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An iterative design and schedule approach to the E22 block cave project and production planning at CMOC Northparkes Mines: a case study

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Abstract

The scheduling of a block cave mine is an iterative process, ranging from early exploration, sampling and metallurgical test work to conceptual designs encompassing footprint RL, drawpoint layout, development requirements, and production modelling. This paper discusses the iterative approach used by CMOC Northparkes for the mine design and production scheduling of the E22 block cave pre-feasibility study. During pre-feasibility, Northparkes uses the Geovia® Gems Dassault Personal Computer Block Cave (PCBC) software package for production scheduling and Deswik® for development scheduling. In this study, the cave development sequence is optimised by pairing the output of each platform, allowing a coupled feedback loop of scheduling decisions. More specifically, the modelling process at Northparkes consists of several stages, beginning with the initial design, which uses a resource block model and the Gems PCBC software package to determine an appropriate footprint RL alongside an approximate production profile. Once a suitable footprint and drawpoint layout is selected, the Deswik software package is used to create a mine design and development schedule, which are used to identify milestones for future production scenarios and ore flow simulations. It is found that the predominant impact of the development schedule on the production profile is the drawbell opening sequence. There were numerous constraints as to why an assumed opening sequence can/cannot be met. However, by diligently scheduling development, the scope of production scenarios can be limited to achievable plans. As models and simulations are developed throughout pre-feasibility study studies, limitations of production rates, caving sequences and development schedules are identified. These deficiencies are addressed by completing an iterative design and scheduling feedback loop within the production planning environment to produce a realistic mine plan. Northparkes have utilised numerical modelling for verifying production/caving scenarios and to understand the stability of the footprint design. This combined approach identified opportunities and limitations, which have been used to update the subsequent design and schedule iterations, leading to an optimised mine that is supported by realistic assumptions. This approach has allowed Northparkes Mines to progress the E22 block cave from the pre-feasibility study into the feasibility stage with confidence in a robust production and development schedule.

Keywords: *block caving, PCBC, footprint design, scheduling, undercut*

1 Introduction

CMOC Northparkes is a copper and gold mine located 27 km northwest of Parkes in the central west of New South Wales, Australia. Northparkes is a joint venture between China Molybdenum Co., Ltd (CMOC) (80%) and Sumitomo Group (20%). CMOC Northparkes currently operate two block cave mines E48 and E26L1N. E48 block cave is situated approximately 1.5 km north of the completed E26 L1 and L2 block caves, and has served as the predominant ore source since production ramp-up commenced in 2011.The E26L1N block cave is described as a remnant mine extension adjacent to the existing E26 cave, the first underground mine developed at Northparkes Mines. The extraction level sits beneath the E26L1 extraction level and above the E26 Lift 2 North (E26L2N) cave, ore is crushed and conveyed to underground ore bins that feed the hoisting system from which it is processed through the surface processing plant.

E22 is a porphyry copper-gold system where mineralisation is present as a discrete sub-vertical ore zone around a cluster of mineralised monzonite porphyry intrusions. E22 has previously been mined as an open cut since 1993 and operated intermittently over the intervening years, with a final cut-back being completed in 2010. In February 2006, a geological block model and resource estimation were completed for the E22 deposit. This work highlighted the future potential for an open pit cut-back or underground block cave mining. Since then, the E22 deposit has undertaken several study phases. The most recent is the E22 block cave pre-feasibility study (PFS), which intends to progress the block cave mining option through feasibility and development.

As PFS studies progressed, it was clear that as design inputs were refined there was an effect on the schedule and vice versa. Therefore, it was necessary to revisit an earlier stage in the planning process and apply the updates. For example, drawbell sequence and opening rates were adjusted iteratively based on the assumptions used in the production schedule. These were, in turn, validated against the assumptions used in the development schedule. Creating this integrated mine plan helped close the gap between planned and mineable tonnes allowing for realistic optimisation of site production planning.

2 Design process

The design process for E22 has gone through several iterations of geological modelling, flow modelling, numerical modelling, footprint finder, production scheduling, footprint design, development scheduling and cost estimation following the process shown in Figure 1.

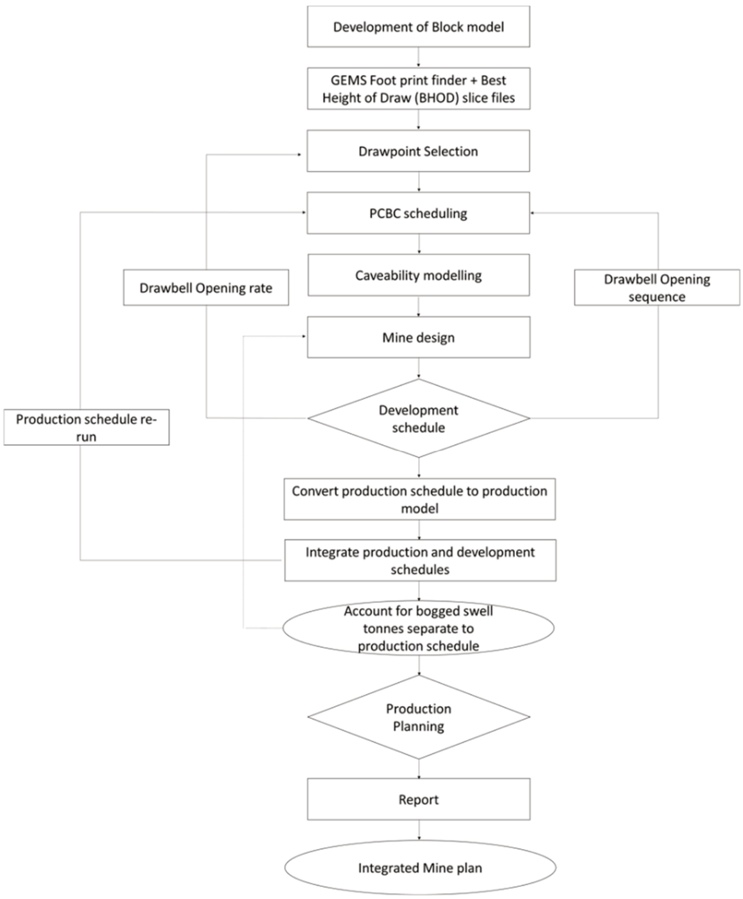


Figure 1 Design process flow chart

Completing each step has delivered improvements to the level of confidence held in the project, the ability of the project to provide ore inventory requirements and adaptations of recent learnings from Northparkes' completion of the E26L1N project.

2.1 The block model

The primary input for the PCBC production schedule is a planning block model. Northparkes conduct block model manipulations to the geological block model within Deswik to create a regularised planning block model which has been modified to include site financial and metallurgical data for use in PCBC analysis, remove air blocks and trim to design surfaces. Prior to using a planning model, a text-based scripting process was used within the Geovia Gems package for slice file generation. Unfortunately the scripting process is difficult to audit as scripts are executed as a background process without visual ques and cannot easily be undone without regenerating the produced slice file. By completing this step within Deswik at the block modelling phase, input parameters can be more easily adjusted, tracked and verified by both graphical display and model interrogation techniques. This change has greatly improved the ability to audit the process, to reproduce and to adapt these parameters for additional models and production scenarios.

2.2 Footprint finder

The PCBC footprint finder module is used to determine the optimal elevation of the extraction level using long-term pricing and estimated footprint costs. The method provides a series of draw scenarios with estimated tonnes and grades. The output, shown in Figure 2, displays the optimal footprint RL range for E22. This figure shows that the 9730 RL provides the maximum tonnage whilst still maintaining maximum net value.

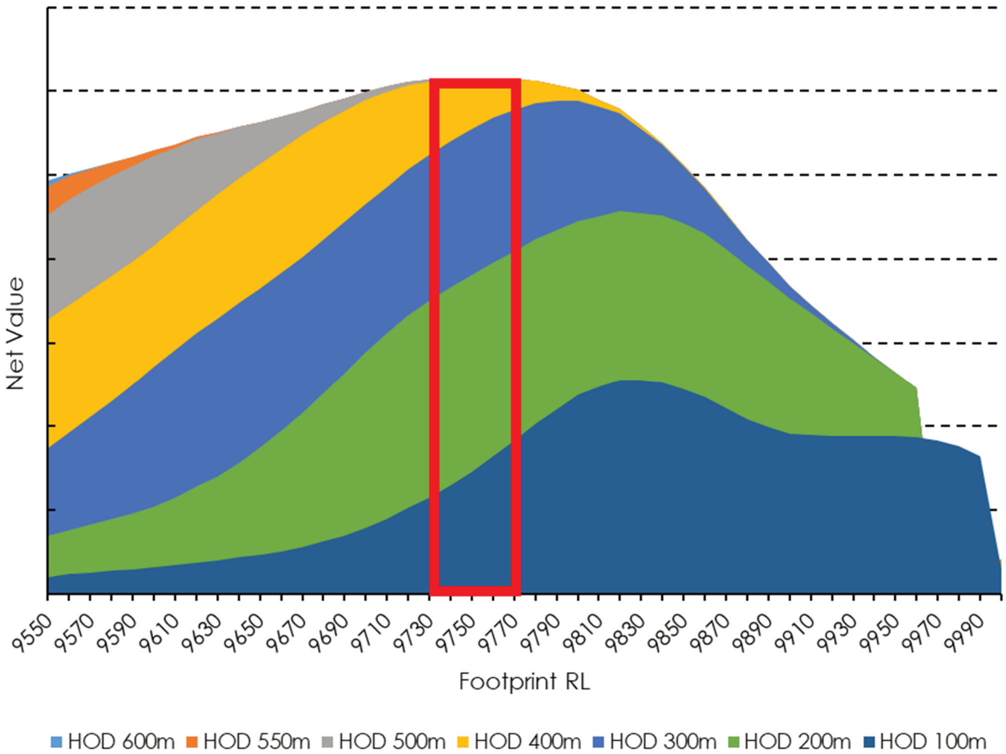


Figure 2 Footprint finder net value results for E22

2.3 Drawpoint selection

Drawpoint selection is conducted considering drawpoint cost of construction, economic margin, minimum span, and footprint shape. This step in the mine planning process may be revisited as detailed cost assumptions are produced alongside refinement of the mine development schedule. E22 has 154 planned drawpoints; the selected drawpoints are shown alongside the excluded drawpoints in Figure 3. Northparkes has found PCBC simulations require drawpoints to cover the extents of the planned cave shape even if not planned to be developed in order for height of draw operations to be performed.

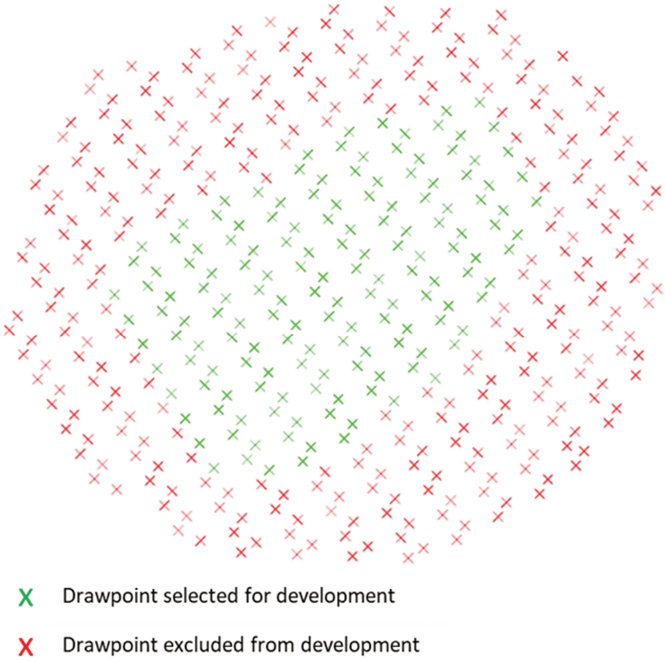


Figure 3 E22 drawpoint selection

2.4 PCBC schedule

PCBC production scheduling is conducted to define mining inventory for the E22 block cave. The software was used to probabilistically model the mixing and flow of material when given a monthly draw target. This information as well as production rate curves and even draw strategies allow PCBC to produce a realistic and development aligned production scenario for an ore resource. Figure 4, shows a typical production schedule for E22, where monthly tonnage targets are met after the initial cave ramp-up.

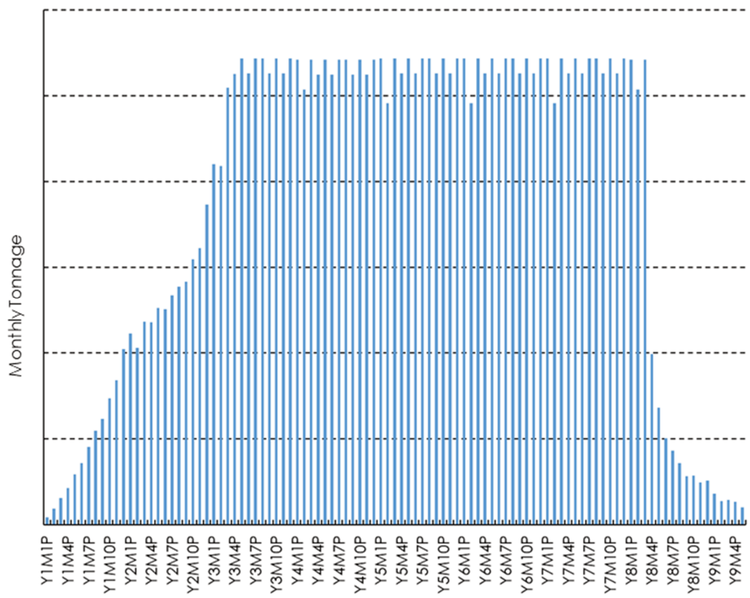


Figure 4 Production profile

2.5 Caveability modelling

After completing several footprint redesigns and initial PCBC analysis, a validation process commenced focusing on caveability modelling. Beck Engineering was engaged to conduct numerical geotechnical modelling for E22. The modelling was performed using the Abaqus explicit finite element (FE) solver to simulate rock mass deformation and cave growth coupled with FS4 flow software to determine material flow and draw. Modelling identified that the east–west drawbell opening sequence as shown in Figure 5, (Beck Engineering 2021), resulted in a flat cave back, undercut front parallel to the extraction level drives, narrow opening area, slower propagation and higher abutment loading. These conditions for cave establishment are unfavourable as they slow cave propagation to surface and concentrate stress across the extraction drives and drawpoints. The east–west opening sequence was initially driven by mine scheduling and prioritisation of critical path areas of the footprint.

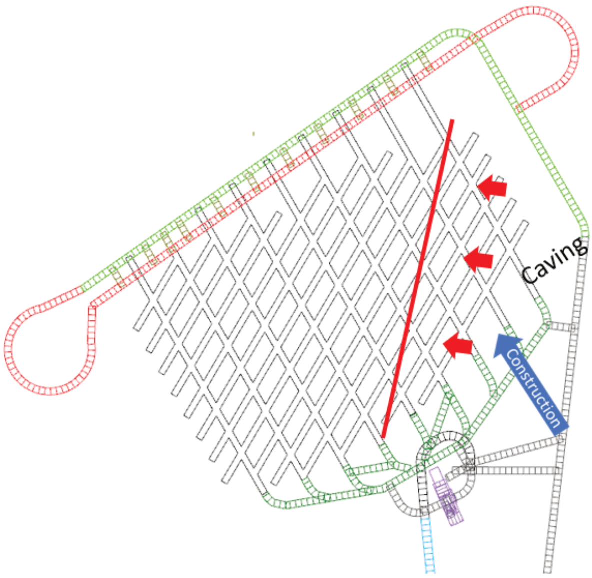


Figure 5 East–west sequence early cave establishment and drawbell opening sequence

However, this sequence causes narrow sections to form on the footprint prior to reaching critical hydraulic radius leading to arching and delayed caving, followed by rapid increase in footprint spans (Figures 6 and 7). Overall this modelling outcome triggered a design and scheduling change to address the identified issues.

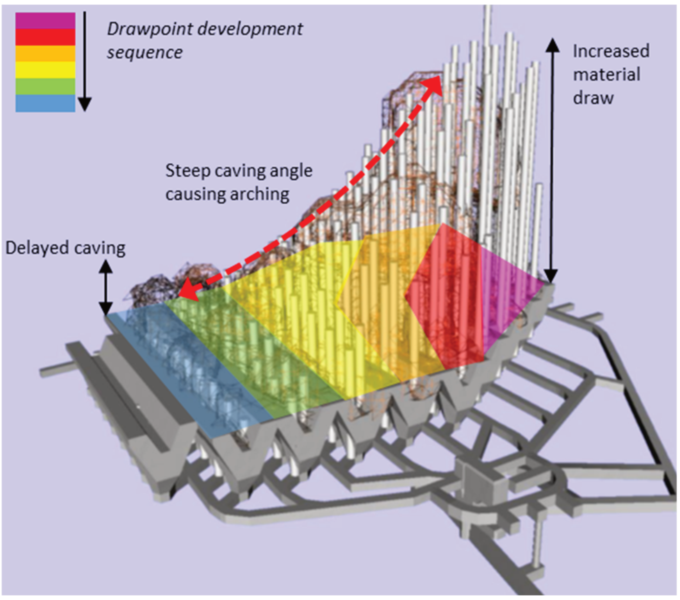


Figure 6 Cave propagation height of draw for the east–west sequence Frame 56

The model simulation identified slow, intermittent and potentially unreliable cave propagation caused by the narrow footprint geometry, which was primarily a function of the starting position and cave establishment sequence in the first design iteration. However, despite some caveability issues during the cave establishment phase for the modelled undercut sequence, the footprint is formed without significant stability or deformation ramifications (Beck Engineering 2021). The second design iteration was created to address the caveability issues identified, which was done by adjusting the cave establishment sequence. This was the driving factor in the altering the cave starting position to a central chevron shape and he according adjustment made to undercut sequence to reduce cave stall and airgap potential at a pre-feasibility level.

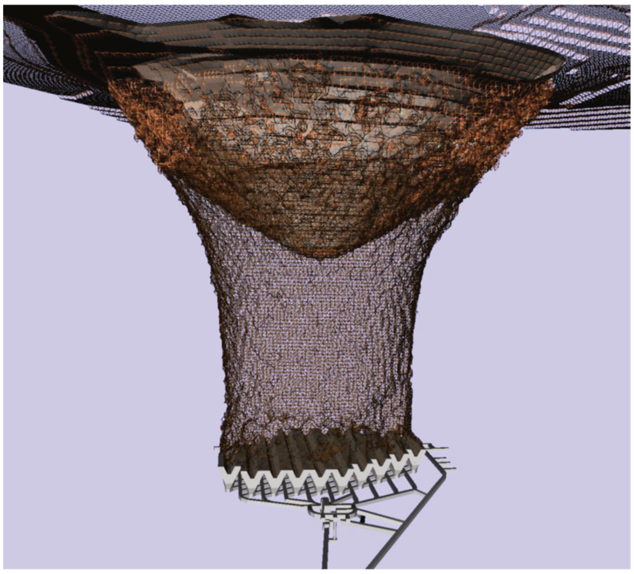


Figure 7 Cave shape Frame 130

3 Opening sequence

The schedule was updated to reflect the central chevron shape drawbell opening sequence Figure 8. This required schedule priorities for ventilation and equipment resourcing constraints to be applied. The proposed opening sequence with a constrained drawbell development sequence was rerun as the PCBC production schedule.

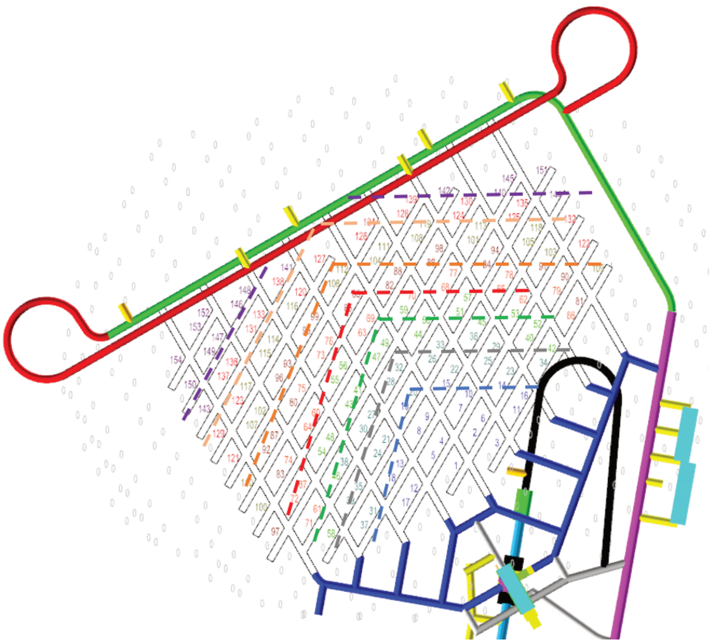
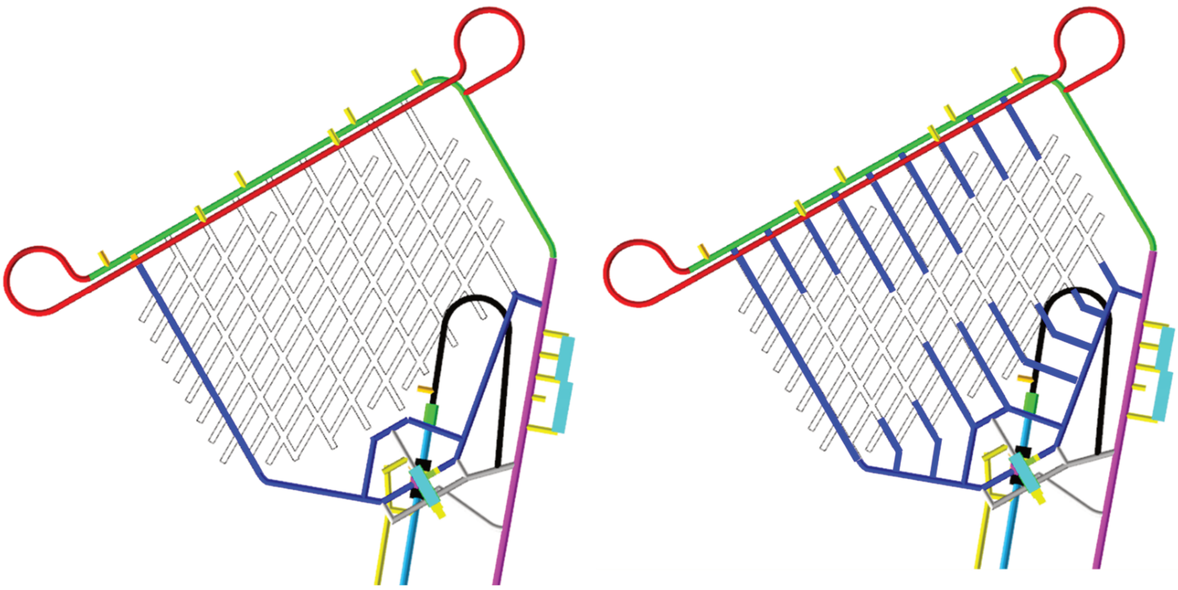


Figure 8 Drawpoint opening sequence

The mining development sequence was constrained to establish access and ventilation across the footprint Figure 9. This sequence changed the initial draw belling rate used in PCBC; due to this change a new iteration of the production schedule is required to deliver the schedule alignment required for cost estimation purposes.



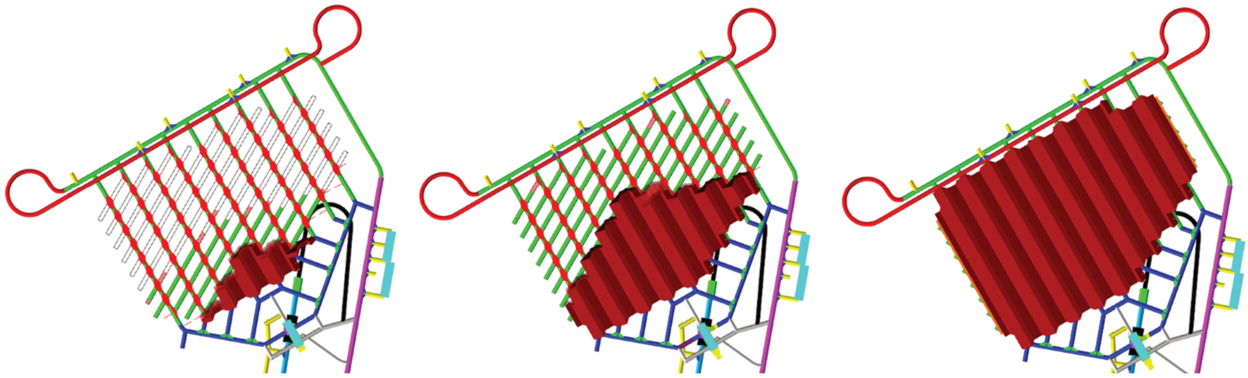
(a) (b)

Figure 9 E22 Footprint development sequence. (a) Establishment of access across footprint; (b) Prioritisation of central extraction drives to commence development of chevron development

The selection of cave initiation point for the undercut and preferred direction of undercut advance can be influenced by several factors (Brown 2003) including the shape of the orebody, distribution of grades within the orebody, in situ stress directions and magnitude, strength of the orebody and its spatial variation, Location of mass excavations and critical infrastructure, presence and orientation of major structural features in the orebody, and presence of caved areas adjacent to the block or panel to be undercut. Additionally, empirical caving classifications revealed a critical hydraulic radius for the rock types at E22 of 25 m (Laubscher 1990) and 26 m (Mathews stability from Trueman & Mawdesley 2003). These values, when compared to the footprint hydraulic radius of 52 m, means that early caving will be controlled more by geometry and structure than by minimum span. The chevron sequence enables the uniform growth of the hydraulic radius of the footprint and facilitates even cave propagation. For E22 the cave initiation point is located in line with the crusher on the southern extents of the footprint, mine development sequencing has prioritised development of the central extraction drives as shown in Figure 9b to target the updated chevron shape of the drawbell opening sequence.

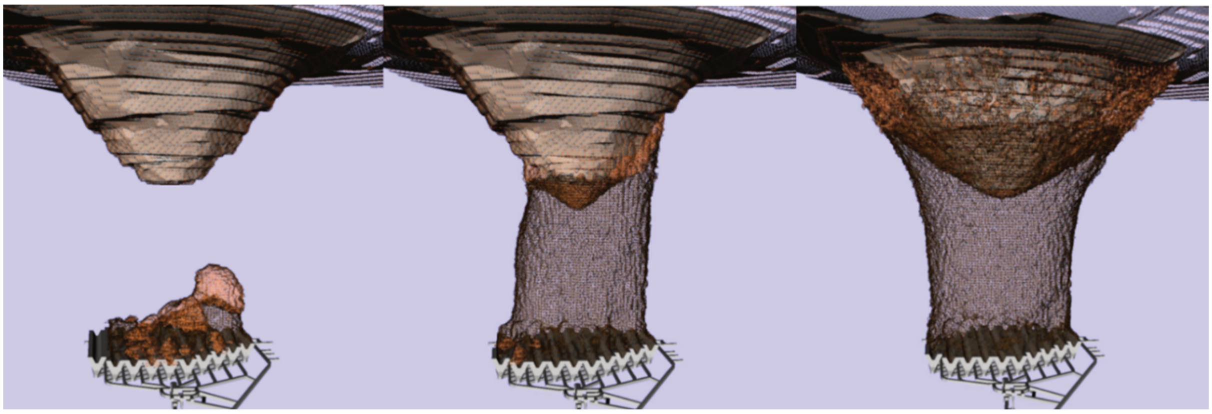
The chevron opening sequence has been selected to promote cave propagation as footprint geometry and avoidance of long narrow areas have been shown to be more favourable for cave propagation (Beck Engineering 2021). Additionally, the centralised starting point of the schedule targets the early establishment of high grade and high tonnage drawbells as a priority in the production schedule and avoids adverse interaction between the cave front and major faults (as far as practical).

This modelling work required an update to the design schedule where scheduling rules were adopted to manage the start of undercutting starts and advances in relation to exterior undercut drill drifts and the development of drawbell and extraction drift roadways as shown in Figure 10. The resultant cave propagation through to surface and resultant finial cave can be seen in Figure 11.



(a) (b) (c)

Figure 10 Chevron opening sequence. (a) Development prioritised at southern extents closest to crusher; (b) Chevron shape is maintained as a development front; (c) Completion of footprint development



(a) (b) (c)

Figure 11 E22 Cave progression. (a) Cave initiation; (b) Pit breakthrough; (c) Final cave shape

4 Mine design

The E22 project has undergone several study phases; the most recent PFS design (specifications listed in Table 1) featuring an El Teniente layout for the extraction level at a 30 × 18 m spacing consisting of nine extraction drives. Drawpoint spacing has been determined based on experience at Northparkes with the E26 and E48 cave footprints, confirmed by numerical modelling which found drawbell spacing to be of appropriate geotechnical stability (Beck Engineering 2021).

Table 1 E22 design specifications

Feature	Value
Layout	El Teniente
Extraction drives	9
Number of drawpoints	154
Drawpoint spacing	30 × 18 m
Drawbell development sequence	Chevron south to north
Undercut type	Inclined sawtooth
Development type	Advanced undercut

The undercut design for E22 is an advanced undercut narrow inclined 'sawtooth' pattern with a single drill drive per drawbell (Figure 12), design adapted from the recently completed E26L1N project, a long and short configuration of the undercut has been used to allow a wider width that will be less prone to bridging against a narrower undercut shape and provide a large major apex pillar for long-term integrity.

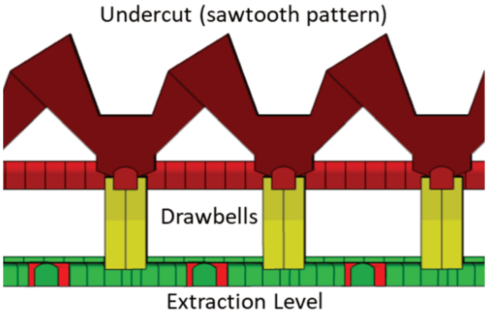


Figure 12 E22 undercut

5 Block cave, production planning schedule integration

Northparkes undertakes block cave production scheduling using PCBC, with each cave being scheduled in a separate file. Typically PCBC schedules would be exported and formatted within an excel spreadsheet for use during production planning activities, in order to improve this process the PCBC production schedule has been adjusted for use within Deswik to allow multiple ore sources to be scheduled together with reduced scope for data handling errors. This has been achieved by formatting the production schedule into the structure of a block model as shown in Figure 13, where blocks are aligned to the centroid of the planned cave shape, the cave shape solid has been cut into slices to intersect the production model without overlapping, each block represents one month's production.

The resultant block model referred to here as the production model, is interrogated directly to a solid within the cave shape in order to retain mining inventory as reported in the production schedule. With production and development schedules now laying within the same schedule file it is possible to apply scheduling rules which align mine development and drawbell sequencing milestones with planned production horizons.

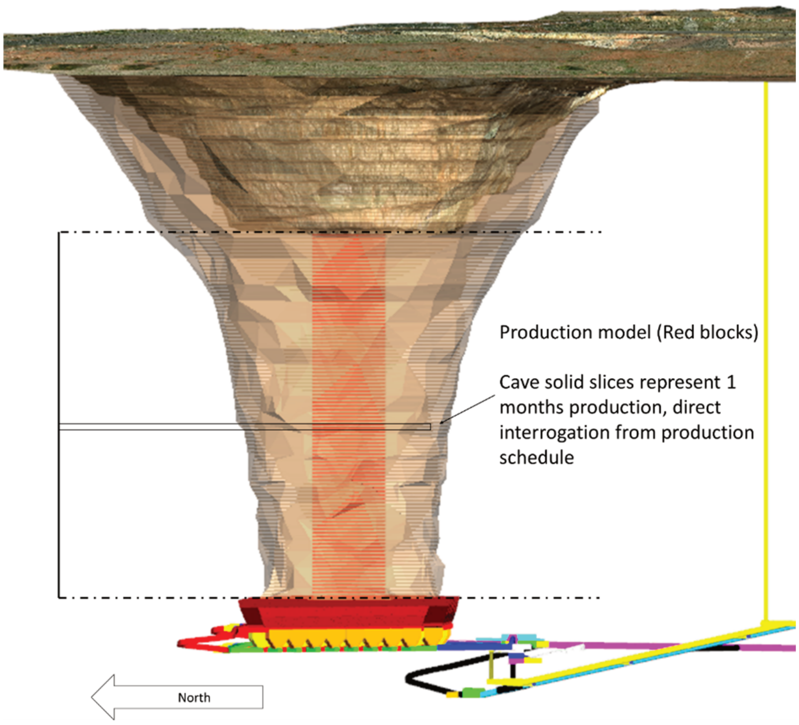


Figure 13 E22 production model

Once the production model has been integrated into the development schedule file the link between drawbell development sequence and starting production can be fixed, allowing the ore source to be moved within the site production profile (Figure 14), and retain consistent relative start dates.

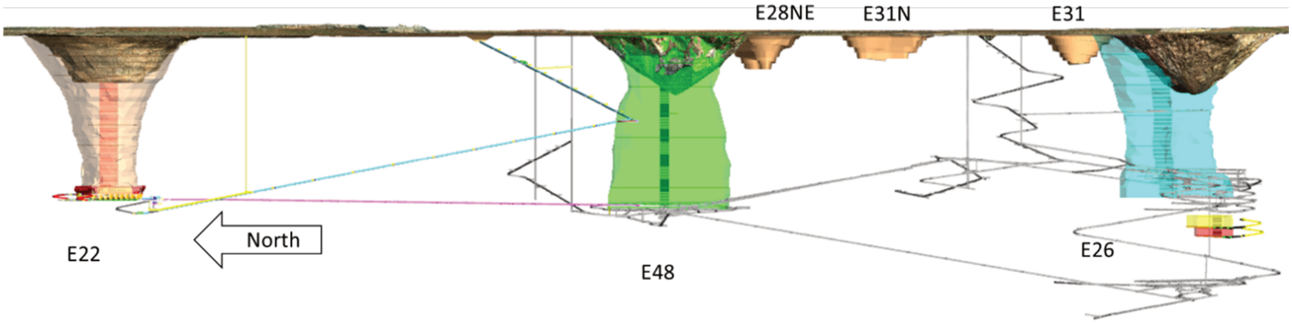


Figure 14 Northparkes mining projects scheduling

As this method brings the missing piece of data into the mine design and scheduling package, multiple resources can be scheduled. For Northparkes this includes open pits, Block caves, sublevel caves and surface stockpiles. By inputting site geological, financial metallurgical performance data, it is possible to complete rapid optimisation works without rerunning PCBC or individual development schedules for each iteration. In addition, tonnes from undercut swell bogging can be audited, as scheduled material is reported separately and checked, preventing double accounting of reserves.

Implementing this process has allowed interrogation of the production and development schedules which identified issues with total tonnes scheduled not equalling reconciled tonnes; misalignment of schedule with mining in the field; roadway intersections typically mine a chamfer to radius turn, in practice however, this is often not accounted for within a schedule; and drawbell designs used for early development schedules are often simplified for ease of scheduling but not matching as-built designs leading to fewer tonnes being scheduled. Upon identifying these shortfalls, redesign and scheduling work can be completed with results updated to the production schedule.

6 Conclusion

The scheduling of a block cave remains a complex process requiring several stages of data reconciliation, modelling, design and scheduling. In addition, a change to any single area will require checking assumptions and analysis to be re-completed on previous steps.

Conducting this iterative design process for the E22 PFS has identified that integrating production data into a development schedule allows ore inventory accounting issues to be readily addressed. This has improved project confidence and reduced rework for the mine planning process. Undertaking the method has yielded further improvements by addressing cave establishment point and drawbell sequencing, drawbell development rate improvements through opening multiple cave fronts, the gap between assumed and scheduled drawbell sequencing by feeding scheduled rates into production simulations affecting production ramp-up and draw strategy has been modified, auditability of tonnes remaining in undercut from bogging material versus tonnes in the production schedule, mis-accounting of design string centreline against surveyed development metres, and exporting production slices to a block model for importing into design/scheduling software, allowing scheduling of multiple ore sources within a single software package.

Northparkes are using the learnings from the project for upcoming optimisation of mine development and production start/finish dates for site production planning, with the integration of ore inventory between underground, open pit, and surface stockpiles now being contained and optimised within the scheduling package.

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