

# Carrapateena block cave mine design and planning: feasibility study

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## Abstract

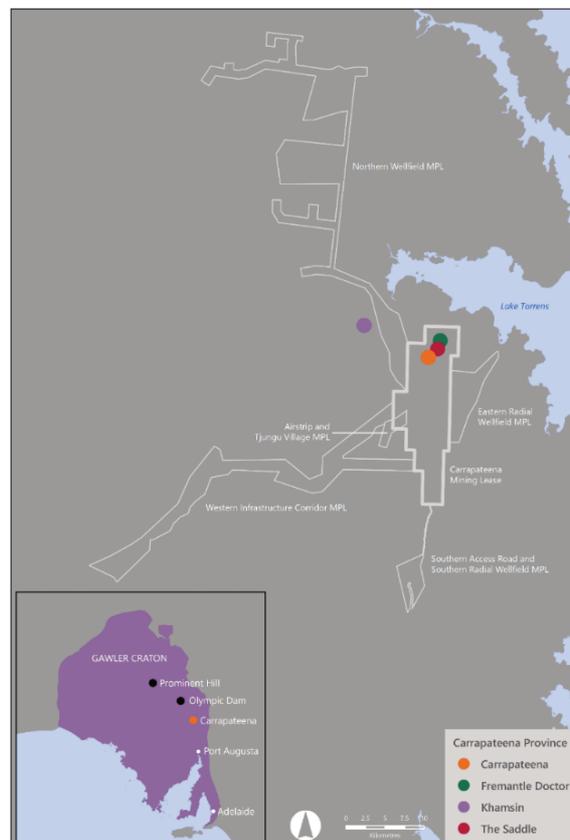
*Carrapateena is an underground sublevel cave operation. To maximise future value from the Carrapateena copper–gold resource, an expansion study has been completed to feasibility study level to assess a larger block cave expansion below the current sublevel cave. This paper will summarise Carrapateena block cave mine design and planning from pre-feasibility to feasibility study.*

*Emphasis will be on the footprint determination, mine layout, and production ramp-up. It will also discuss the material handling system selection, ventilation design and mine dewatering. As the block cave will be built below the sublevel cave operation, the transit from the sublevel cave to a block cave mine will be discussed, particularly on production plan, risk control and resources management.*

**Keywords:** Carrapateena block cave, mine planning, sublevel cave and block cave interaction

## 1 Introduction

Carrapateena is located in the highly prospective Gawler Craton in South Australia, approximately 160 km north of Port Augusta (Figure 1). It is an underground sublevel cave operation.



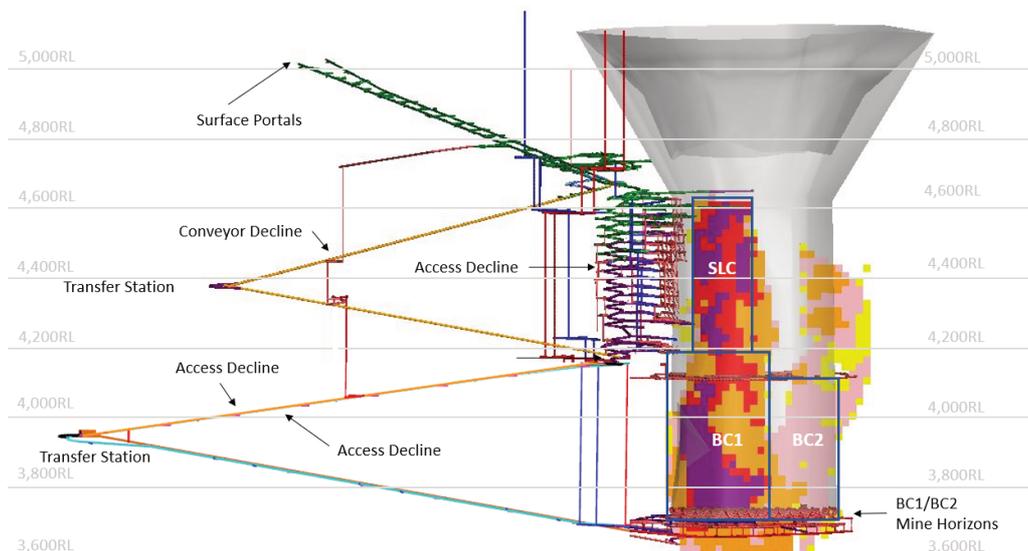
**Figure 1 Carrapateena Province copper resource deposits and exploration targets**

Carrapateena expansion project focuses on a transition from the sublevel cave (SLC) to block cave (BC) for the lower half of the Carrapateena resource. The Feasibility Study concluded significant value is delivered by replacing the bottom half of the current sublevel cave with a larger block cave. Value is derived from increasing production rate to 12 Mtpa at a lower operation cost and cutoff grade than the sublevel cave. The block cave mine method also allows the higher-grade ore at the bottom of the orebody to be mined in earlier stage of the mine life and leaves the lower grade in the middle to the later of the mine life.

The Carrapateena block cave targets a 70,000 m<sup>2</sup> high-grade footprint Block Cave 1 (BC1) initially. This enables future Block Cave 2 (BC2) development with lower grade.

## 2 Mine design

The mine design focuses on value optimisation and geotechnical and operational risk control. Mine layout is shown in Figure 2 with BC1 and BC2 located lower than SLC. The block cave extraction level on the 3680 RL and the undercut on the 3700 RL. The twin declines are designed with the access decline to access the extraction level and undercut level and the conveyor decline for material handling. An off-footprint primary crusher on the extraction level is to primarily crush the ore from drawpoints before loading on the conveyor system to haul to the surface.



**Figure 2** Indicative Carrapateena mine layout

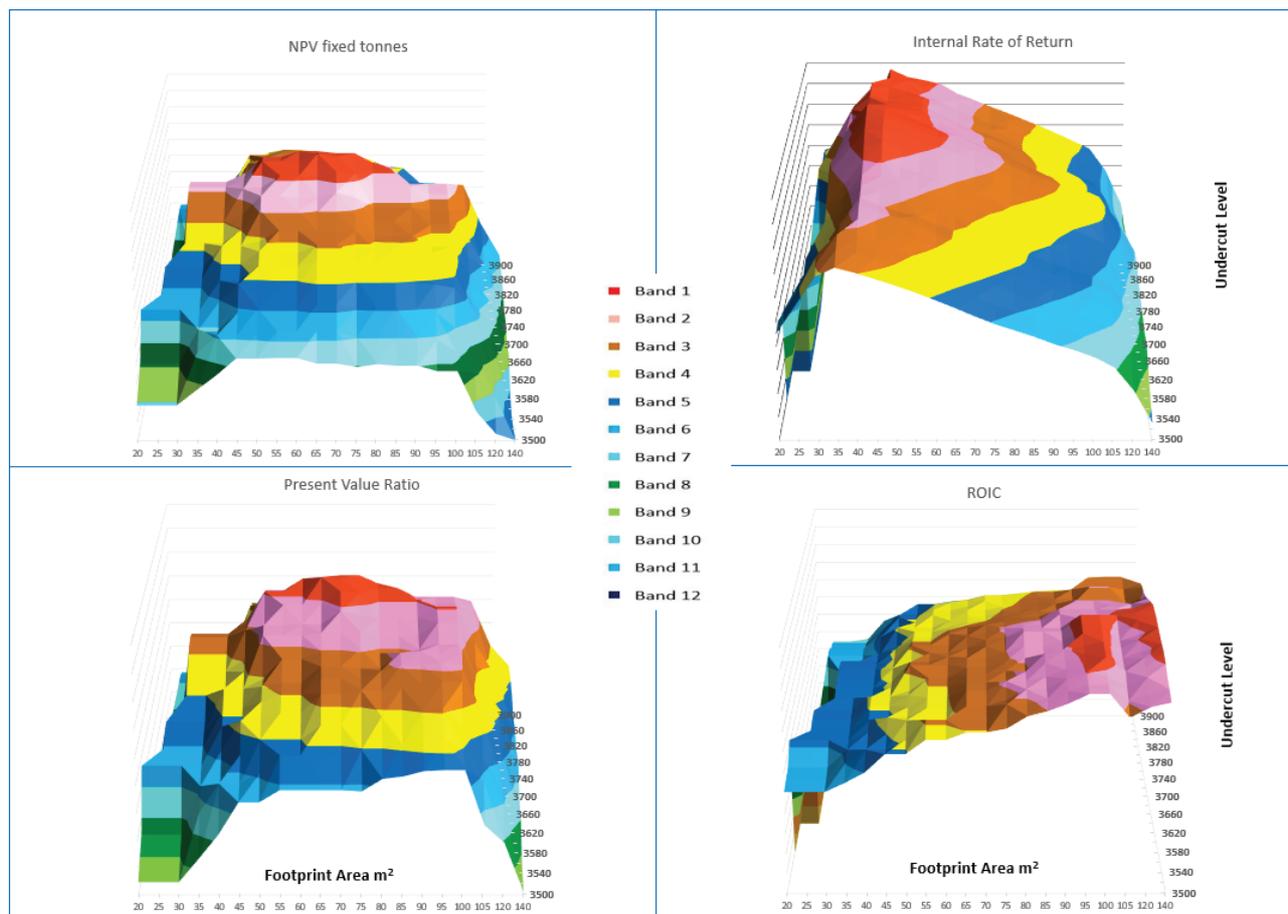
### 2.1 Define block cave production level and footprint size

The block cave production level elevation and size are determined using both Hill of Value (HOV) methodology and the Personal Computer Block Cave (PCBC) footprint finder (Diering et al. 2010). The aim is to define the block cave footprint to maximise the financial return.

As the sublevel cave is mined top down, the block cave draw height will exceed the RL of the sublevel cave in the later life-of-mine. Therefore, the tonnes and metals extracted by the sublevel cave needs to be depleted from the original resource model for the analysis. This is done via Deswik Datamine Commands.

Hocking et al. (2020) developed the HOV optimisation tool, as shown in Figure 3, for OZ Minerals to determine the optimised net present value (NPV), present value ratio (PVR) and internal rate of return (IRR) of the Carrapateena deposit based on the production rate, footprint size and footprint elevation (RL). This method allowed the SLC to be depleted while simultaneously evaluating the RL, footprint size and the mining rate. Both the HOV and the PCBC footprint finder concluded a 12 Mtpa block cave with 70,000 m<sup>2</sup> of the extraction level on the 3680 RL and undercut level on 3700 RL for BC1.

As BC2 is lower grade and to be developed in later years, it is planned to be on the same elevation but lower production rate.



**Figure 3 Hill of value analysis for the Carrapateena BC1 cave (Hocking et al. 2020)**

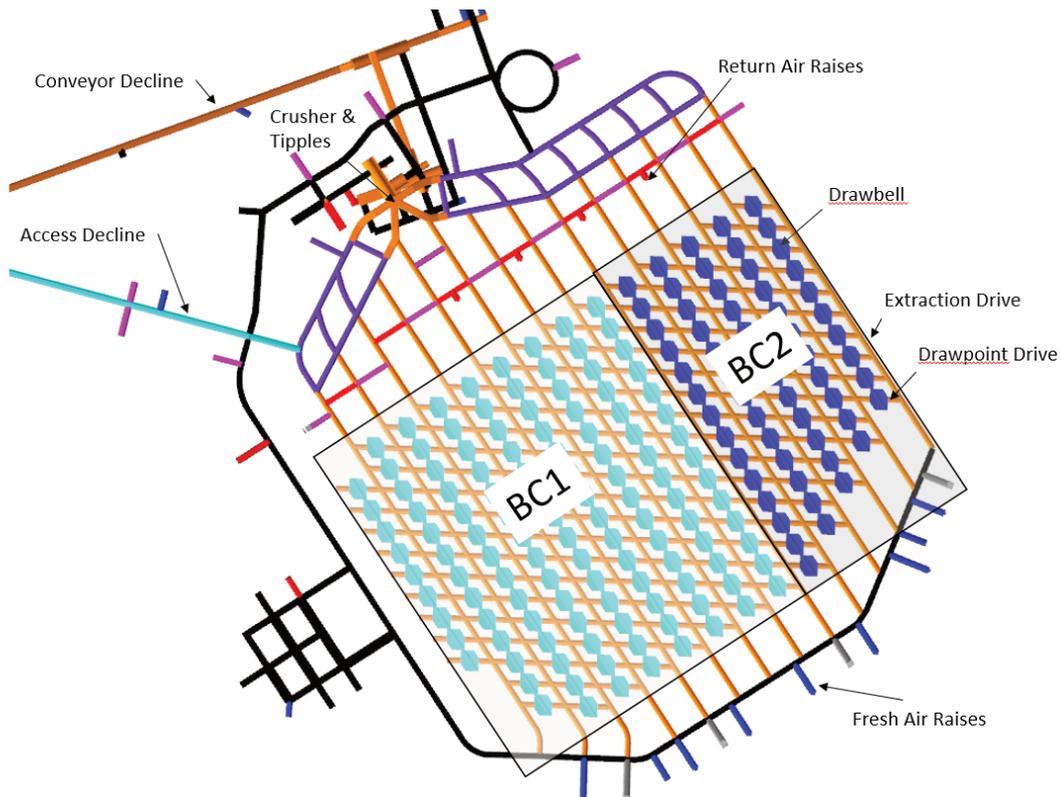
## 2.2 Extraction level

The extraction level is designed in consideration of ore recovery and mine stability. As the layout shown in Figure 4, the footprint is developed in stages with BC1 development initially to recovery the high-grade orebody. A crusher is installed at the end of the footprint with a stand-off distance determined by geotechnical analysis. Ore is moved from the drawpoints to the crusher by LHDs (load–haul–dumps) that can access the top of the crusher via tipples drives. This arrangement can minimise the interaction at the tipples and therefore increase the throughput.

To accommodate large LHDs, the extraction drives and drawpoint drives are at large tunnel profile, 5.0 mW × 5.0 mH. There are four tipples drives for LHDs to share. Each extraction drives are connected to two tipples drives to reduce the interaction. This is also to prepare for the future autonomous fleet when the technology is advanced. The location of the drawpoints are determined based on the economic evaluation, stress management and geotechnical constraints on footprint shape.

El Teniente layout is chosen in the design due to its advantages in the reduction of the development time and of larger pillars to maintain the stability. The drawpoint spacing is determined in consideration of the ore recovery and stability of the extraction drive. Based on the theory of the interactive draw (Laubscher 1994), a full interaction can be achieved at the drawpoint spacing of 32 m × 22 m as in the design.

The turnout angle between the extraction drive and the drawpoint drive is designed to be 56° to align the drawpoint drive orientation with the major principal stress. This is to optimise the long-term stress management and efficient for LHDs to bog the drawpoint.



**Figure 4 Proposed extraction level layout**

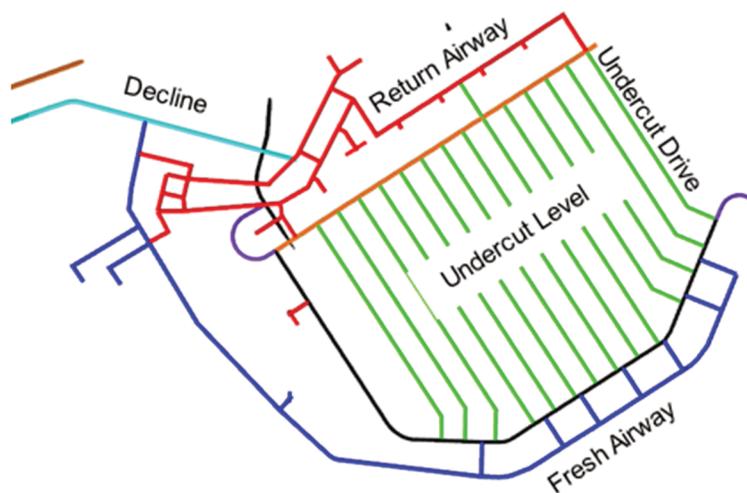
The air travelling through the extraction drives will return to the return airway directly as required by the radon management. The short ventilation raises are designed at the both ends of the extraction drive to allow the fresh air to flow to the extraction level and used air to the return airway before reaching the crusher. Small ventilation raises are developed between the undercut level and the extraction level to have fresh air sent down to the extraction level. The fresh air is pushed to the extraction drive via secondary ventilation fans that are also installed at the collar of the return air raises to pull the exhaust air to the return air way. This is to ensure the air is equally distributed to each extraction drive. It is designed to have 25 m<sup>3</sup>/s per extraction drive to control the dust, radon and maintain the proper working temperature.

### 2.3 Undercut level

The undercut level, displayed in Figure 5, is 17 m (floor to floor) above the extraction level. The undercutting is to extract the undercut so that the void is created to initiate the cave. The advance undercut strategy is selected in the feasibility study based on the orebody knowledge up to date. With ongoing update of the drilling data, stress measurement at depth and the risk control methodologies, OZ Minerals maintains the flexibility to further assess the undercut strategy in following years before the development reaches the footprint.

For the advance undercut strategy in design, the undercut is fired in advance of the drawpoint drives and drawbells. This allows the mine activities on the drawbells to be undertaken in a lower stress environment on extraction level. The Big W undercut drill and blast design is chosen in the design as it provides the largest apex pillar than other common design such as the crinkle undercut design. Therefore, it could provide higher pillar stability in the life-of-mine. The detailed drill and blast design are to be developed with a trial in Carrapateena in following years before the implementation.

Ventilation drives are located at the undercut level. It is designed with the tunnel profile of 6.0 mW × 6.0 mH for the high air volume at the BC1 ramp-up period. Small ventilation raises are developed between the undercut level and the extraction level to have fresh air sent down to the extraction level and the used air returned to the return airway directly.

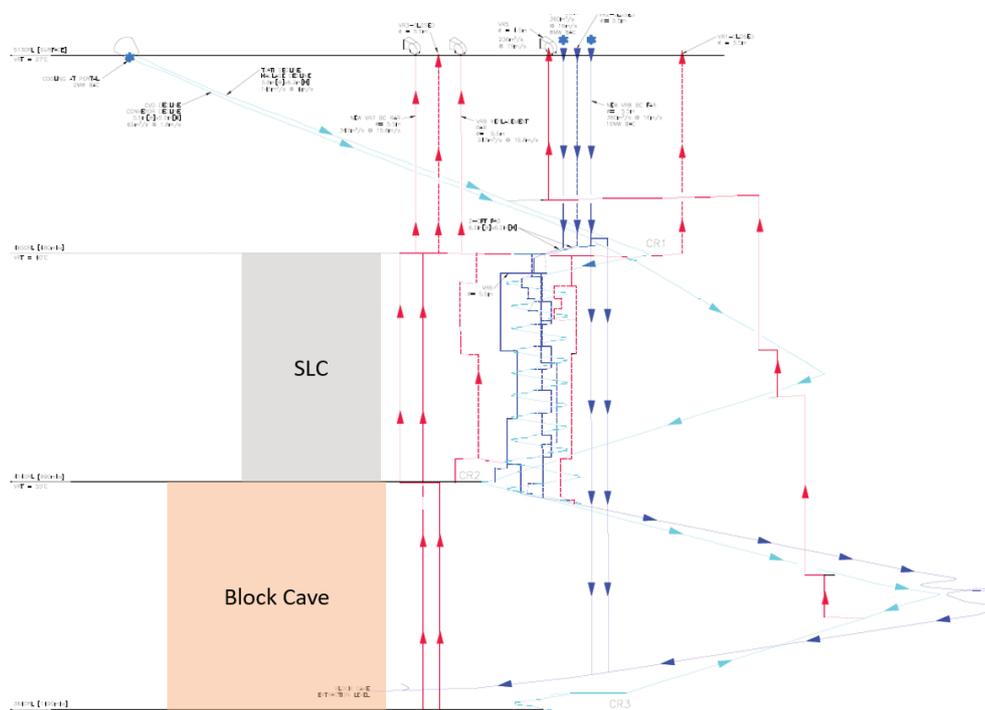


**Figure 5 Proposed undercut level layout with fresh and return airway**

## 2.4 Ventilation

The block cave will be developed below the current sublevel cave operation in Carrapateena. During the block cave establishment period, Carrapateena will keep production from the upper SLC to ensure a smooth production transition from the SLC to block cave. This is also the peak period with the highest ventilation requirement for Carrapateena underground operation.

As shown in Figure 6, the SLC ventilation is supplied by two intake air raises and two exhaust air raises with the exhaust vent fans installed at the surface collars of the exhaust raises. At the peak period, the SLC will still use full capacity of the ventilation supplied by its system. Therefore, new vent raises are required to be developed for block cave.



**Figure 6 Proposed Carrapateena underground mine ventilation design layout**

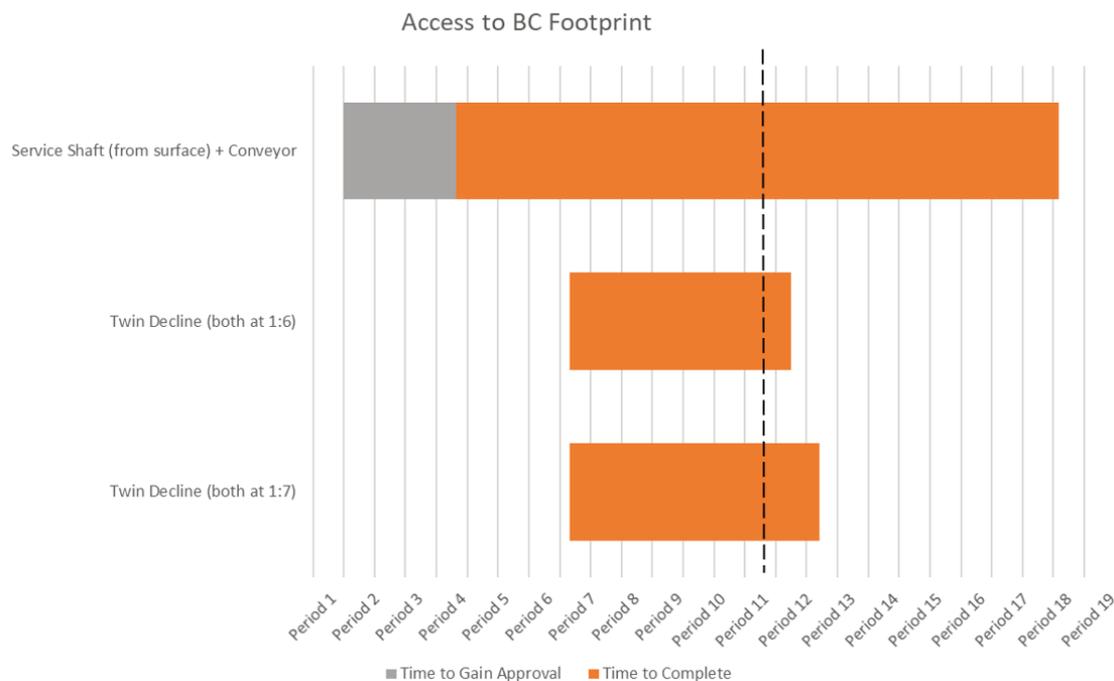
Ventilation requirement is assessed based on the equipment, radon control, dust control, heat and other contaminants in underground mine environment. Ventilation modelling concluded it is required to have 900 m<sup>3</sup>/s at the peak period of the block cave development. The air quantity can be supplied via two new

4.7 m intake raises and two new 4.7 m exhaust raises developed all the way from the surface to the block cave footprint. New primary vent fans are installed at the collar of the exhaust raises to pull return air from underground.

As more intensive mine activities are carried out during cave establishment period due to the nature of the block cave, more air volume is required to support the work areas than the block cave steady state when bogging is the main activity on the extraction level. The ventilation requirement reduces when the bogging and secondary breakage become the main activities on the extraction level post the completion of the development and production firing. It is estimated that 640 m<sup>3</sup>/s is enough to support the steady state operation in Carrapateena block cave.

## 2.5 Mine access

Carrapateena block cave enables the 12 Mtpa production throughput and therefore early access to the block cave creates significant value. Multiple mine access methodologies were considered in the design including shaft sinking, twin decline at 1:7 gradient and twin decline 1:6 at gradient. Figure 7 shows the twin decline at 1:6 gradient gives the earliest access to the block cave footprint.



**Figure 7 Mine access option schedule comparison**

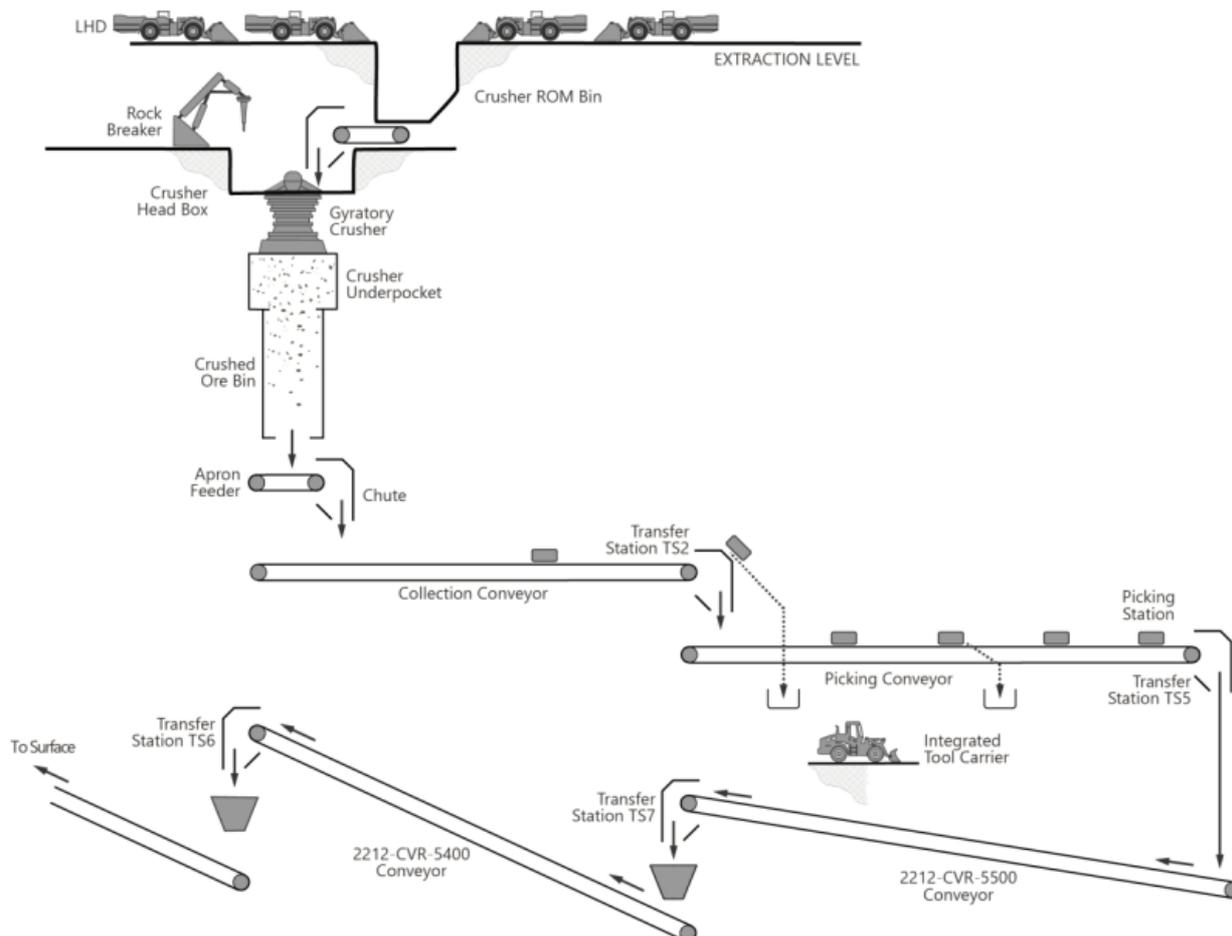
Twin declines at the same gradient also enables multiple crosscuts development between them, which forms a simpler ventilation circle. In Carrapateena block cave design, the access decline services as intake airway, while the conveyor decline as the exhaust airway.

## 3 Underground infrastructure

### 3.1 Material handling system

An off-footprint primary crusher is designed to primarily crush the ore from drawpoints before loading on the conveyor system to haul to the surface in Carrapateena block cave design. The main components of the material handling system can be seen in Figure 8. The LHDs on the extraction level dump the ore into the run-of-mine (ROM) bin directly below the tipples shown in Figure 4. An apron feeder with variable speed drive is installed between the ROM bin and the crusher, which allows the crusher feed to be controlled to

prevent oversize rock into the crusher before broken by the rock breaker sit aside. Jaw Gyratory crusher is selected as the primary crusher for Carrapateena block cave due to its reputation of the high performance achieved. A crushed-ore-bin (COB) provides 1,000 t surge capacity, followed by collection conveyor, picking conveyor and main conveyor system. The system has design throughput rate of 1,850 tph.



**Figure 8 Proposed material handling system**

### 3.2 Mine dewatering system

The GEHO pumps are designed for the permanent dewatering system due to its high reliability. The dewatering requirement is estimated based on the development and production drilling, drawpoint dust control and underground aquifer. To provide maintenance flexibility and risk control on the unplanned outage, additional pump capacity is installed as standby. The duty and stand by pumps make up the total primary pumping capacity for block cave.

The dewatering on the extraction level is managed with the secondary pumping system. The water drains away from the crusher, which not only protects the critical infrastructure from the risk of underground flooding, but also allows the extraction level to be used as surge capacity.

### 3.3 Mine refrigeration system

Refrigeration plant is required to supply chilled air to BC operation in Carrapateena. The cooling requirement varies based on the air volume requirement and mining activities at different stage of the life-of-mine. Current SLC operation has a 9 MW refrigeration plant in commissioning, which will provide chilled air to support the block cave decline development. The SLC refrigeration plant can be expanded up to 18 MW capacity with reasonable low cost as the major infrastructure has been set up to support it. Additional 6 MW

cooling capacity is required if the SLC still needs to use partial of the 18 MV cooling at the development stage of the block cave.

### 3.4 Mine raw water system

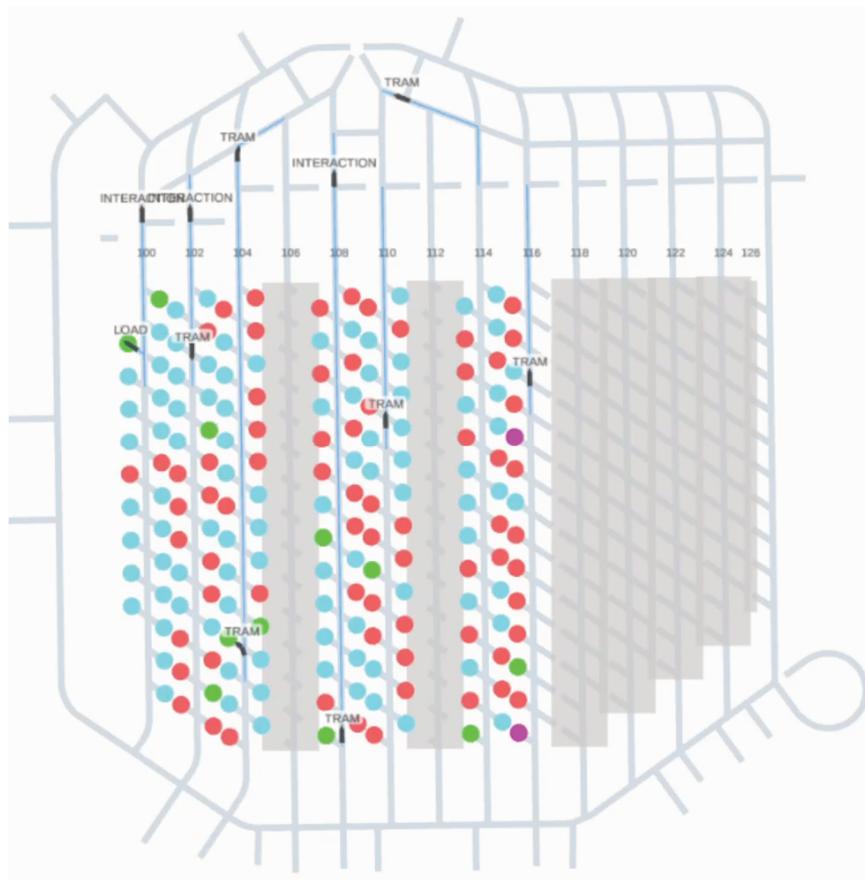
The peak water usage is estimated based on the underground mine activities. The underground raw water system supplying is designed to distribute raw water for the block cave development and production activities, dust suppression and washdown. All critical infrastructure areas that equipped with fire suppression system will have the water supply from a dedicated fire water network. Underground break tanks are planned to manage the pressure of the system.

## 4 Production simulation

A simulation model has been developed to define the number and size of equipment and the interaction on the extraction level to meet the target production rate of 12 Mtpa at the steady state. The model focuses on LHD movement, drawpoint access and interface with material handling system.

### 4.1 Model inputs

The block cave extraction level is configured to represent the real LHD movement from the drawpoints to tipples. As shown in Figure 9, the extraction level is set up as a path network with extraction drives, access to drawpoints, tipples and turnaround points. Logic is assigned prevent the interaction between LHDs and network lockups via the management of the occupation of paths. An LHD can only continue the running cycle between an allocated drawpoint and a tipple when it has access to both.



**Figure 9** Production simulation on extraction level

The ratio bogging methodology (Donaldson et al. 2021) is applied to inform the best drawpoint to place the draw order when the tonnes in previous drawpoint is bogged out. This can prevent the excessive bogging in any single extraction drive and maintain the even draw strategy.

The detailed breakdown of the LHD movement is used as inputs in the simulation. The cycle time is built up with the bogging time, acceleration, tramming, deceleration and tipping. The bucket fill factor is applied to estimate the tonnes moved per running cycle.

The LHD is assigned to the drawpoint with a draw order based on below inputs.

- Drawpoint availability and extraction drive availability – this is impacted by the hangup frequency, secondary breakage activities, mine service work and road work. The inputs are informed by forecasts and industry benchmark data.
- Draw order size – this is the maximise tonnes that can be bogged from a drawpoint before LHD has to move to another drawpoint. It is determined by the mine plan and industry benchmark data.

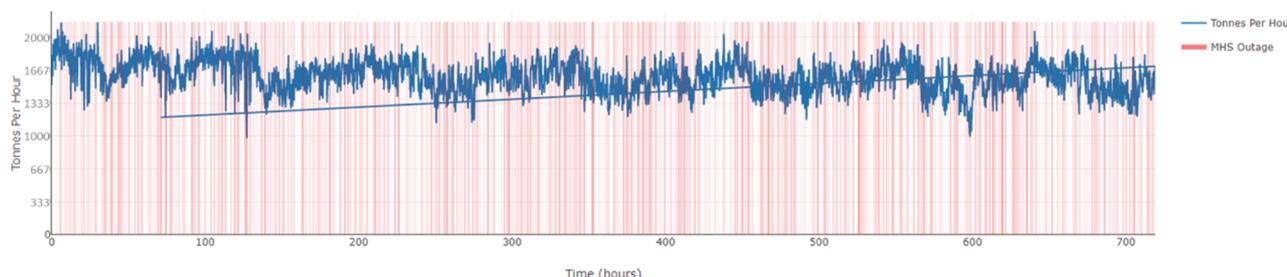
## 4.2 Model outputs

Both diesel and electric LHDs are simulated on the designed extraction level. Table 1 states the simulation results as the fleet number required to meet the target production rate of 12 Mtpa and other scenario analysis.

**Table 1 Simulation results**

LHD Type	Diesel LHD	Diesel LHD	Electric LHD	Electric LHD	Electric LHD
Payload (t)	21 t	21 t	18 t	18 t	14 t
Fleet Number	6	7	6	11	13
Achieved Production Rate (Mtpa)	Yes	Yes	No	Yes	Yes

The interface with the material handling system is shown in Figure 10.



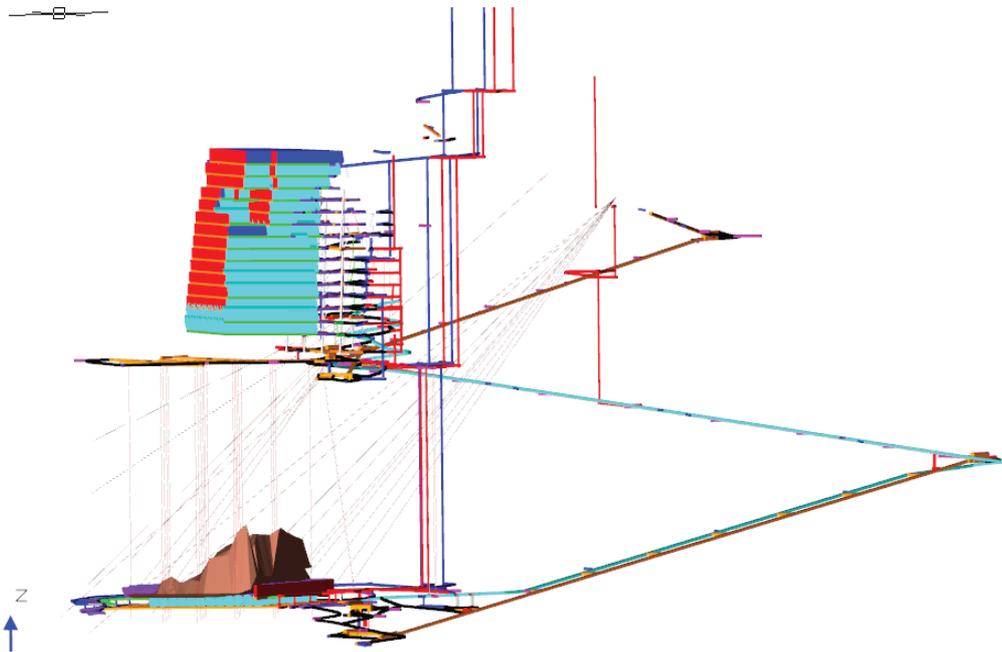
**Figure 10 Production rate in simulation using 21 t diesel LHD**

## 5 Mine schedule and transition from SLC to BC

The block cave will be mined below current sublevel cave operation. During the block cave establishment period, Carrapateena will keep producing tonnes and metals from the upper SLC to ensure a smooth production transition from the SLC to block cave.

The planned time to stop SLC production is assessed based on the block cave propagation and geotechnical risks. A more detailed analysis of this decision and its economics is discussed in Pitcher and Hocking (2022). It can be seen in Figure 11 that the cave height still has enough distance to the SLC level when SLC production finishes. The sublevel cave to block cave transition maintains continuous ore production during the project, with the sublevel cave ramping down when the block cave rate exceeds ~5 Mtpa, and means the sublevel cave activity finishes approximately 12 months prior to geotechnical connection of the two caves. Proper risk

control will be applied in execution stage to constantly monitor the seismicity response and the cave growth. Therefore, the timely decision can be made to cease SLC operation.



**Figure 11** Indicative block cave height while SLC operation stops

## 6 Conclusion

Block cave is the planned mining method to extract the lower half of the orebody below current sublevel cave operation in Carrapateena. It creates value via the increasing production rate at a lower operation cost and cutoff grade. The block cave mine method also allows the higher-grade ore at the bottom of the orebody to be mined in early stage of the mine life and leaves the lower grade in the middle to the later of the mine life.

The Carrapateena expansion project has the block cave mine designed and planned in the feasibility study, including footprint analysis, detailed mine design and ventilation design. The block cave mine is designed to be accessed via twin declines to ensure the shortest time is taken to develop to the footprint. Detailed engineering work has been completed to support underground infrastructure design including material handling system, dewatering, mine service and refrigeration. To ensure the design can produce the mine throughput rate of 12 Mtpa, a simulation model is built to analyse the footprint, the production fleet and material handling system. As the block cave is developed below the sublevel cave, it has been risk assessed to ensure a successful transition with the ongoing controls in place.

All proposed design in the feasibility study is based on the most updated knowledge and data at the time. With ongoing data collection and learning from the existing operation, OZ Minerals maintains the flexibility to further refine the work where it could while proceeding to the execution phase.

## Acknowledgement

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## References

- Diering, T, Richter, O & Villa, D 2010, 'Block cave production scheduling using PCBC', SME Annual Meeting, Phoenix, Preprint, pp. 10–97.
- Donaldson, SN, Hollies, BL, Wynn, K, Potts, L & Evans, M 2021, 'Real time LHD dispatch optimisation with ratio targets as Newcrest's Cadia Valley Operations', *Proceedings of the Underground Operator Conference, UGOPS2021*, The Australasian Institute of Mining and Metallurgy, Melbourne, pp. 206–213.

- Hocking, RJ, Mooney, AJ & McFadyen, L 2020, 'Hill of Value financial metrics used to optimise the Carrapateena project', in R Castro, F Báez & K Suzuki (eds), *MassMin 2020: Proceedings of the Eighth International Conference & Exhibition on Mass Mining*, University of Chile, Santiago, pp. 1039–1047.
- Laubscher, DA 1994, 'Cave mining the state of the art', *Journal of South African Institute of Mining and Metallurgy*, 1994, vol. 94, no. 10, pp. 279–293.
- Pitcher, A & Hocking, RJ 2022, 'Assessing the risk of a sublevel cave–block cave transition using dynamic decision tree analysis overlain with Monte Carlo analysis', in Y Potvin (ed), *Proceedings of the Fifth International Conference on Block and Sublevel Caving*, Australian Centre for Geomechanics, Perth, pp. 815–824.

