be improved by creating a dynamic DCF model that models uncertainty and how it can be resolved over time as decisions are made in response to unexpected events. By taking a traditional DCF model for Carrapateena and integrating additional flexibility through lateral development and undercutting schedules, followed by conducting a Monte Carlo simulation, a risk-adjusted incremental NPV could be computed. This valuation provides managers additional insight by quantifying geotechnical risks inherent to block caving and providing a probability distribution reflecting both upside and downside potential scenarios in a quantifiable financial value.

By going one step further to address the reality that managers can make decisions throughout the life of a project to react to downside risks, a second valuation of the expansion can be computed using decision tree analysis to determine the path forward with the highest incremental NPV. The results demonstrated an average recovery of approximately AUD 20 million to the valuation for Carrapateena and increased the minimum incremental NPV to be greater than zero, which confirms based on the model assumptions and probability distributions that OZ Minerals should decide to pursue the Carrapateena block cave expansion.

A third simulation was undertaken of the difference between the first and second valuation to compute the NPV of the decision tree itself and its associated probability distribution, which indicated that management decisions can minimise the downside risks of delays in development and ramp-up at Carrapateena by an NPV of up to 15%. These results support the use of decision tree analysis in DCF analysis for brownfield block cave projects and points to its potential value for financial modelling of capital-intensive mining project with long lead times to the first ore production.

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