Caving 2022 - Y Potvin (ed.)

doi:10.36487/ACG_repo/2205_04

Northparkes E48 block cave: the mining history of a successful block cave

L Snyman *CMOC Northparkes, Australia*

S Webster *CMOC Northparkes, Australia*

Abstract

Northparkes operations consist of underground sublevel cave and block cave mines and an ore processing plant which produces copper and gold concentrate. Production is transitioning from the E48 Lift 1 to the E26 Lift 1 North block cave. Block cave ore will be supplemented with E26 sublevel cave and open cut ore. The E48 extraction level is located approximately 581 m below surface in a low to moderate stress state. The construction used a post-undercut strategy that was initiated in 2009, with production commencing in September 2010 and cave-through to the surface occurring approximately four months later in January 2011. The fast cave propagation and initial, low swell factor is uncharacteristic of block caves.

The E48 cave experienced complex problems with large ground displacements that lead to drive and drawpoint closure. Lessons learned from the E48 experience were used to improve ground support design to minimise potential damage in the extension area.

The mine was originally proposed with eight extraction drives and ten drives were developed. Through reserve upgrades the final extraction level now consists of 13 extraction drives and 270 drawpoints. Changes to the cutoff grade and price/earnings to growth ratio prices meant that Northparkes was able to develop an additional two drives to the north of the existing cave and one additional drive to the south. Developing the extension drives mid-way through the cave life posed further challenges and learnings in the areas of mine design, ground support, undercutting geometry, caveability and reserve recovery. The reserves recovered have exceeded initial estimates and the evaluation of cave shapes defining tonnes from the footprint have required iterative, ongoing evaluations.

In the final years of E48 the mine is focusing on management of extraction level stability, grade prediction and ramp down to closure of the drives and eventually the whole level.

This paper looks at the life of the E48 block cave – the challenges, the failures, and the successes.

Keywords: *block cave, stability, redevelopment*

1 Introduction

E48 was designed and built as a state-of-the-art block cave with concrete roadways, level illumination and loader automation, to name a few of the advances incorporated throughout its life. Being the first post-undercut block cave mine at Northparkes, there were several unknowns about how the rock mass would respond to the stress change. The block was fully hydrofractured from the surface – a first for any of the Northparkes caves. Challenges included several undercut delays, an early breakthrough to the surface, considerable damage to the extraction level and plugging of three drives, midlife extension to the north and south of the footprint, redeveloping the plugged drives, ongoing convergence management and closure of drawpoints as they reached shut-off. Along with these challenges, E48 consistently delivered metal for Northparkes and total tonnages have exceeded that in the initial feasibility study (FS) (Rio Tinto 2006).

2 Studies and early works

2.1 Feasibility mine design

The 2006 E48 FS was based on an eight-drive (Figure 1) block model with a mineable reserve of 36 Mt at 1.03% Cu and 0.45 g/t Au. In parallel, a nine and ten drive design were evaluated however due to metal prices the smaller footprint was considered the most valuable. On review, it was decided that the 10 drive option was most appropriate to ensure caving of the ore column.

The footprint design was a herringbone extraction level with a post undercut to reduce development, construction time and to reduce the amount of bogging from the undercut level. Concrete roadways were installed as poured lengths on the extraction level to improve loader cycle time. At the time of the FS, loader automation technology was still being trialled and established at Northparkes. The FS production rate of 5.5 Mtpa was within the capacity of the mine material handling and haulage system (MHS) and could be ramped up should ore processing increase. The MHS utilised a KRUPP BK 160–190 jaw gyratory crusher.

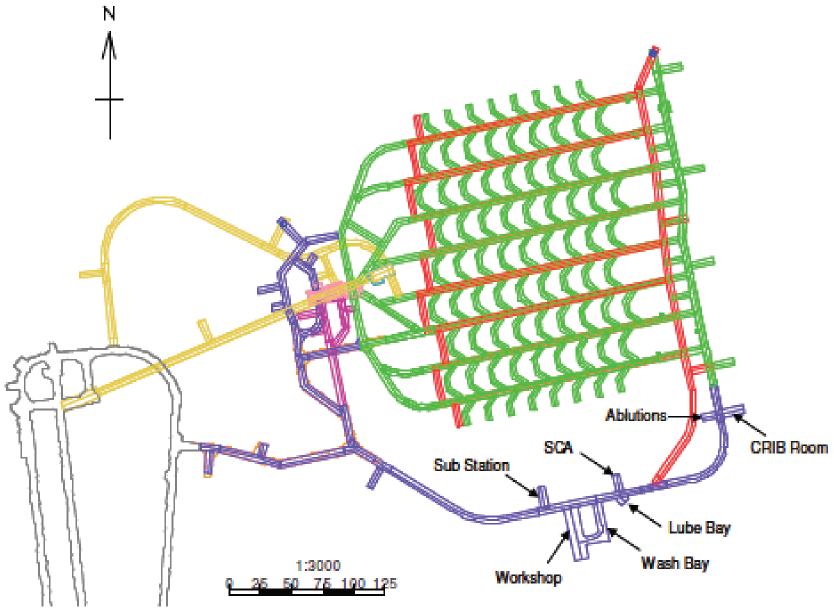


Figure 1 E48 early design with eight drives

2.2 Preconditioning

Prior to cave construction, a preconditioning program from the surface was performed covering the E48 reserves (Figure 2). This was for improving caveability due to the significant block height of 580 m, near-surface stress environment and narrow footprint. Hydrofracturing effectiveness is inherently difficult to quantify, particularly with the influence of shears. For this reason, a 'mine through' trial took place where the effectiveness of the fracture span could be measured (Duffield 2006).

This program allowed the extent of a propped hydrofracture to be measured through the visualisation of various coloured plastic injected to form markers (Figure 3). The results showed that the fractures formed horizontally along with the minimum stress orientation. The hydrofracture path was observed to cross high shear strength structures (fractures, veins) and either stopped or was offset in lower shear strength structures (shear zones). Using seismic data, surface monitoring and observed fracture extents, a diameter of 90 m could be assumed for the design of hydrofracture hole spacings.

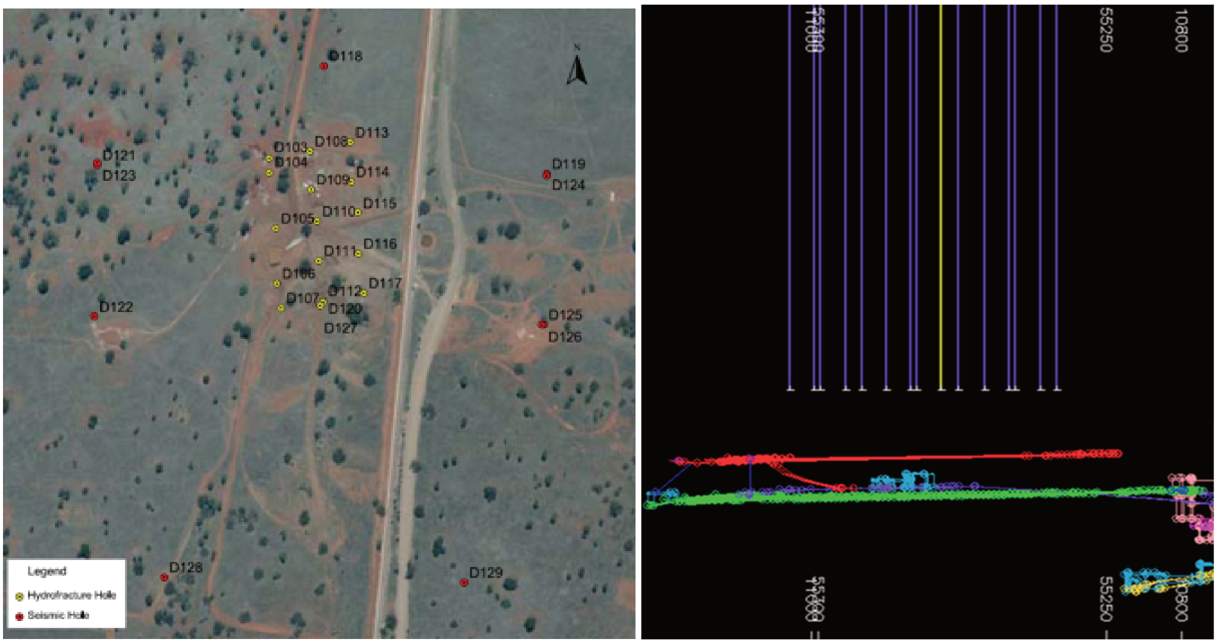


Figure 2 Plan of hydrofracture holes over E48 (a) and section (b)

Figure 3 Hydraulic fracture cutting a shear zone in E48 drive (a) and cutting veins (b)

3 Interruptions early on

E48 was the first post-undercut block cave at Northparkes. The Global Financial Crisis in 2008/2009 had an impact on the initial stages of the undercut due to the requirement to halt development, and significant stress loading conditions were experienced on the extraction level during undercutting in late 2010. This resulted in damage primarily in the form of horizontal deformation with lateral pillars on the extraction level experiencing on average 3% strain or 75–200 mm convergence measured in some parts of the extraction level (Figure 4).

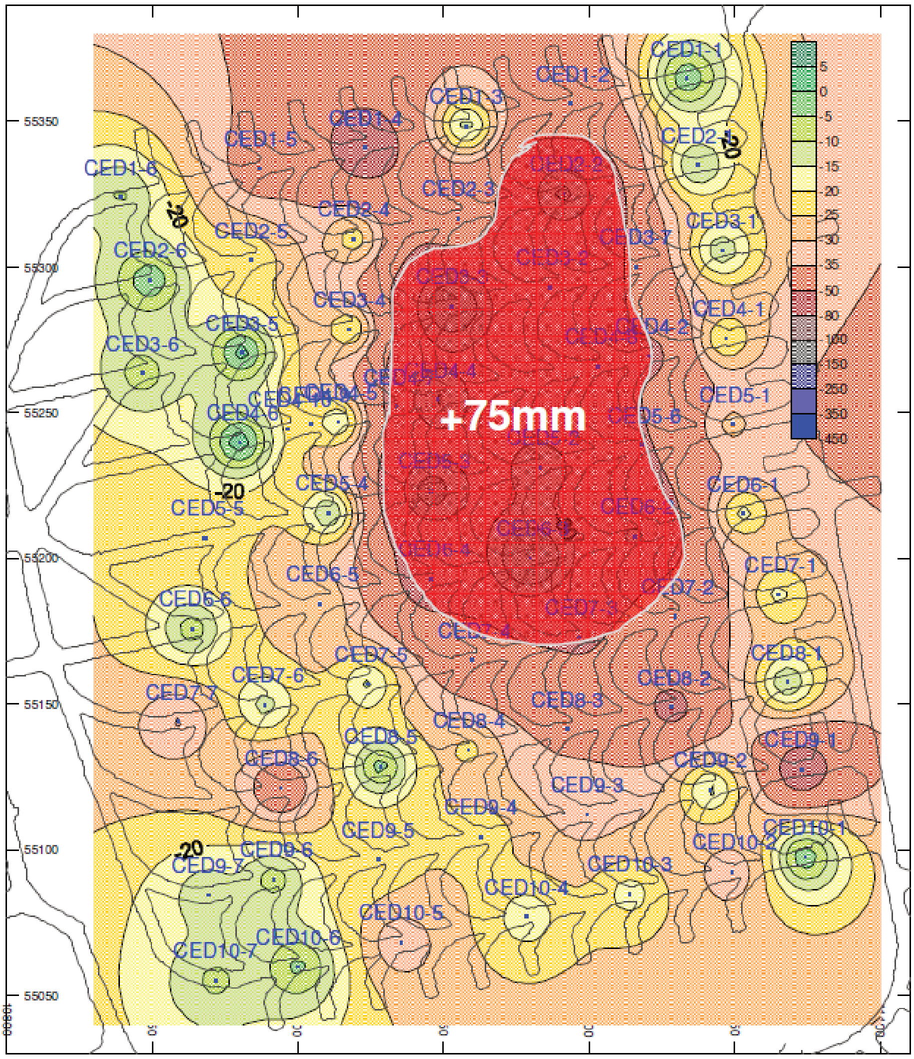


Figure 4 E48 Extraction level horizontal convergence

Significant convergence (Figure 4) was experienced in the eastern region of the extraction level as active caving commenced in the west and abutment stresses increased along the undercut front which was being developed from west to east. The rapid cave breakthrough to the surface occurred in early 2011 which is believed to be aided by the intensive hydrofracturing program undertaken in the E48 orebody, as well as due to a plug subsidence mechanism (Lilley 2016) caused by the persistent near-vertical faults across the orebody. This early cave breakthrough (cave growth rate of ~4.6 m/day), combined with the already weakened ground due to increased abutment stresses along the undercut front, resulted in elevated convergence and ground support damage (Figure 5), as well as instability of drawpoints adjacent to extraction drives 3, 4 and 5.

Figure 5 Progressive failure over three weeks of ED4–4N5 area

Despite all the interruptions early on, the cave propagated to surface much quicker than expected and was in full production by 2011.

4 Redevelopment and extensions

In Extraction Drives (ED) 3, 4 and 5, the extent of the damage resulted in filling of the excavations with concrete to provide immediate support and stability and to prevent deterioration spreading across the level. ED4 was the first drive to be impacted and it was filled first, followed by ED3 and then ED5 (Figure 6).

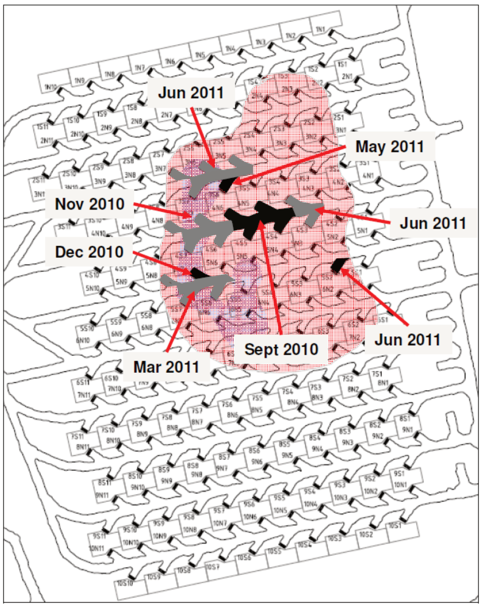
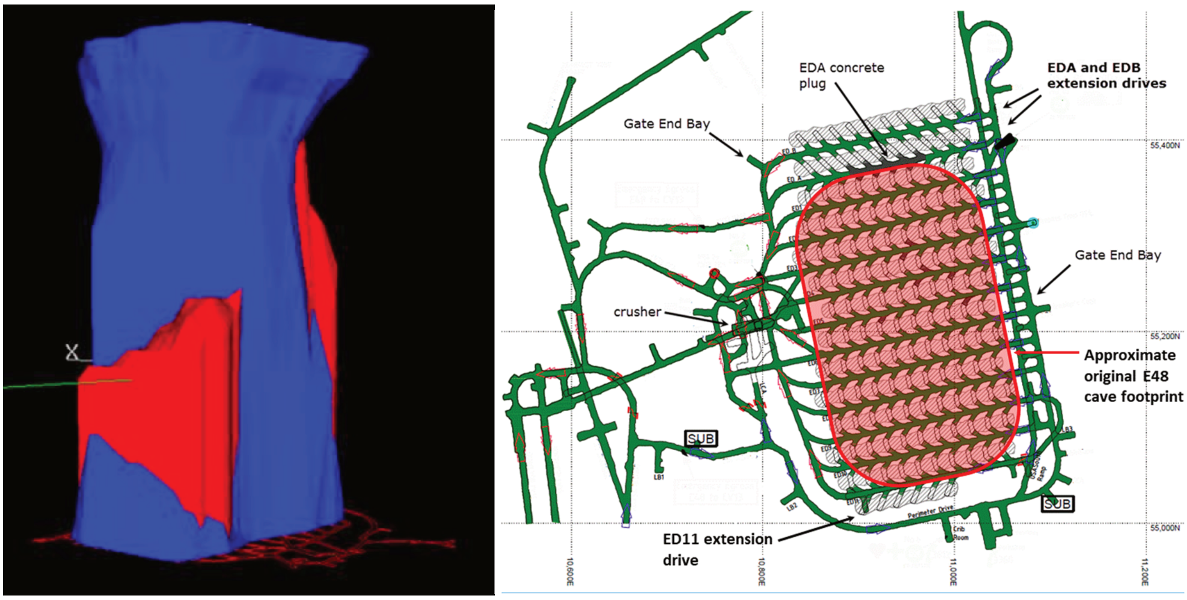


Figure 6 Concreted areas on the E48 extraction level

Resin injection and cable bolt installation in the surrounding areas was undertaken during 2011 and 2012 prior to redevelopment, to control convergence before it caused significant damage to pillars in other drives. Resin injection provided consolidation of the ground to enable anchor holes to be drilled and remain open. Twenty drawpoints and their adjacent extraction drives were plugged. The implications of the concreted drawpoints and extraction drives were significant in terms of loss of ore reserves resulting in reduced revenue and mine life, increased operating costs, increased operating risks including equipment damage and personal injury, and restricted implementation of loader automation along with many other implications. The redevelopment was required to make E48 a workable block cave. The redevelopment project is detailed in Brenchley et al. (2013).

The E48 extension was mined concurrently with redevelopment activities to realise co-development cost opportunities, including labour, equipment, and ground support supplies. More details of this extension can be found in the paper by Snyman et al. (2016). The extension was not a large span and questions were raised on the likelihood of recovering the reserves. To improve the likelihood of the cave growing and reserve recovery, a hydrofracturing program was performed on the North and South sides. Further details of this preconditioning project are within the paper by Webster et al. (2016). The development was used as an opportunity to trial design changes such as an El Teniente footprint layout, alternate drawpoint angles, alternate brow support and cobblestone roadways. The El Teniente layout is considered a stronger layout from a geotechnical perspective. To produce from the drawpoints facing opposite directions with tethered loaders requires design considerations of cable tether locations and learnings such as these were fed into future designs (Webster et al. 2020).

The E48 cave extensions encompass mineralisation to the north and south of the existing cave (Figure 7) which at the time of the original feasibility study was not considered economic. Execution of the cave extensions was expected to significantly increase the likelihood of the recovery of uncaved reserves to the north and south of the existing cave. Two drives were developed to the north and one drive to the south of the existing E48 footprint. Extraction drive A was developed next to ED1 and the drawpoints on the southern side broke through to the existing cave above ED1 without any issues. After several months of production, a dry fines inrush from one of the drawpoints (Figure 8) resulted in a new fragmentation category being developed at Northparkes, now referred to as ‘superfine’ – baby powder sized material. Subsequent fines inrushes have occurred and are almost always located along the cave boundary and/or associated with lithology contacts and/or geological features.



(a) (b)

Figure 7 (a) Isometric view looking southeast showing reserves outside the cave volume in red; (b) Plan view of E48 footprint with original and extension drive locations

Figure 8 First fines inrush from AS6 in October 2014

Five months after the first fines inrush, convergence and drive deterioration were noticed in the middle of Extraction Drive A (EDA). Every effort was made to curb the convergence with the installation of additional ground support (Figure 9); however, the deterioration reached the point where the safety of personnel working in the area was at risk and the decision was made to plug the drive with concrete. A 54 m length of ARMCO arch that was available onsite for another project was placed in the drive and backfilled to ensure that ventilation and drainage could be maintained (Figure 10). In just one month, EDA progressed from minor convergence to the drive requiring plugging with concrete.

Figure 9 Deterioration in EDA during March 2015

In 2016 a study was completed (Lilley 2016) on the benefit of recovering the EDA plugged drive through focusing on the recovery of the reserves above EDA and (Extraction Drive B) EDB (northernmost extension drive). The caveability modelling assessed the difference in cave growth with and without redevelopment of EDA. The results of the modelling showed that above the extensions would cave up a vertical fault, parallel to the drive. This formed the controlling factor on the caveability, more so than the bogging strategy from the drives below. The study also found that the deformation in EDA was the result of a plug subsidence mechanism, similar to the original deformation of ED3, ED4 and ED5, and caused by persistent near-vertical faults across the extension area. From this modelling, it was concluded that it was not economical to re-open EDA however to best recover this reserve the bogging of the extensions should be prioritised to progress the height of draw relative to the adjacent, mature cave. The recovery of the cave extension material became focused more on catching up the draw and promoting a higher velocity flow of the extension material relative to the rest of E48.

Figure 10 Western end of EDA plug with AS8 to the right

5 Production and draw control

The intention of the E48 cave management plan was to follow an even draw strategy for 100 m column height to minimise dilution and mixing and to maximise the recovery of the reserve. As the cave matured it would transition to a best height of draw strategy where each column will be drawn in proportion to the remainder of the ore column sitting above the drawpoint. The economic ore column was determined from the shut-off value which was set in the early cave to ensure the upfront investment of constructing the cave delivered value. As the cave continued to produce and perform, a declining shut-off value was adopted, balancing footprint production, tonnages required for production and reserve recovery.

Even draw involved following the cave management plan ramp-up rates with a rule around minimum bogging across the entire footprint and not exceeding a maximum bogging rate per cycle, despite the temptation of high-grade drawpoints. The management of converging drives took precedence and required an increase in bogging at and around the converging drawpoints to shed the load of the cave. This resulted in an uneven draw column across the cave. In response, plans were put in place to even the draw across the cave through increasing the call tonnage to drawpoints lagging and drawpoints that were overdrawn had a lower order in the priority. Managing a cave is not simple however, and accommodating the requirements of ongoing convergence, automation installation, drive availability, oversize handling, reserve recovery and production targets created a challenge for designing and enforcing the draw call.

5.1 Draw call for convergence

Redevelopment of ED3, ED4 and ED5 was successful but required a careful balance in the draw call – bog too much and convergence would resume – bog too little and the same thing would happen. The redevelopment project included the need to reinstate the flow of ore from drawbells that had not been mobilised during the period when the drives were plugged. The objective of the initial draw strategy was to reduce the stress loading in the middle of the extraction level and redistribute the stresses to the boundary or abutment. This was successful and through trial and error a happy medium was found, and the extraction level remained stable.

Bogging continued over the years with hotspots flaring up – several resin injection campaigns were required to 'glue' the rock mass together to be able to drillholes for rockbolt or cable bolt installation in areas where rehabilitation was required.

5.2 Automation

In 2015, Northparkes became the world's most automated underground mine with 100% production from automated loaders. This allows continuous operations 24/7. Higher daily production is achieved at a significantly reduced cost, but importantly it also reduces the risk profile. Operators are located in an office on surface rather than underground in the loader cab, eliminating the risk of dust, noise, vibration and impact injuries. One experienced operator can operate three loaders at the same time. Travelling at speeds of up to 21 km/h, the loaders operate autonomously for 80% of their cycle time and the rest of the operation cycle is tele operated (Australian Mining 2019).

The automation had the benefit of ensuring more adherence to the daily draw call where previously, at times, daily production targets were being met through changing to short cycle options. The data available from the automation system also enabled statistics of cycle times for various drives to be understood. From this data, the production tonnages from the level could be further optimised. The benefit was especially seen when the production tonnage became focused on the northern half of the cave, and uncertainty on loader congestion at tipples could be quantified and confident production tonnages forecast.

5.3 Fragmentation

The fragmentation for E48 was analysed using Esterhuizen's Block Cave Fragmentation (BCF) software version 3.04. This was based on a fracture frequency block model for the basis of the study. The analysis indicated secondary fragmentation to be considered manageable with around 81% of the block sizes <2 m^3 (Figure 11). Fragmentation was thus unlikely to result in production delays or prove problematic during the life of the cave. Due to the oversize encountered in the E26 caves, the focus was on the coarse component of the prediction and BCF primary focus was not on the fine component of the fragmentation distribution.

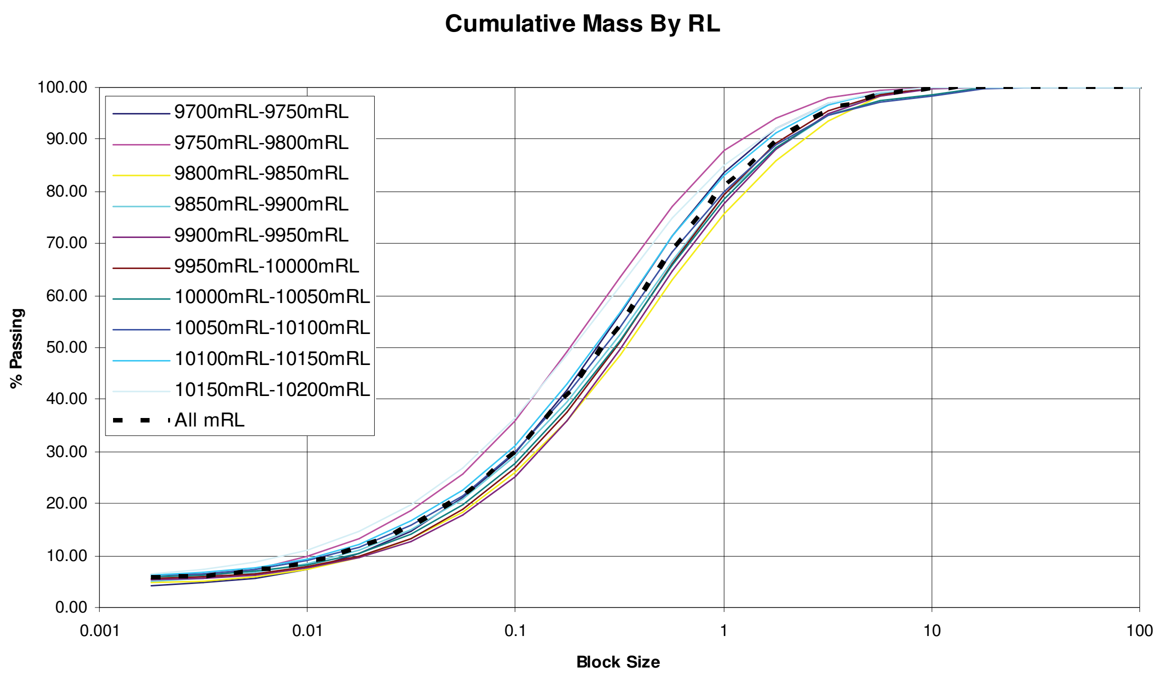


Figure 11 Feasibility Study cumulative frequency distribution of the secondary block size from the 9700 mRL to the 10200 mRL (note this is volume in m^3)

Following mining of the undercut material, the coarse component of the cave decreased from <20% of feed in 2010 through to <10% in 2012 and <5% in 2014 (**Figure** 12). As the cave matured, the fine component has steadily increased. Large float oversize forming hang-ups are still encountered in 2022 that can load steel set support at brows, requiring blasting. It is thought that such oversize is no longer comminuting in the cave due to their size relative to the surrounding finer feed that rills around them.

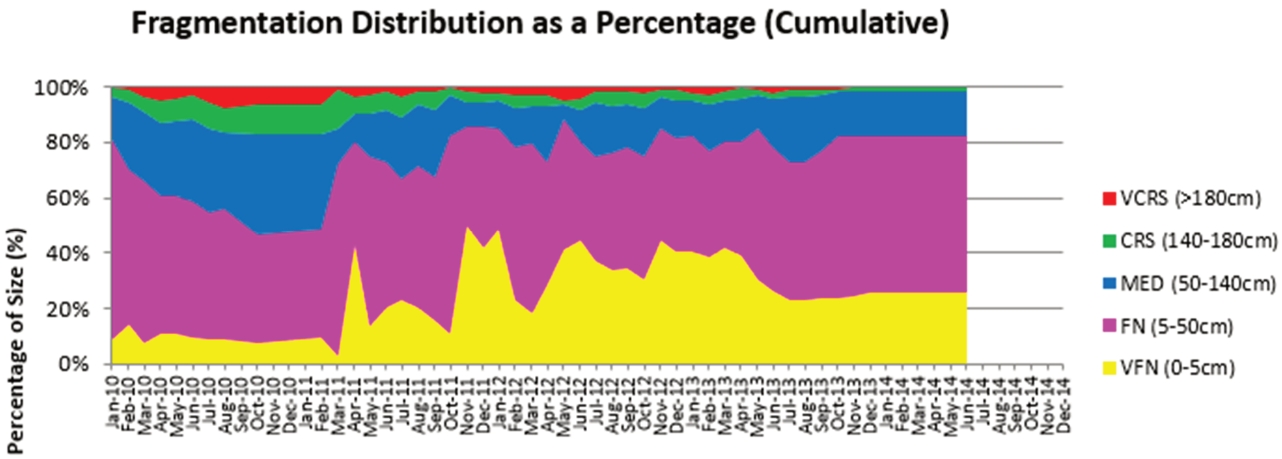
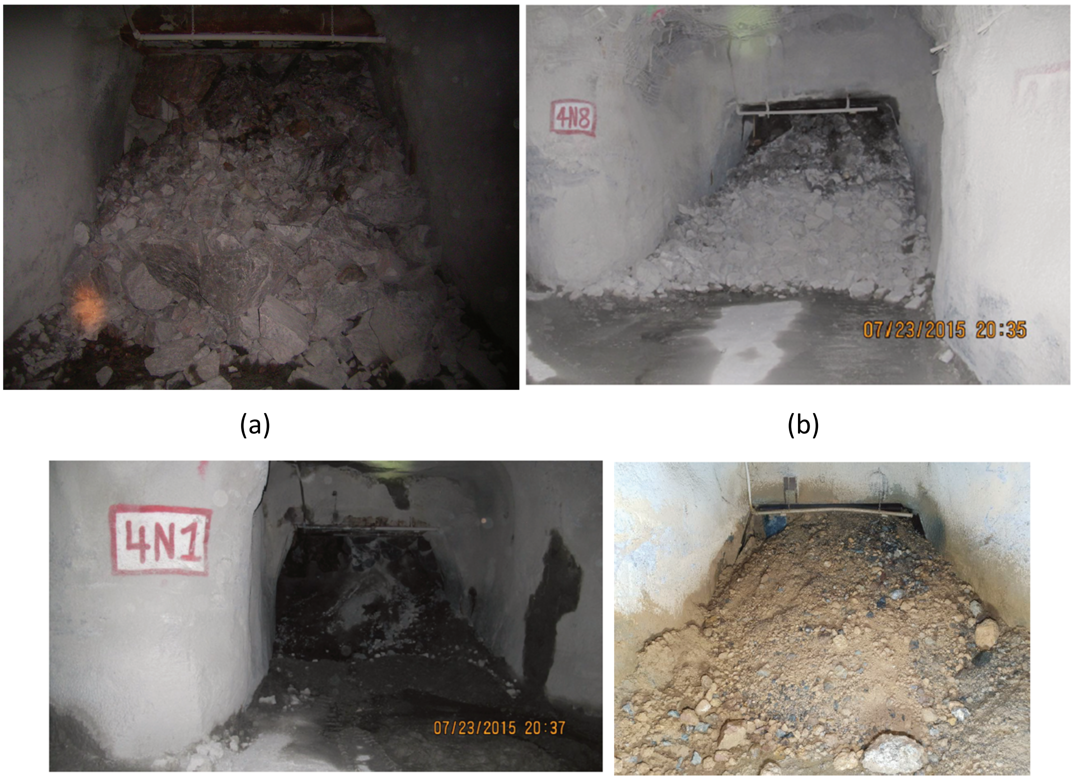


Figure 12 Fragmentation distribution as a cumulative percentage of total observations from 2010 to 2014

The fines component has increased above the initial prediction and further investigation attributes this to a greater proportion of soft mineral alterations associated with faults and monzonite contacts as well as microfractures and microveining (Burgio 2016).

E48 was the primary ore source for Northparkes and the finer product (Figure 13) prompted the mill to change the configuration from a SAG mill approach to that of a ball mill. The fines also formed a packing layer in the mill resulting in more energy required to achieve the target crushing threshold of the coarser component. This cushioning effect was also seen in the secondary crusher where the gyratory mechanism was less effective in reducing E48 material. In 2020 a screening plant was installed at Northparkes to remove the fine component and improve effectiveness of the crushing phase. As the mine moved towards a smaller crushed product, with increasing component of cave fines, the crushed ore stockpile (COS) saw the resonance time in the stockpile reduce. This resulted in material fed to the COS travelling through narrow funnels to the feeder, not blending with other material on the stockpile. This is a similar phenomenon to the finer material in the cave funnelling to the drawpoints causing challenges with ore recovery and reconciliation. A learning from this process is that the fragmentation prediction plays an important role in not only the resources to treat oversize underground but also the changing life-of-mine (LOM) material handling and crushing strategy.



(a) (b)

(c) (d)

Figure 13 (a) 2010 cave fragmentation; (b) 2015 cave fragmentation in the cave centre; (c) 2015 cave edges finer and wet fragmentation; (d) 2021 clay in cave centre drawpoint 8N6

5.4 Reserve recovery and cave growth

E48 caved to the surface much faster than predicted and the cave shape typically created to define the cave propagation was difficult to update between undercutting and breakthrough. As shown in Figure 14, the cave shape steadily grew over the life of the mine. The interpretation is based on subsidence surveys and open boreholes. The open borehole data is difficult to maintain throughout the life of a cave and additional drillhole programs were hampered on the Eastern side by a thick regional shear zone, termed the Altona Fault. Nevertheless, a cave interpretation is required and a balance between available data and interpretation were used.

The cave shapes are fundamental inputs to understanding the metal balance and grade trends in flow modelling and defining the reserve. The move from a flat shut-off to a declining shut-off value to evaluate economic draw columns had the effect of prolonging the life of the E48 reserves. The result being that a healthy balance of tonnage remained in the cave however with less metal. To the end of 2021 over 60 million tonnes of ore had been mined, >70% more than then original feasibility study with approximately 10 million tonnes remaining in the reserves. The remaining grade is more difficult to forecast, and the associated tonnages are being regularly assessed. A write down of the tonnages occurred in the 2021 reserves and may happen again for E48. A learning from the reserves and life-of-mine management is that the later life of a block caves reserves should be treated with lower confidence than the original reserve classification. This would further support the communication of uncertainty to other disciplines, not familiar with the technical management of a cave.

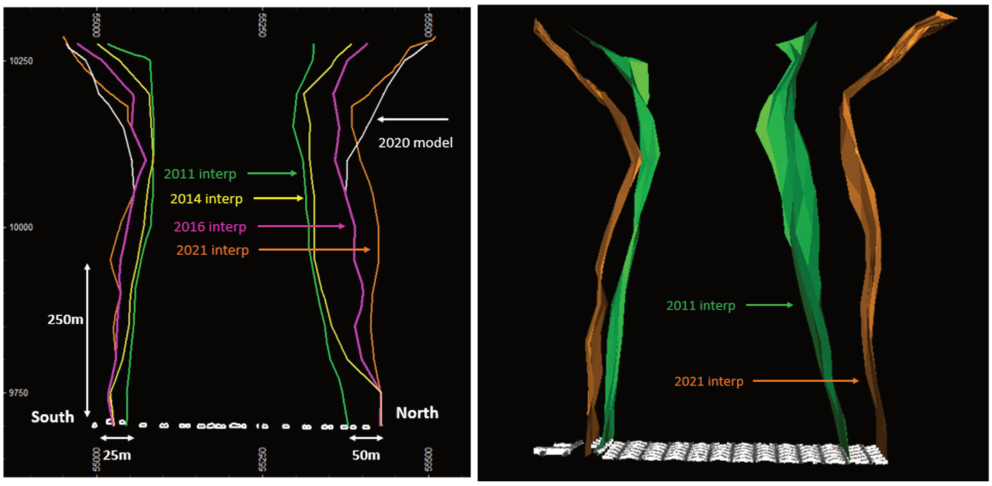


Figure 14 E48 Cave interpretation shapes from 2011 through to 2021 showing lateral growth over mine life

6 The final years

E48 has progressed into the stage requiring a closure strategy involving consideration and management of the extraction level stability, drawpoint closure methods, loader fleet reduction and formal method of permanent drawpoint closure. Thanks goes to the technical staff at New Afton for sharing learnings from their operation on drawpoint closure management.

In the early years of E48 the cave grade reconciled above PCBC predicted grade. This was taken as a bonus however metal balance and assay analysis indicated the grade difference trend was converging and would reverse in the future. Several flow modelling tools were adopted to further understand and quantify the remaining metal and forecast the future grade. These involved PCBC's template mixing and cellular automata models with mixed sucess. Due to the maturity and intense mixing of the material, the cave is now being forecast through forward projecting drawpoint assay values.

In 2018 the first drawpoint was permanently closed by concrete backfill due to continued ground condition deterioration. Between 2018 and at the time of writing in 2022, 100 out of 260 available drawpoints have had to be closed (Figure 15) due to the three-month rolling average grade dropping below the cutoff grade. Of those 100 drawpoints, only four required concrete plugging due to deteriorating ground conditions. The concrete provides stability to the surrounding extraction drive and allows the drive to remain open for bogging of surrounding drawpoints.

The remaining tonnes and grades of E48 are forecast with growing uncertainty. Figure 16 shows the variability of forecasts and the duration of the remaining years. The closure date for the cave will occur in the coming years and is reliant on grade and the amount of clay reporting to the level and ability for the MHS to manage this material.

A learning from the metal reconciliation and grade forecasting is that flow is highly variable throughout the life of a cave and that a variety of tools and opinions are required. The cave production has been forecast and back analysed with all the commercially available flow software packages as well as dissected through hand drawn plans and sections. No one person or package was completely successful in predicting the grade however all contributed to the understanding.

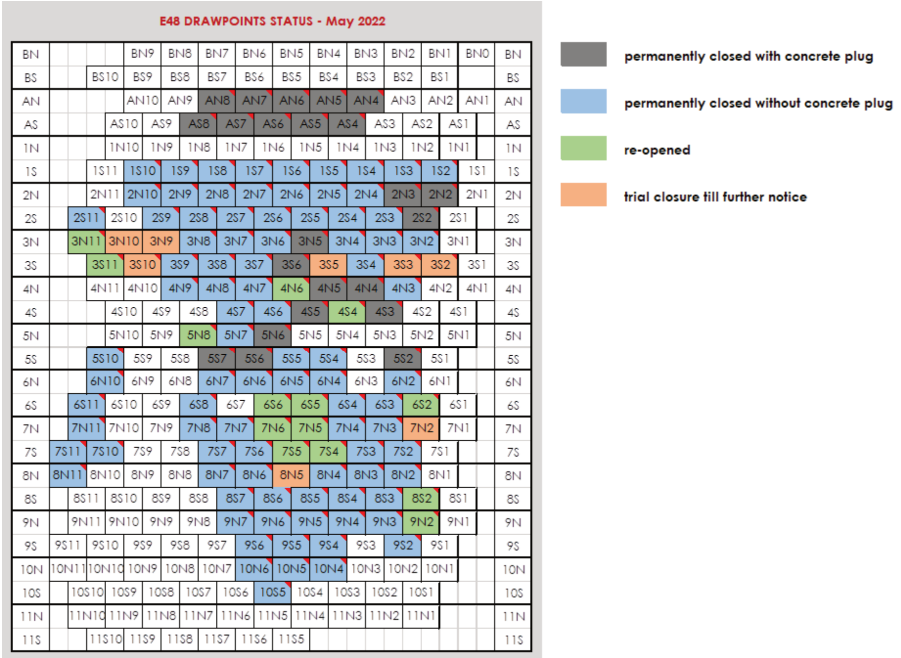


Figure 15 E48 drawpoint closure status as at end May 2022 – note drawpoints plugged in EDA, ED3, ED4 (excluding 4N4) and ED5 were plugged prior to 2018

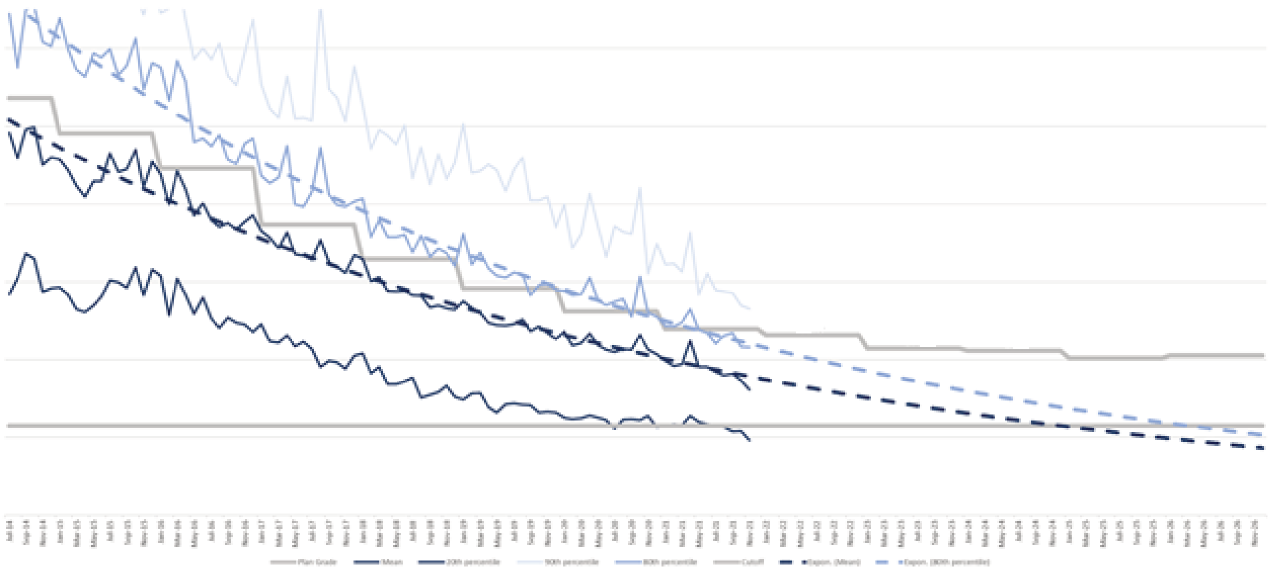


Figure 16 Mean/median/90th/80th percentile monthly drawpoint grades

7 The highlights

E48 is a unique cave – it has experienced a number of challenges over its 11 year mine life. The mine was designed, constructed and operated to be highest standard with ongoing analysis and support from Northparkes technical staff and experienced caving professionals.

The project commencing during the global financial crisis brought challenges in a pause to construction and follow on effects of extraction level instability. The redevelopment project was onerous however the technical staff alongside the operations team endured and achieved the reopening of the closed drawpoints in the centre of the cave. Alongside extraction level convergence, maximising the recovery of reserve was the focus of draw strategy.

E48 was the first underground mine in the world to be completely mined using loader automation, a learning shared with the international community.

The closure of the cave is being managed to promote longevity of the remaining grade alongside clay ingress and ramp down of tonnes.

For a cave first designed with 35.8 Mt reserves, E48 will deliver more than 60 Mt of ore. Although the current grades are low, they still provide value and people recall the gravy times of E48's early years. The overall value extracted from this deposit has been immense and the cave can be considered a success.

Acknowledgement

This paper has been compiled from unpublished Northparkes and CMOC reports. The authors acknowledge their colleagues at Northparkes Mines for their great contribution to the E48 project. Thanks are extended to CMOC Northparkes Mines for their permission to compile and publish this document.

References

Australian Mining, 2019, 'Automation pays off for Northparkes', *Australian Mining*, viewed 5 May 2022, https://www.australianmining. com.au/news

Brenchley, P, Snyman, LA, Samosir, J & Coxon, B 2013, 'Redevelopment support at Northparkes Mines', in Y Potvin & B Brady (eds), *Ground Support 2013: Proceedings of the Seventh International Symposium on Ground Support in Mining and Underground Construction*, Australian Centre for Geomechanics, Perth, pp. 451–460, https://doi.org/10.36487/ACG_rep/1304_30_Brenchley

Burgio, N 2016, *3rd Interim Report – Benchmarking Fragmentation*, internal report, Stratavision Pty Limited.

Duffield, S 2006, 'E48 Feasibility Study Memorandum, E48 Mine-Through Trial', internal document, Northparkes Mines.

Lilley, C 2016, *Assessment of Cave Growth for EDA Rrecovery Options at E48*, report, Beck Engineering, Sydney.

Rio Tinto 2006, E48 Project Feasibility Study October 2006, internal document, Rio Tinto.

Snyman, L, Webster, S & Samosir, J 2016, 'E48 cave extension at Northparkes', *Proceedings of the Seventh International Conference & Exhibition on Mass Mining (MassMin 2016)*, The Australasian Institute of Mining and Metallurgy, Melbourne.

Webster, S, Samosir, E & Wyllie, A 2020, 'Learnings from mining cave extensions at Northparkes Mines and new technology to improve the value of future cave designs', in R Castro, F Báez & K Suzuki (eds), *Proceedings of the Eighth International Conference & Exhibition on Mass Mining (MassMin 2020)*, University of Chile, Santiago, pp. 92–102.

Webster, S, Snyman, L & Samosir, J 2016, 'Preconditioning E48 Cave Extension Adjacent to an Active Cave', *Proceedings Seventh International Conference & Exhibition on Mass Mining (MassMin 2016)*, The Australasian Institute of Mining and Metallurgy, Melbourne.