doi:10.36487/ACG_repo/2063_01

Learnings from mining cave extensions at Northparkes Mines and new technology to improve the value of future cave designs

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Abstract

Northparkes Mines are located 27 kilometres north of Parkes in central New South Wales, Australia. The operations consist of two block caving areas, one sub-level cave and a 6.5Mtpa ore processing plant which produces high-grade copper and gold concentrate. E26 block cave mining began in 1997 and the ability to extend cave footprints and utilise existing infrastructure has been successful in providing continual ore sources and value, along with several technical challenges. Northparkes is currently developing the next extension, E26 Lift 1 North, and first sub-level cave from the system. Before these extensions, 46 Mt of the planned 61 Mt had been produced from E26. This paper summarises the improvements and learnings from cave extensions for undercutting and extraction level geometries, designing for ingress of old cave material, cave back growth, and mining high lift draw bells amongst remnant infrastructure. Changes to electric loaders and automation technology are revisited against the layout of future extraction levels. The paper also explores the process of realising the value of remaining cave material through the creation of a residual model of remaining grade using cellular automata. Near mine exploration indicates a continuation of mineralisation to the north and east of E26 making the success of recovering reserves from extensions and capital cost management important to the longevity of the business.

1 Introduction

Northparkes Mines has been mining for 26 years and continues to find economic mineralisation at the periphery of existing underground mines. The perimeter infrastructure to block caves is capital intensive, and to gain efficiencies through mining rates, the crushing and hoisting systems involve large excavations. Positioning cave extensions around such infrastructure makes designing the mine akin to remnant mining and further increases the number of considerations for mine design. Extensions do however benefit from the existing infrastructure of declines and material handling systems to reduce the upfront capital and lead time for a cave.

Northparkes mine design extension learnings are shared in this paper from the mining areas of E26 Lift 2 North (E26L2N), E48 Extension, E26 Sub Level Cave (SLC) and E26 Lift 1 North (E26L1N) construction to date (Figure 1).

Another key aspect of mine extensions is the characterisation of the original caved material and how it will interact with the new cave. To mitigate the risks and predict the behaviour of old cave material in E26L1N the mine design had to also consider the aspects of undercutting geometry, drive orientation, cave edge ground conditions, dilution, cave backs buttressing, inrush and blockages to material handling systems. There is value still in old caved material for Northparkes and this has been quantified through a residual cave grade model. The construction of this model is also discussed in this paper.

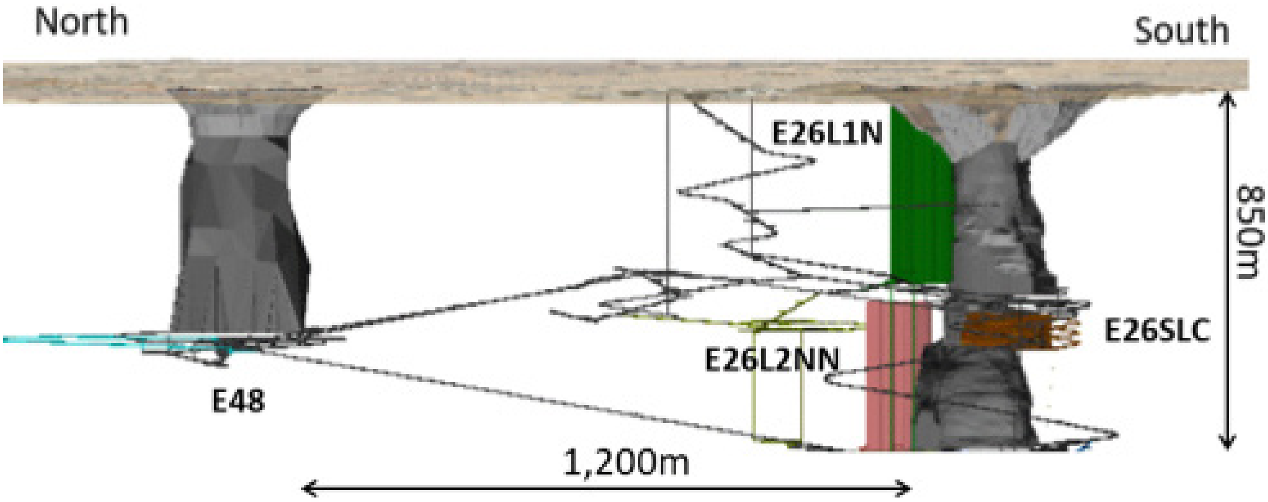

Figure 1 North South section through E48 and E26 caving areas

2 New cave infrastructures amongst existing infrastructure

The orientation of the extraction and undercut level drives are typically placed considering the orientations of the ore body, principal stress, major geological structures and ore haulage distances. Designing a cave footprint amongst existing infrastructure and caved rock limits the orientation options and requires a rethink of how the extraction level would traditionally operate, particularly for ventilation and loader automation zones.

2.1 E48 block cave and extension

E48 block cave was commissioned during 2010 with a reserve of 56 Mt of copper and gold ore. The extraction level layout has access drives on the east and west providing access on both sides to the extraction drives. The material handling system comprises one crusher located on the western side of the extraction level (Figure 2). App production from E48 is produced using automated, electric, Sandvik loaders. The 13 extraction drives are split into 4 production zones to manage production traffic and interactions on the level. The electric loaders are tethered with the cable reel at the rear of the loader supplying power from a gate end bays on the eastern side of the extraction level. The loader operates in one direction dumping into the crusher on the western side of the extraction level. The draw points are herringbone layout and face open to the east which is determined by the gate end bay as the cable must be behind the bucket when bogging the draw point.

E48 extension was mined as Herringbone layout for one drive in the south and El Teniente layout in two northern drives to trial a range of draw point turn out angles with automation. This layout required gate end bays on both sides of the extraction level for bogging draw points facing west and east. These mine extensions risked incomplete caving and a hydrofracture program was performed to mitigate this. The mining of E48 extensions is further detailed in Snyman et al, 2016 and Webster et al. 2016.

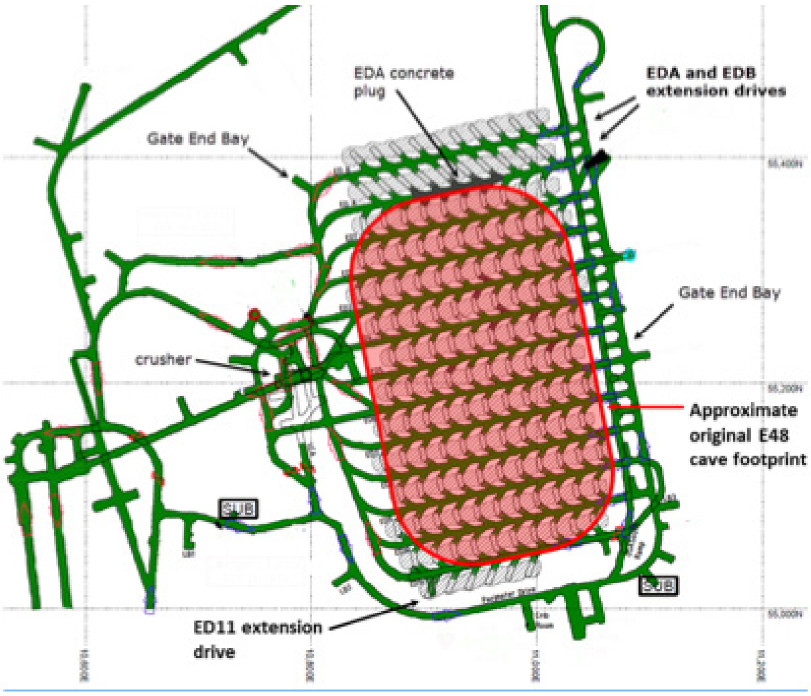

Figure 2 E48 extraction level – 9,700 m RL. EDA = extraction drive A, EDB = extraction drive B, SUB =electrical sub station

2.2 E26 block cave extension

Designing the new cave abutting against the existing E26 cave reduced the number of edges that can be accessed around the footprint. This is seen in Figure 3 where to allow access to both ends of the extraction drives allowing flow through primary ventilation to be established across the level drives need to be oriented east-west. Risks to this design were loss of drives on the southern side against the existing cave edge. Ground conditions and modelling indicated this was a real risk to the design. An additional consequence of losing access through these drives, with a tethered loader, is that mining from the blocked eastern side of the footprint would need cables to extend through an adjacent, intact drive and around to the eastern draw points. Such scenarios are currently performed at E48 however production rates in these areas are lower than dual access drives. Should the connection be lost to two drives from the cave edge then the life of mine production rates for the cave would be at risk.

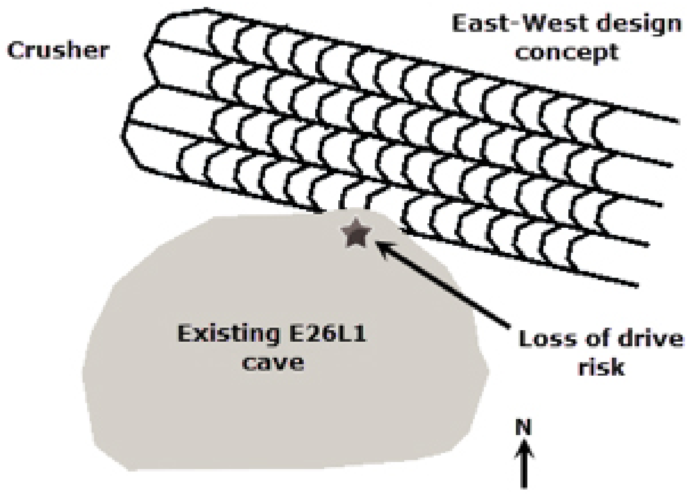

Figure 3 E26L1N East-West drive orientation concept design

Orienting drives north-south removes access to the south side, introducing entrapment risks and secondary ventilation requirements to the drives end against the cave (Figure 4). The risk of entrapment during production is reduced using automated loaders however personnel access for monitoring, inspections, secondary breakage and maintenance is still needed. Monitoring technology planned for the project aims to eliminate the presence of people from performing these tasks on the drive. Where technology cannot eliminate the task, trigger action response plans (TARP) are used for managing risks of fines inrush, rockfall, and equipment fire.

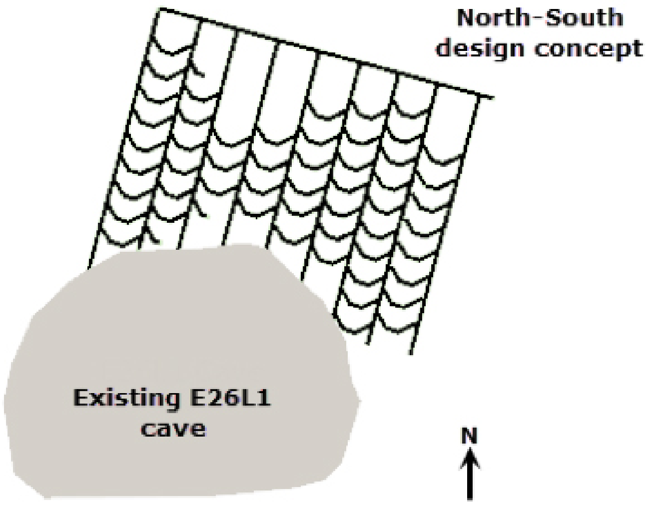

Figure 4 E26L1N North-South drive orientation concept design

Single side extraction level access changes how automation zones are set up and additional tip routes drives (and associated capital) are included to allow multiple tethered loaders to work in single automation zones. With battery technology developments, Northparkes has further adjusted the mine design to be optimised for untethered then battery loaders when efficiencies are proven. This has allowed constraints on the design detailed in this paper to be removed for draw point layout, automation zones and gate end bay locations.

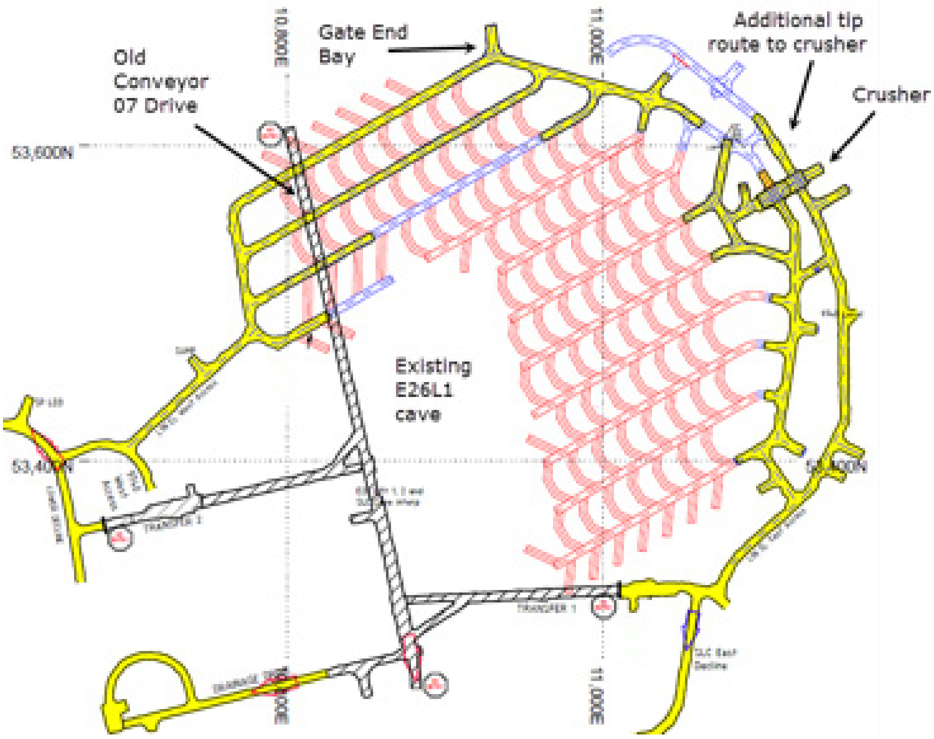

Figure 5 E26L1N extraction level – 9,760 m RL – Design September 2019

3 Undercutting geometry

The experience from undercutting parallel to an existing cave boundary is that post undercut method introduces issues, where finely fragmented cave edge material can flow preferentially into the undercut blasted space limiting the clearing of swell and creation of free space for the next firing. This was observed with E48 extension post undercut with holes drilled down from the undercut drive (Figure 6). After ring firing the swell of the blast was cleared from the draw point in the extraction level below (EDA). Where the first drive extension adjoins the cave edge, newly blasted undercut material is fired against finely ground material at the cave boundary. When bogging from the new draw point below, the fine material flowed preferentially making the clearing of the undercut swell ineffective. Additional slashing rings were fired in an attempt to move the undercut material with mixed success. Following the completion of undercutting, the convergence of the extraction drive increased significantly and was unable to be reduced by draw control leading to the decision to plug the drive with concrete (EDA concrete plug Figure 2). It was concluded that this portion of the undercut was not continuous and formed a bridge transferring load onto the extraction drive.

E26L2N extension was formed with advance undercut geometry. The advance undercutting utilises blast holes drilled up from the undercut drive. After firing the undercut rings, the swell is bogged from the undercut drive to create room for the next ring firing. This allowed freshly blasted undercut material to be cleared ahead of the finer cave material behind the blast. Although fines material can flow preferentially to coarser material, the geometry allowed sufficient undercut swell to be cleared and the void created for subsequent undercut ring firings (Figure 6).

From these learnings, an advance undercut geometry is adopted for E26L1N to increase the likelihood of complete continuity of the undercut, particularly against the old cave.

4 Growing a new cave or growing a cave extension

Analysis was performed to weigh up if the E26L1N cave extension would behave as a standalone block cave footprint or an extension to the existing block cave. A risk to the stand-alone cave was the limited span or hydraulic radius of the footprint that may result in cave stall. E26 Lift 1 cave experienced cave stall and catastrophic, sudden cave back collapse in 1999 from a footprint with a hydraulic radius of 43 m (Ross & van As 2005) and minimum span across the cave centre of 150 m.

The E26 SLC wraps around the E26 lift 2 cave and contains a footprint HR of 25 m and minimum span of 60 m. The caving outcome of this mine held some uncertainty as to if it would behave as a standalone span or if the existing cave would contribute to the instability and assist in caving. The SLC is now producing from its fourth level and the crown pillar has caved through to the E26 L1 extraction level above it.

The new E26 L1N design has a footprint hydraulic radius of 47 and a minimum span across the cave centre of 110 m. The new cave, including the existing E26 lift 2 cave area, has a hydraulic radius of 60 m and minimum span of 145 m. It is understood that only the actively drawn footprint areas are to be considered when calculating the caveability hydraulic radius. The SLC did, however, see instability on the northern edges from abutting against the discontinued E26 cave.

In 2019 low production resumed from the E26 lift 2 cave and although the level of production is unlikely to reach to the level of E26 L1N, the broken material is assumed to again assist caving where E26L1N abuts against it.

Modelling of the E26L1N caveability indicated that continuous caving would occur however early years require a measured ramp-up of production to allow propagation and to minimise lateral movement and ingress from the old cave (Beck 2017).

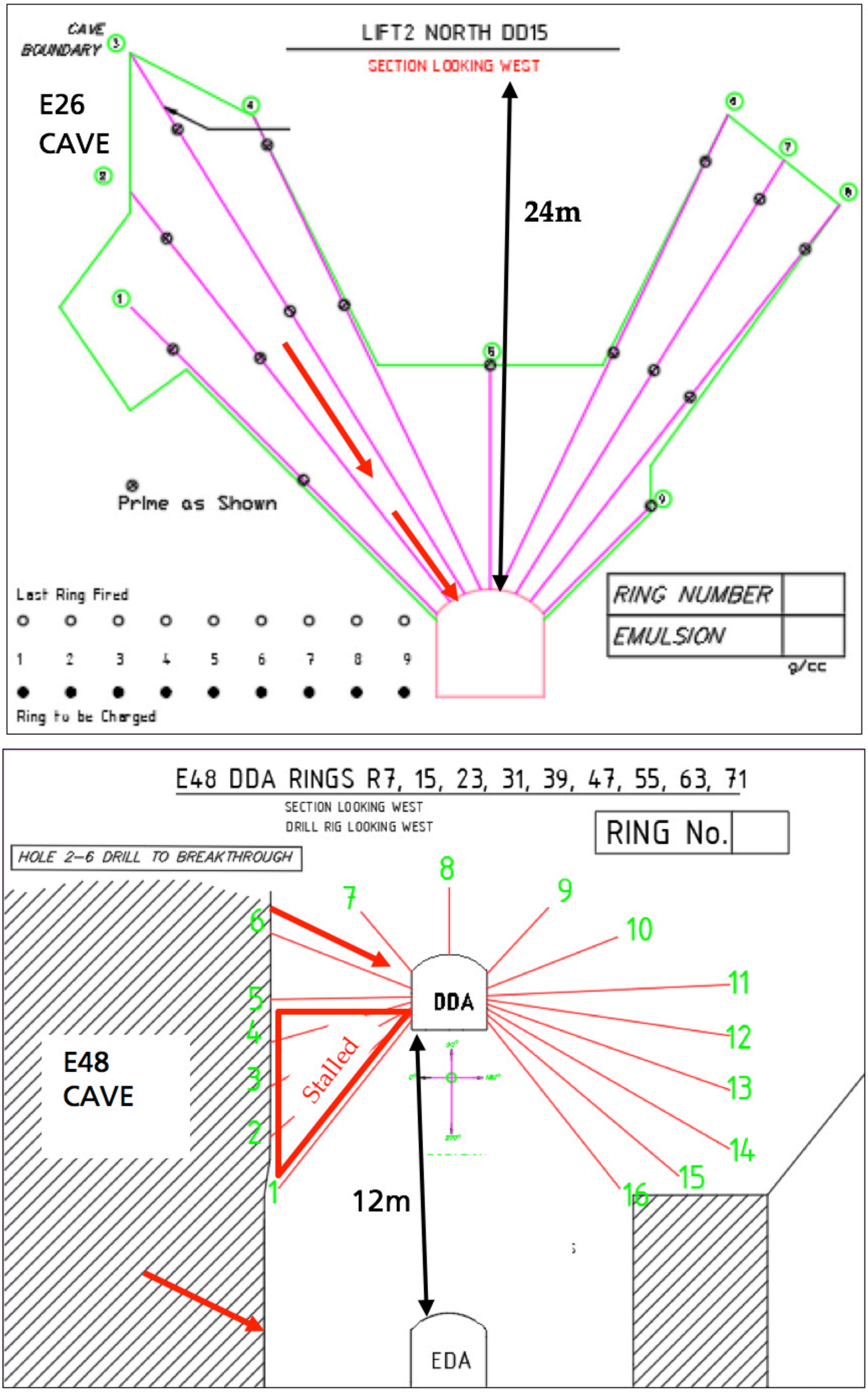

Figure 6 **Undercutting parallel to existing cave boundary showing blasted material flow in red arrows in E26 Lift 2 North (top) and E48 extension (bottom)**

Scenarios of leaving a pillar between the caves to create a standalone new cave were explored with inventive mine geometries. These designs however introduced risks of concentrating stress onto a separating barrier pillar and loading the extraction level, potentially increasing seismicity and infrastructure damage. This design introduced more risks and costs than it eliminated and thus the pillar between cave footprints scenario was not pursued.

Modelling of the cave extension did highlight that the cave extension risked incomplete recovery of the reserve from cave back arch over (Figure 7). This scenario directly involves the ingress of old cave material buttressing the growing cave back through filling any air gap and diluting ore. An extensive part of the E26L1N study included characterising the old cave material, a mixture of E26 cave and surface oxide. This characterisation looked at re-estimating the metal balance, quantifying the material properties and re-designing solutions to material handling system (MHS) issues that had ceased production from this cave in the past. Through designing the MHS to better manage this material, the dilution ingress could be accommodated rather than not tolerated as in the past.

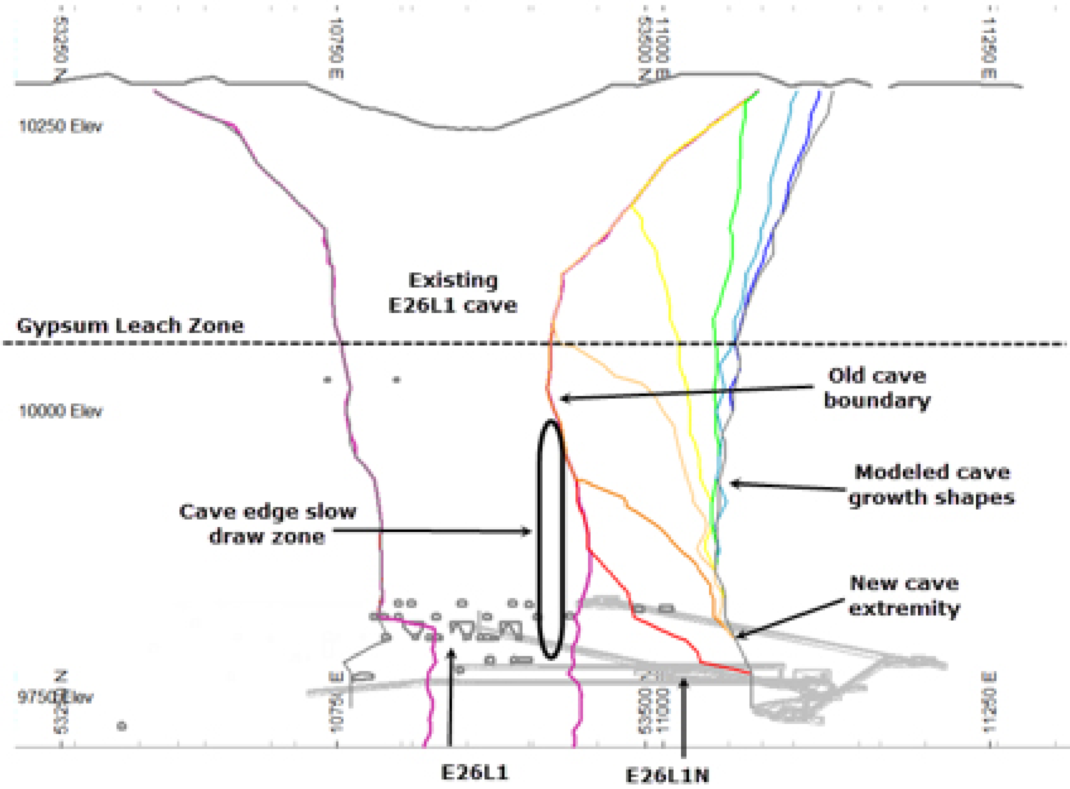

Figure 7 **Vertical section parallel drive and through the crusher. Cave growth sequence shows arch over of the cave through to cave break back**

A draw strategy that considers geomechanical properties of cave growth and cave maturation is incorporated into the mining schedule. The draw strategy specific to E26L1N increases draw at new cave extremities and decreases draw at the old cave boundary. At this old cave boundary, a 'crush pillar' or a slow-moving cave zone will be maintained between the old and new cave. This low draw area allows shedding of built up stress as well as reduced lateral movement of diluting material. The higher draw at the new cave extremity aims to create conditions to promote caveability through continual removal of ore and maintaining a manageable airgap for further cave growth. Achieving the greatest cave growth and reserve recovery also relies on the complete connection of the undercut through to the old cave and removing convoluted shapes from the footprint perimeter. The chosen economic footprint aims to balance excluding uneconomic draw bells from the perimeter while still maintaining spans to place the rock in the unstable and caving domain.

The E26 caving area is hosted in volcanic and a monzonite intrusive sequences. Historically volcanic units cave preferentially to the monzonites so the more competent monzonite is targeted for preconditioning using hydrofracturing. The focus of the treatment is cave edges susceptible to arch over. Undercut sequence starts in volcanics and moves towards monzonite intending to put caving stress to work in damaging this more competent unit. The cave growth needs to be sustained for 300 vertical metres until the highly fragmented gypsum leach zone is reached, upon which rapid vertical caving occurs (Figure 7).

To manage the cave during the growth stage, cave back and cave flow monitoring tools are installed. The production rate is fixed at 3.5 Mtpa until the cave back has arched indicating likely recovery of the reserve. After this occurs the draw call and production rate can be increased and less constrained. The monitoring installations aim to give the mining team the best information they need to manage the cave in this fashion.

5 High lift draw bells amongst remnant infrastructure

Positioning the undercut and extraction level between infrastructures brought the need to rethink drive geometries, gradients and drill and blast designs. A challenging area for E26 Lift 1 North is an abandoned conveyor drive (CV07) that traverses through the undercut region of the southwestern side of the cave (Figure 5 and Figure 8). Within this area, the undercut volume could not be blasted to designed height due to the conveyor drive. Considerations for addressing this included backfilling the drive with consolidated backfill and drilling through the backfill to form the undercut or blasting undercut volume situated above the conveyor from the conveyor drive then remainder from undercut dive below. A third option was to trial firing high lift draw bells from the extraction level in the absence of an undercut.

Northparkes has partnered with Orica to establish WebgenTM wireless detonators in the sub-level cave and furthering this work we have since performed a trial with WebgenTM blasts to form a single draw bell and undercut shape in a location at Northparkes. This trial has highlighted that the loading and grouting long holes is critical to success and these learnings will be incorporated into the next Northparkes trial. Successfully blasting from the extraction level to form the major and minor apex geometries is a significant change for block caving designs. The changes are envisioned to be incorporated into Northparkes next block cave to achieve a reduction in capital infrastructure and lead times to reach the first production. This opens opportunities through improving the economic viability of marginal draw points, extensions and whole orebodies.

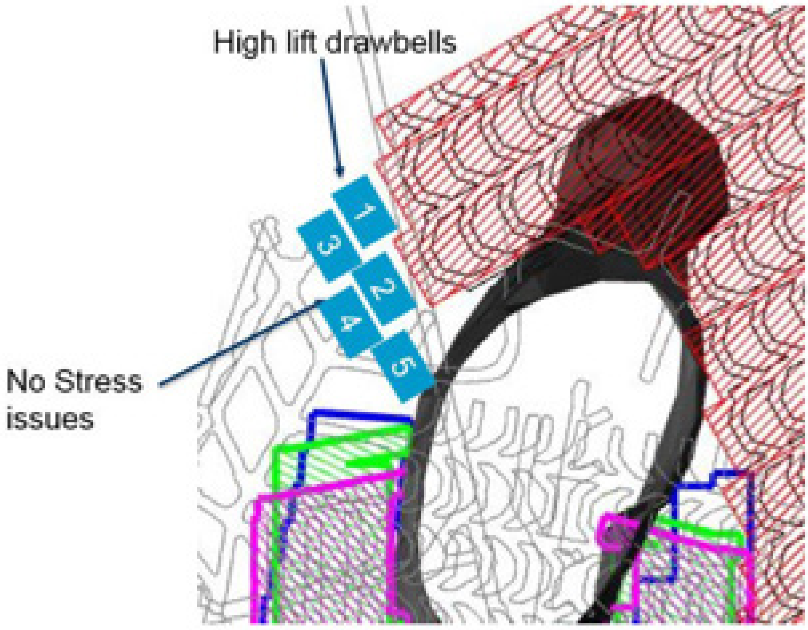

Figure 8 Area of undercut where high lift draw bells can be further trialled for the E26L1N (Lovitt & Degay 2018)

6 Characterising old cave material for economic benefits

The E26 cave contains material of variable Cu and Au grades and material types with the potential to add value to future caves. Until recently however this material was treated as having zero grade. This section details the process of creating a mass balance of metal for an average grade of the remaining cave material then a residual model of the grade to detail spatial variability.

Underground mining of E26 lift 2 ceased prematurely due to excessive clay reporting to the draw points causing blockages in the material handling system and flotation issues in the mill. At this time some 13.3 Mt of reserve remained in the cave, mixed with clay. Further mining around E26 has inspired efforts to re-estimate the E26 caved material and create a residual model. This model now informs grades remaining at E26 Lift 2 footprint as well as likely dilution grades adjacent E26L1N and E26 SLC. Benefits include improving grade forecasting of E26 mines and additional value gained from restarting mining at E26 lift 2.

Numerous residual models were attempted over the last decade using a range of packages. Only models and methods from Geovia flow modelling packages are detailed in this document. Due to the high consequence of assigning grades to caves, detailed checks were performed for each model. The first check of a residual model is the total metal balance of the reconciled versus modelled. The second check of the residual model is the timing of grade reconciliation. The third check of the residual model is the spatial distribution of the grade presenting at the draw points.

Mass metal and tonnage balance calculations were completed using the original block model defined inside interpreted cave shapes, updated with probe drilling and sub-level cave intercepts, and reconciled mined values. E26 open pit was depleted from the block model using an as-built wireframe shape. As the SLC is being actively mined it was not included in the cave shape for mass balance purposes. This calculation indicated 39 Mt at 0.47% Cu and 0.04 g/t Au cave material was remaining in the old cave, however no spatial context for the grade distribution within the volume.

The density of the remaining, bulked cave material is an important parameter for estimating the tonnes and grade of E26L1N with correctly assigned dilution properties. To determine density, the volume of the remaining material was calculated using the cave shape and a flyover survey of the subsidence zone as 20,128,958 m^3. Dividing the remaining tonnages of 39 Mt into the volume indicates a bulk density of 1.94. This is checked by using the average SG of the material of 2.53 and a bulking factor of 1.3 to calculate a typical bulk density of 1.95. This result is within the TARP guidelines of bulking factors for global stability of voids within the cave. This check is important as the movement of material within flow modelling packages needs a reliably determined density of caved material to avoid incorrectly calculated resultant metal balance and grade.

Both PCBC template mixing and cellular automata (CA3D) Geovia packages were used for residual model creation. The CA3D residual model process follows the methodology of Villa, D & Farias, F, (2016) and Northparkes was assisted by the author to create the initial models.

The same E26 block model from PCBC template mixing has been used for the CA3D project however it was sub-blocked from 20×20×20 m^3 to a smaller block size of 10×10×10 m^3. This smaller block can be computed much faster with CA3D compared to traditional PCBC run times with all block values, i.e. grade elements, per cent, rock type, etc. in the new sub-block remaining unchanged. The smaller block size assisting in resolution of the grade variability with mixing through moving closer to actual fragmentation block sizes within a cave.

The final cave shape interpretation defines all material available to be drawn by the cave. It is also critical to define interim cave shapes to best replicate material movement within the cave. Up to thirteen cave shapes are used for constraining the material flow within CA3D including internal growth stages and the final shape (Figure 9). A total of 66 scenarios have been run for the project with variation to diagonal, vertical, and horizontal mixing, fines, frozen material and cave sequence, sub-block, orthogonal exaggeration, mixing horizon, density, swell factor, riling angle, and toppling angle.

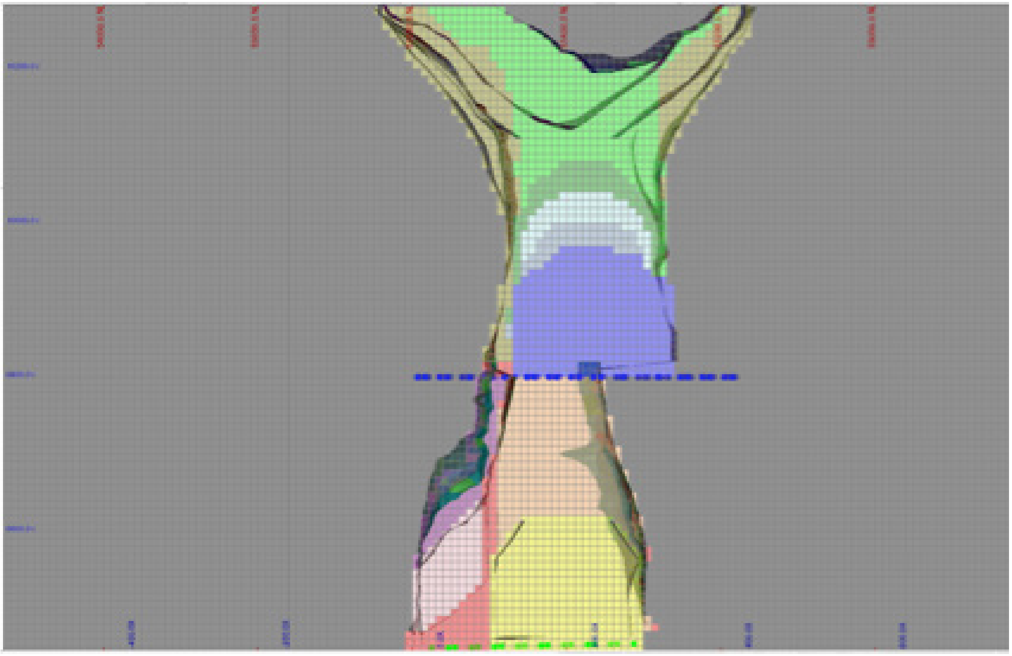

Figure 9 South-North section through the block model indicating internal and final cave shapes used to constrain the CA3D model

The second criteria for evaluating the residual model is the timing of grade reconciliation. The CA3D schedule grades were evaluated for each of the cave lifts against their monthly reconciliations grades. Schedules that tracked closest against the monthly grades were retained for further evaluation.

The locations of the residual copper grade within the cave form the third criteria for the scenario. The multiple mining areas of E26 make the tracking of the cave material challenging. Figure 10 shows the in-situ block model and one scenario after E26L2N mining. To determine which model best represented the copper and gold grade distributions spatially the residual model grades were compared to historic draw point production samples from E26L2 and E26L2N as well as recent samples from open draw points of E26L1 and cave intercepts from probe drilling the old cave material. On a draw point by draw point assay to residual model comparison, the reconciliation is poor however looking at regions of around ten draw points and the average grade is a closer match to the residual model. A project to restart the E26 lift 2 cave is underway with a sampling program to improve understanding of grades. Initial grades varied widely from sample to sample which may be due to difficulty sampling clays and compacted material and ore variability. The relatively high standard deviations suggest between 17 and 68 samples are required to estimate grade to within 10% margin of error, 90% of the time. This variability makes it difficult to write off draw points below cut-off grade. Historic assays for the draw points can give a better indication of overall grade trends and draw points which returned a low grade in the trial may improve slightly with time.

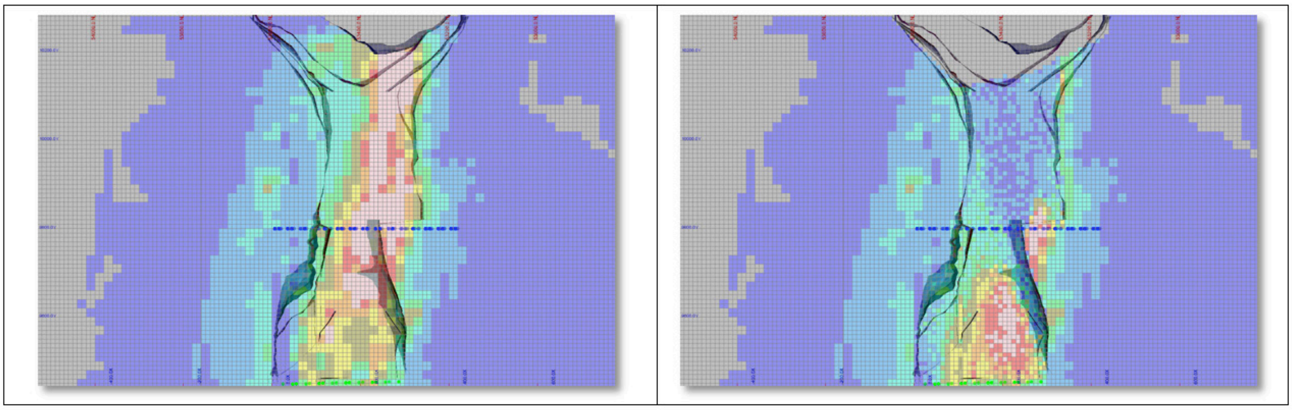

Figure 10 In-situ (left) and E26L1 Run100, CA3D on L1 only (Right), North-South Cross Section (Samosir 2019)

The visual CA3D models highlighted that although grades could be matched overproduction years the distribution of remaining grade from those runs closest to reconciled metal showed pronounced variability between them. When working with block caves of considerable mixing or age it is generally understood that predicting grades becomes less accurate. The visual model allows this variability to be more clearly communicated.

7 Conclusions

Northparkes has successfully continued to provide economic ore through mining extension to block caves. This has prolonged the life and value of existing capital including crushers, hoist shaft, and declines. The new ore sources can be brought online faster than new caves as they are close to and leverage off existing infrastructure.

Learnings from the lessons of past extensions are built into the design to mine safer, more successful geometries.

Designing the cave layout to adapt to new technology such as battery loaders and WebgenTM opens the opportunity for further value-adding where reduced capital can bring draw points into an economic territory and change project dynamics.

Quantifying spatially the residual cave grade has allowed the tonnes and grade to be scheduled for a financial evaluation to determine its value and greater confidence with production forecasting. The model has also provided dilution grades to cave extensions to improve forecasting of the shut-off grades and cave life.

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