doi:10.36487/ACG_repo/2435_C-12
9th International Conference and Exhibition on Mass Mining, Kiruna Sweden 17-19 September 2024

Enhancing preconditioning strategies in block and panel caving: Bridging the gap from research to operational excellence

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ABSTRACT

In block and panel caving, effective cave initiation and subsequent propagation are crucial for operational success. To mitigate inherent risks and address site specific geotechnical uncertainties, cave-induction techniques, such as preconditioning, are employed with the aim to enhance cave propagation and extraction processes. These techniques include hydraulic fracturing and confined blasting. This paper presents insights gained from more than 15 years of implementing preconditioning techniques in mass mining operations, focusing particularly on the concept of intensive preconditioning of massive ore bodies. The paper documents two specific case studies, providing a snapshot of the implementation process. The paper also highlights key gaps in our current understanding and argues that despite the reported benefits of preconditioning, there still uncertainty associated with the adoption of one technique over the other, or the simultaneous application of both (i.e. intensive preconditioning). Doubts arise mainly from the challenge of adequately quantifying their impact on caving mechanics. The paper concludes with a brief discussion on our learnings from applied research and identifies the focus of a new research partnership that will help bridge the gap between research and operational excellence for future caving operations.

1. INTRODUCTION

Effective cave initiation and its subsequent propagation are essential to the success of a block and panel cave mining operation. As we move into deeper and more competent deposits, there is an increase in the inherent risks and geotechnical uncertainties. In order to manage some of these risks, cave-induction techniques such as preconditioning are being applied, these include hydraulic fracturing (HF) and confined blasting (CB) or a combination of both as outlined by Catalan et al. (2012, 2014).

The term preconditioning has since been adopted within the caving mining industry to describe the process of "modifying" a rock mass to enable better control or management of the cave mining process. The term “modifying” is used in this context to mean the process of artificially inducing multi scale fractures into the rock mass.

Practical experiences on the implementation of preconditioning have accumulated for over 20 years, they include applications in operations such as El Salvador, El Teniente, Andina, Northparkes, Ridgeway Deeps, Cadia East, Chuquicamata underground mine and Deep Mill Level Zone underground mine. The evidence and impacts of these techniques on caving performance have allowed for some definition of site-specific guidelines, however learnings have not all been documented or shared widely. To date, one of the most comprehensive documented examples of hard rock preconditioning involving the combination of hydraulic fracturing and confined blasting is the work published by Catalan (2014). This project aimed to design and implement intensive preconditioning at the Cadia East operation, its success was in part due to a strategy that supported a strong collaboration between applied research and operational practice.

Over the years, the authors of this paper have worked together to continue to promote research partnerships, making continuous advancements in the application of intensive preconditioning at other operations such as the Chuquicamata underground mine. This paper retrospectively examines these two case studies, providing insights into key design parameters and lessons learned.

The paper concludes by identifying key knowledge gaps and a new research initiative aimed at addressing those gaps. This pursuit is geared towards developing more comprehensive engineering design guidelines for preconditioning applications.

2. PRECONDITIONING CASE STUDIES

It is important to recognise that industry experience in preconditioning has mainly focused on the application of hydraulic fracturing (HF) (van As et al 2000, 2004, Chacón et al 2004, Molina et al 2008, Catalan et al 2012, Lowther et al 2016). Codelco Chile has been applying the HF method almost "routinely" at several of its caving operations at the El Teniente mine, as well as in its newly established projects (Landeros 2022). Most recently, in the Deep Mill Level Zone (DMLZ) underground mine, an HF preconditioning program was also implemented to mitigate several significant seismic events (Nugraha et al 2020).

The combined use of hydraulic fracturing (HF) and confined blasting has not been as widely documented but successfully implemented at Cadia East and Chuquicamata Underground. Insights drawn from these specific case studies offer valuable perspectives on the potential advantages and challenges associated with this integrated approach. The following sections provide a brief description of these two case studies.

2.1. Cadia East PC1 case study

The Cadia East ore body is located in Cadia Valley approximately 25km southeast of Orange in New South Wales, Australia. The mine is one of the deepest panel caves in the world and Australia's largest underground mine.

The Cadia East mining complex operates a series of panel caves (Figure 1) which are denominated as Panel Cave 1 (PC1) and Panel Cave 2 (PC2), both are located approximately 1,200 m and 1,450 m below surface respectively (Lowther et al 2016).

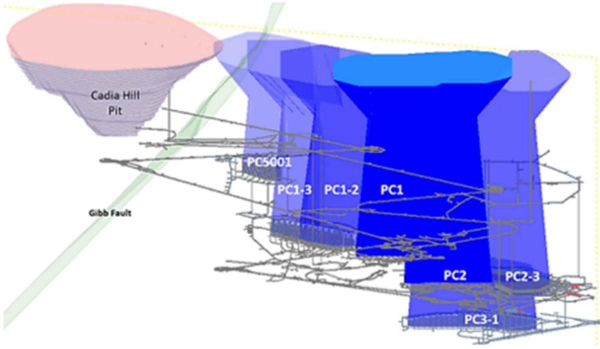

Figure 1 Cadia East panel caves.

Intensive preconditioning was implemented at Cadia East PC1 using down-holes for HF fractures, followed by up-holes for confined blasting as illustrated in Figure 2. (Catalan et al 2012).

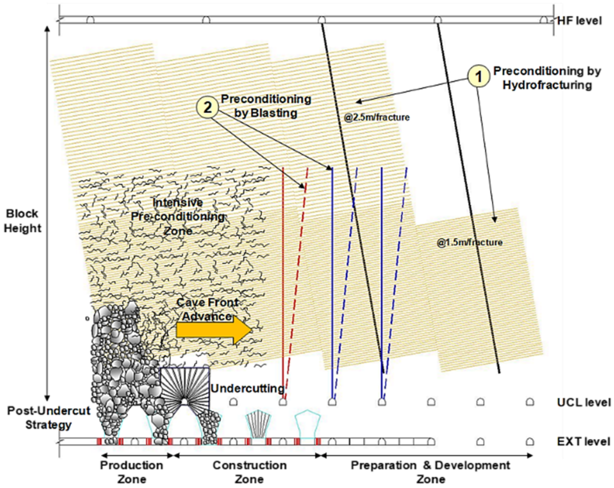

Figure 2 Intensive Preconditioning diagram (Catalan et al 2012)

Prior to the implementation of the combined techniques, Cadia East undertook a series of full-scale hydraulic fracturing and confined blasting trials between September 2009 and February 2010. The aim of these tests was to provide full scale data in ongoing applied research efforts but also to support the definition of key operational parameters. More specifically, objectives can be summarised as follows:

Hydraulic fracturing:

- To understand pressure requirements in relation to HF extent and geometry;
- To define hole spacing requirements between fractures;
- To verify the generation of hydro-fractures down to 550m from the collar of the hole; and
- To support the optimisation of designs for the complete HF implementation program.
- Confined blasting:
- To quantify the impact of the different designs in terms of the degree of rock mass damage;
- To establish optimal operational and safe procedures;
- To collect data to calibrate and validate supporting numerical modelling tools;
- The help estimate the degree of damage (direct and indirect methods) from single and multiple hole firings; and
- To determine the optimal timing and placement of boosters (points of initiation).

2.1.1. In situ HF preconditioning trials

Hydraulic fracturing (HF) in situ trials were performed to define parameters such as breakdown pressure (Pb), instantaneous shut-in pressure (ISIP) as well as injection volumes. Results are discussed in more detail by Catalan et al 2012 and 2014.

In order to validate the orientation and propagation of hydro-fractures, additional information was collected from the mine through the use of proppants emplaced during the CE HF trials (Jeffery 2010; Catalan et al 2012). These intersections (Figure 3) showed a good correlation in terms of geometry, orientation and length with simulated hydro-fractures (i.e. hydraulic fracture lengths of about 40 m and spacings of 1.25 or 2.5 m). The data demonstrated parallel growth of these closely spaced hydraulic fractures over a mapped distance of 15 m, which was consistent with initial predictions. Figure 3 shows the four mapped HF fractures that were visible along the tunnel at Cadia East.

Figure 3 Mine through of hydro-fracture proppants.

Using the intersection observations coupled with the interpreted fracture path from a hydraulic fracture model, it was possible to estimate the propagation distance of these fractures. By using the propagation distance and the propagation time, a fracture growth chart was produced and the analysis provided confidence to define design parameters and operational constraints (Catalan et al 2012, 2014).

2.1.2. Confined blasting preconditioning trial

The confined blasting trial consisted of two up holes (95 and 150 m long), charged with DX5039S, a solid sensitised emulsion with a nominal VOD of 5,600 m/s. The trial was monitored with a network of 3 tri-axial accelerometers with a measurement range of ±5,000g and higher broadband resolutions (PCB Piezotronics, Inc, USA) were set out between both holes (i.e. near-field monitoring sensors) to monitor the peak particle acceleration. Additionally, two far-field tri-axial accelerometers (i.e. 500g) were installed 80 m and 130 m from these charges. Instrumentation components are shown in Figure 4 (Catalan et al 2014).

These trials were a key component of the applied research that aimed at testing the effectiveness of advanced blast modelling tools to understand fracturing and interaction zones in confined blasting. Outcomes from the combined monitoring and modelling work supported the definition of final up-hole layouts that allowed for blast induced stresses to interact and increase the likelihood of both macro and micro fracture generation. The final implementation of the intensive preconditioning program at Cadia East PC1 is illustrated in Figure 5. The key design parameters adopted in both methods is given by Catalan et al 2014.

Figure 4 Preconditioning by blasting. Instrumention and configuration of full scale field trials.

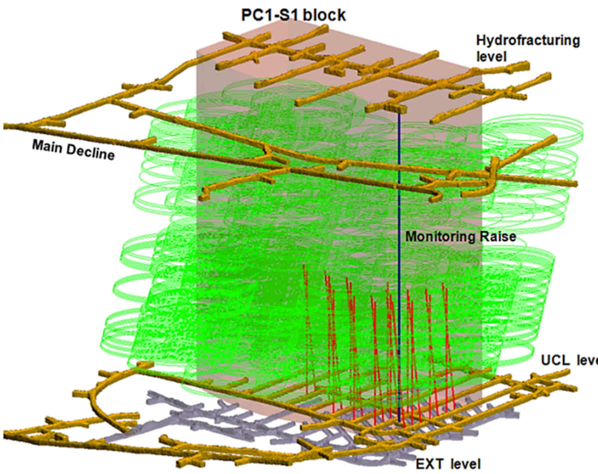

Figure 5 Intensive preconditioning applications at the Cadia East panel cave PC1 (Catalan et al 2012).

2.2. Chuquicamata underground case study

The Chuquicamata Mine is located 15 km north of Calama and 2,870 M.A.S.L. in the middle of the northern Chilean main mining district in the Atacama Region. Underneath the existing open-pit mine, the construction of a new block cave mine is taking place, following the best technical and economical option to extract the copper ore reserves beyond 1 km in depth (Flores & Catalan 2019).

The Chuquicamata Underground Project (PMCHS) has involved the construction of a massive underground mine site and infrastructure to recover around 1,701 Mt of mine reserves at an average grade of 0.70% of copper and 521 ppm of molybdenum. The mine plan involves a ramp-up of seven years to achieve the production steady state of 140,000 tpd and a life of mine beyond 40 years.

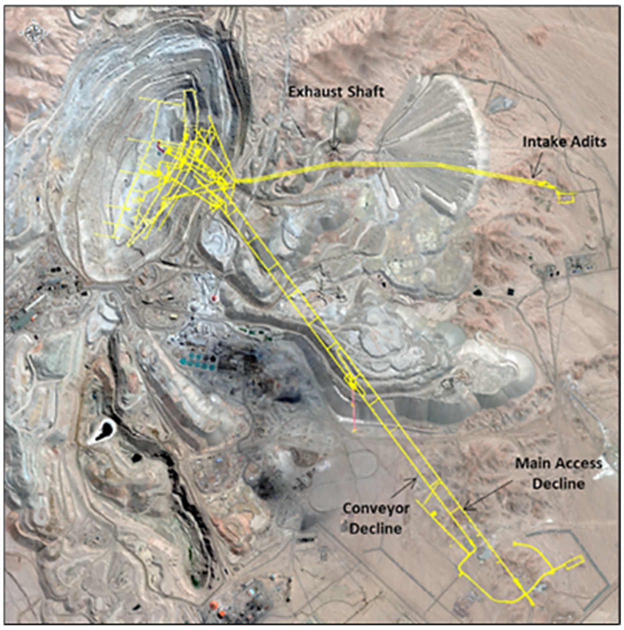

Figure 6 Chuquicamata underground mine (Flores & Catalan 2019).

The production system involves a large Block Cave using Macro-Blocks (MB) of 70,000 m^2 each, the first was situated approximately 230 m below the lowest level of the pit bottom, where two levels operating simultaneously are supplying ore to achieve the steady state. A single MB consists of eight extraction drives using the Teniente layout, with spacings of 32 × 16 m and 32 × 20 m for the arrangement of extraction drives and drawbell drives. A rock pillar of 20 m separates the production and undercut levels (Mühlenbrock et al 2020).

In Chuquicamata Underground, intensive preconditioning was used for the purposes of managing cavability, cave growth geometry and fragmentation. Intensive preconditioning was performed in the first macroblock as shown in Figure 7.

Preliminary in situ trials were also conducted to establish key operational parameters following similar objectives as those identified in the Cadia East project. These trials supported the definition of final design parameters.

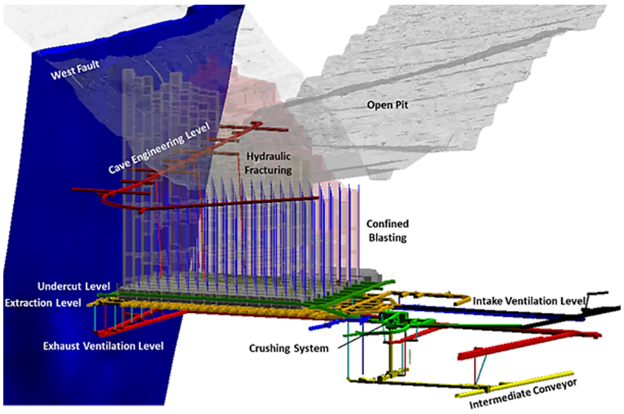

Figure 7 Intensive preconditioning macroblock N01/S01 Chuquicamata UG mine (Flores & Catalan 2019).

2.2.1. In situ HF preconditioning trial

Technical parameters were determined from different in-situ trials during the early phases of engineering studies to validate the full implementation in the PMCHS geotechnical conditions. To estimate the growth of the hydraulic fracture, the influence of permeability and hydraulic conductivity on the injection rate, and the propagation of the fracture, a simple Radial analytical model was evaluated by varying the injection rate using this technique.

2.2.2. Confined blasting preconditioning trial.

A comprehensive in situ trial and monitoring program was also carried to further understand, quantify and subsequently model the effect of explosive induced preconditioning. As in previous studies, the trial was supported by arrays of triaxial accelerometers with the ability to measure peak acceleration and vibration amplitudes very close to the explosive charges (i.e. to within 5 m). Analysis associated with the contribution of the first and closest preconditioning hole, indicated average peak particle velocity values of 735 mm/s, 985 mm/s and 1475 mm/s for the radial, transverse and vertical components respectively at an approximate distance of 8 m. The mean peak vector sum was estimated to be ~1920 mm/s. Figure 8 shows the typical set up of one of the confined blasting trials.

The post-processed data from the monitoring program was used to study near field vibration attenuation and used as input for the calibration of the Hybrid Stress Blast Model, HSBM (Onederra et al, 2013). The aim of the advanced modelling stage was to estimate the zone within the rock mass which could be identified as “pre-conditioned”. Modelling results indicated that drillhole configurations in 3 and 4 hole modules at distances of 8 to 10 m were theoretically adequate to induce incipient damage, that is macro fracturing within the vicinity of the charge and micro fracturing expected within interaction zones.

Figure 8 Preconditioning by blasting full-field trials PMCHS (QMR Blasting 2019).

2.2.3. Implementation of intensive preconditioning at Chuquicamata underground

For the implementation stage, and with regards to hydraulic fracturing, six (6) HQ3 holes were drilled in the central MBs (N01 and S01), developing a total of 195 hydraulic fractures. The separation between fractures was approximately between 1.5 m and 2.5 m in where drillholes geotechnical conditions were feasible. Additionally, MBs N02, N42 and S02 were also hydro fractured. A total of 423 fractures were generated of which 385 were validated with sustained propagation pressure, injection rate and field observations. Figure 9 depicts the implementation of the HF preconditioning program for the Central macroblocks at PMCHS.

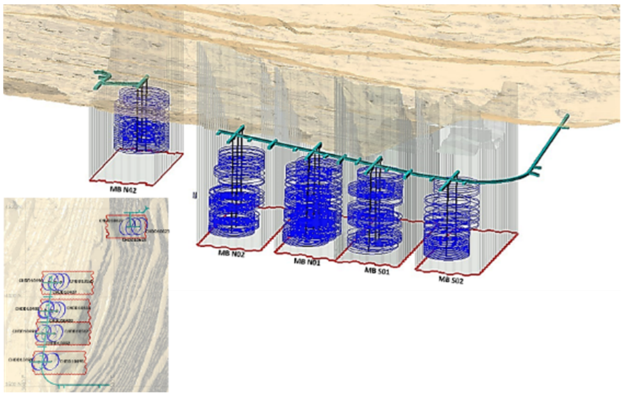

Figure 9 Implementation of Hydraulic Fracturing in central macroblocks.

With regards to confined blasting in the MB S01/N01, a total of 229 holes were drilled, 112 from the extraction level Drawbell access drives, at the drawbell midpoint; and 107 from the undercut drives. Confined blast preconditioning considered modules of three (3) to four (4) simultaneously initiated explosive charges to maximise the likelihood of wave superposition and coupling. A total of 67 modules were fired during the entire implementation period (Mühlenbrock et al 2020).

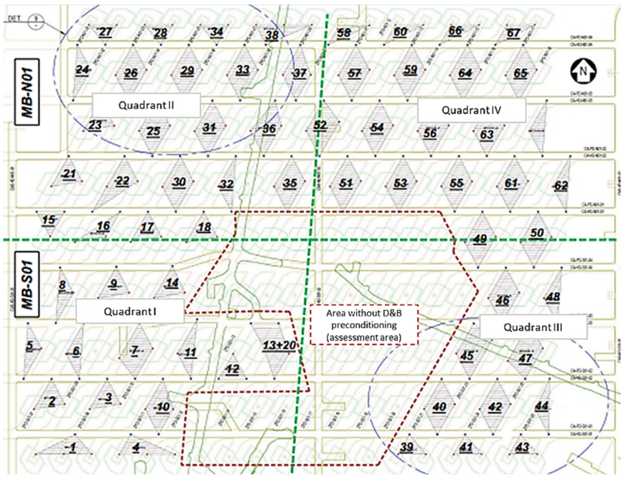

Figure 10 Plan view implementation drilling and blasting confined preconditioning at central macroblock N01/S01 (QMR Blasting 2019).

Figure 10 provides a plan view of the preconditioning carried out at MB S01/N01. Additionally, as shown in Figure 10, an area without preconditioning was defined to conduct post-evaluations and comparative analysis.

3. LEARNINGS FROM APPLIED RESEARCH

As discussed earlier, applied research played an important role in the successful implementation of preconditioning techniques. This section provides a brief description of some of the key learnings.

3.1. Applied research of Hydraulic fracturing in caving.

There is an extensive amount of research and know-how of hydraulic fracturing practices in the oil and gas industries for permeability enhancement or well stimulation. Transition into hard rock mining was driven by the need to "modify" the condition of rock masses that were outside the envelop of cavable ore bodies.

Some of the early research work was conducted as part of the International Caving Study (ICS) I and II (Chitombo 2005). In ICS II, site experiments of preconditioning by hydraulic fracturing were undertaken in Australia and Chile. These experiments were implemented to provide design criteria for carrying out efficient and effective rock mass preconditioning prior to caving moderately stressed and naturally jointed rock masses. The objectives of this particular research were to define the size and orientation of hydraulic fractures; map their interaction with natural fractures; quantify the induced changes to the rock mass within the prevalent in situ stress field; quantify and develop methods for modelling the fluid leakage into the rock mass; measure relative amounts of opening and shear fracture growth and predict the amount of each; and to ultimately estimate rock mass cavability and primary fragmentation before and after a hydraulic fracturing program.

In Australia, tests were undertaken at Northparkes Mine E26 Lift 2 block cave (van As et al. 2004). The work at Northparkes mine established the basis for designing and applying preconditioning and post conditioning parameters in block and panel caving. In this work, there were no significant changes observed in relation to the effects of hydraulic fracturing on overall rock mass strength and in situ stresses.

In Chile, Chacon et al. 2004 documented full-scale HF preconditioning design and implementation tests in the Inca Central West area of Codelco's El Salvador Mine. These field tests showed that hydraulic fractures in competent rock masses containing natural discontinuities with hard mineralization could be successfully generated. Operational improvements such as reductions in secondary fragmentation and lower number of hang-ups were reported; in addition to a reduction in drawpoints damage. However, these tests did not quantify the effects of hydraulic fracturing on rock mass strength and overall caving performance.

Subsequent implementations in block and panel caving operations such as Northparkes, El Salvador Mine, Andina, Ridgeway Deeps, El Teniente, Cadia East, Chuquicamata underground mine and Deep Mill Level Zone have shown important benefits including improvements in rock mass seismic behaviour, quantified by a reduction in the number of seismic events of high magnitude; and an increase in the activity of smaller-magnitude seismic events. Improvements in overall cavability and propagation have not been documented except for the work recorded by the extraction of PC1 at Cadia East using intensive preconditioning.

3.2. *Confined blasting preconditioning research.*

As outlined by the case studies presented in this paper, both in situ monitoring and advanced modelling were central to the definition of design parameters. Confined blasting at the scales required was, however, an area that required more attention as the advanced blast modelling techniques available had to be adequately calibrated; and the implementation of near field blast monitoring was not trivial.

The authors of this paper were involved in a number of near field blast monitoring campaigns to better understand the degree of potential interaction between the induced stresses generated by the simultaneous detonation of confined charges (Catalan and Onederra 2017). An example of such test is shown in Figure 11, in this case, several accelerometers and triaxial geophones were fully grouted, including for the first time the use of 100,000 g radial accelerometers, installed very close to the explosive charges. This test consisted of 45 m and 50 m long blastholes (BPC1 and BPC2) with a charge length of 25 m and 30 m respectively. The explosive used was a pumpable Emulsion with a density of 1.2 g/cc. Note that horizontal boreholes (yellow dashed lines) had to be drilled from an upper-level drive to monitor within the region of interest.

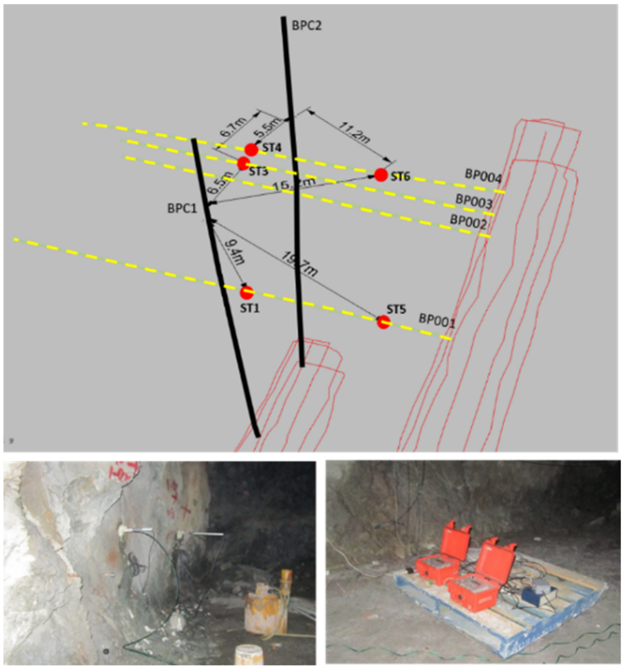

Figure 11 Near field monitoring using a combination of accelerometers and geophones. Image also shows the data acquisition systems (Onederra and Quidim, 2013).

This test was implemented to study the degree of interaction by comparing particle velocity amplitudes in different regions of the preconditioned volume. Results showed higher than expected particle velocities and the significant differences between measurements provide evidence of positive interaction of waves occurring between the two simultaneously initiated charges. For instance, accelerometer ST4 located 5.5 m from BPC2 recorded a peak radial velocity of 3600 mm/s after adequately integrating the acceleration waveform. Post blast assessment of the region correlated well with particle velocity damage thresholds estimated for this particular rock mass.

Results from these types of trials provided a deeper insight into the potential extent of damage and alluded to the generation of both the macro and micro scale fractures. At the micro scale, recent controlled experiments have shown how it is possible to induce micro fractures in intact rock samples by subjecting them to detonation induced stresses (Lopez, 2023 and Lopez et al 2023).

Figure 12 Spall damage due to reflection mechanisms when primer location was 8m from the top of the stemming zone.

3.2.1. Advanced computational modelling

As discussed earlier, particle velocity measurements have provided input for the calibration of computational models such as the HSBM (Furtney et al 2009). This has supported the definition of design and charging parameters such as primer positioning. The model calibration process involves mapping velocities against history points at distances equal to the ones implemented in the in-situ monitoring program.

Through careful direct observation and the utilisation of a calibrated model, an important insight was gained regarding the precise placement of the initial initiation primer in relation to the stemming region. Damage on drives in preliminary confined blasting preconditioning trials were observed when primers were located 8 m from the stemming zone. This meant that higher than expected blast induced stresses were generated downwards into the drive from this 8 m column, causing damage through tensile spalling mechanisms (see Figure 12). Modelling work helped identify that for the prevalent conditions, a 4 m column would be best to eliminate this type of damage.

Further modelling applied at both the Cadia East and Chuquicamata underground projects provided support to define the number of blastholes and size of the preconditioning modules by evaluating multi hole configurations (see Figure 13). For the Chuquicamata case study it was found that the geometric configurations (i.e. distances between holes) in 3 and 4 hole modules for the two predominant lithologies were adequate to induce incipient damage. The models showed potential interaction at distances of 8 to 10 m. This type of analysis follows the approach first proposed by Onederra et al (2013) during the initial research into the application of the HSBM platform.

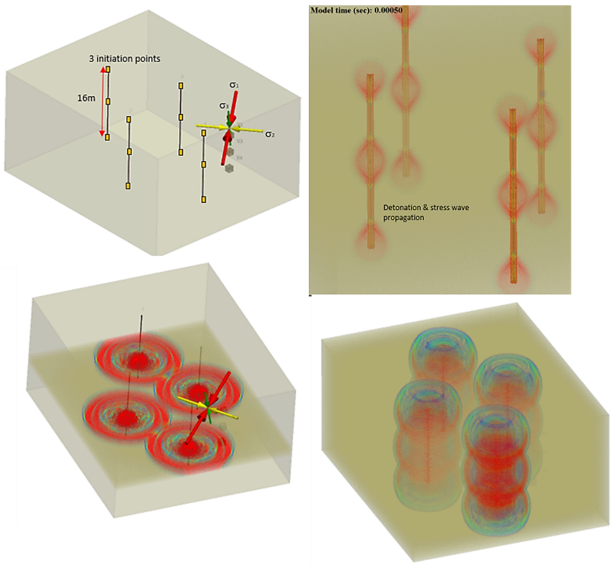

Figure 13 Typical multi hole modelling output quantifying interaction between explosive charges in a 4 hole module. Red contours track the 1000 mm/s level.

The initial concepts aimed at identifying fracturing, disturbed and interaction zones within a particular module as shown in Figure 14.

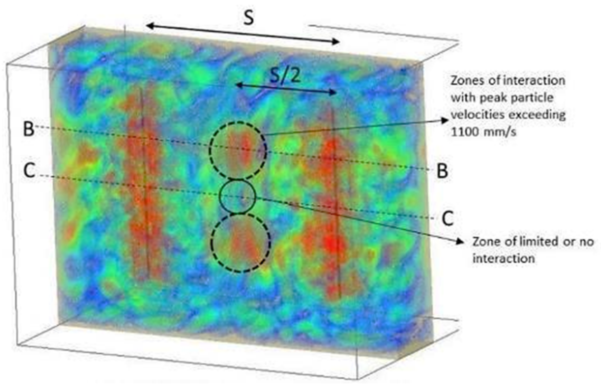

Figure 14 Isometric and plan section views describing the criteria used to define disturbed zones from stress interaction/superposition (Onederra et al 2013).

4. EVALUATION OF INTENSIVE PRECONDITIONING ON CAVING PERFORMANCE

Most of the debate related to the effectiveness of one form or both forms of preconditioning hinges on the difficulties and costs of quantifying key performance indicators over time. Catalan (2014) and Catalan et al (2017) attempted to quantify the impact of intensive preconditioning on cave performance. The evaluation involved a benchmarking study that included a number of block and panel caving operations in Chile, South Africa and Australia. It focussed on operational data such as induced seismicity and draw rates, comparing the outcomes of different preconditioning techniques, including intensive preconditioning. This section provides a summary of that analysis to generate further discussion and help define a common standard to evaluate preconditioning performance.

4.1. Assessment of caving behaviour using micro seismicity.

Figures 15 and 16 consolidate the results of induced-mining seismicity for the caving operations that were part of the benchmarking study. With regards to the behaviour of a rock mass with one preconditioning technique, (i.e. hydraulic fracturing or confined blasting), the analysis indicated that intensive preconditioning showed a reduction in the likelihood of high magnitude events (see Figure 15), while at the same time diminishing considerably the frequency of seismicity. When comparing the event frequency and magnitude of a rock mass without preconditioning, mining induced seismicity is less favourable than a rock mass with intensive preconditioning (see Figure 16).

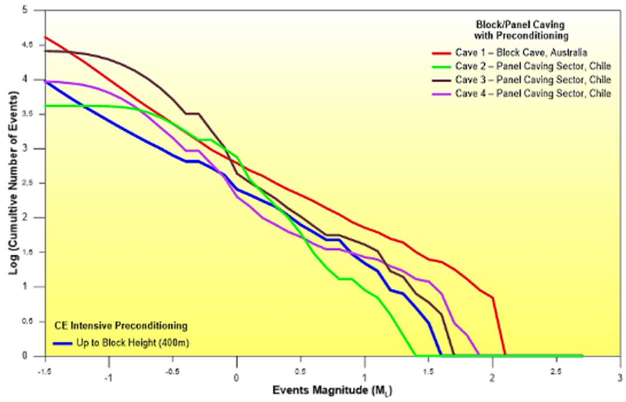

Figure 15 Summary frequency-magnitude for induced-mining seismicity with preconditioning.

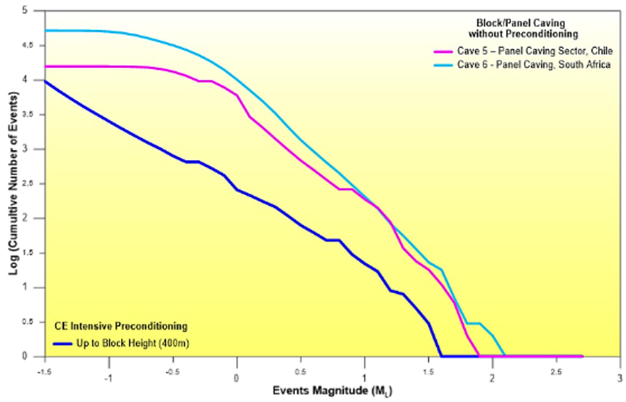

Figure 16 Summary frequency-magnitude for induced-mining seismicity without preconditioning.

4.2. Comparison of caving performance using draw rates.

A comparative analysis was also carried out for draw rates recorded during caving until the breakthrough process. In this case, a relative comparison was carried out with the ratio tonnes/day-m^2 because it correlates well to daily production rates (tonnes/day) for a given influence area (m^2) of individual drawpoints.

Figure 17 shows draw rate versus block extraction. The analysis indicated that the intensive preconditioning base case reached draw rate values 15% to 28% higher than block and panel caves that applied hydraulic fracturing as the preconditioning technique. It is interesting to note that draw rates can be up to 38% higher in the case where intensive preconditioning was applied. Table 1 provides a summary of cave propagation rates to evaluate performance.

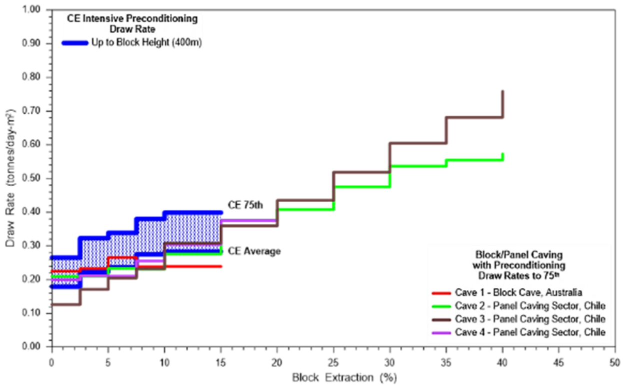

Figure 17 Draw rates during the cave propagation up to 400m (block height) and Block/Panel caving without preconditioning.

Table 1 Cave propagation rates during the breakthrough

Cave propagation rate	Reference	Caving condition	Preconditioning technique
538 mm/day	CE PC1	Cave back reached the block height design	Intensive preconditioning
345 mm/day	Cave 1	The breakthrough towards an exploited area	Preconditioning by Hydraulic fracturing
415 mm/day	Cave 2	The cave back reached an exhausted area	Preconditioning by Hydraulic fracturing
355 mm/day	Cave 3	The breakthrough towards an exhausted area	Preconditioning by Hydraulic fracturing
328 mm/day	Cave 4	The cave back reached an exhausted area	Preconditioning by Hydraulic fracturing

Figure 18 shows that the draw process during caving and to breakthrough from the base case (intensive preconditioning) is much more favourable than for Cave 5 and Cave 6. As shown, draw rates are between 10% and 15% higher in relative terms. Interestingly, draw rates are also shown to be 25% higher than block / panel caving without preconditioning.

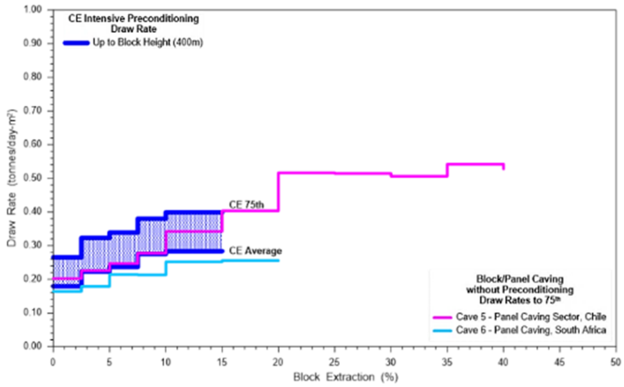

Figure 18 Draw rates during the cave propagation up to 400m (block height) and Block/Panel caving without preconditioning.

As summarised in Table 2, those cases without preconditioning achieved cave propagation rates much lower than the base case where intensive preconditioning was implemented.

Table 2 Summary cave propagation rates during the breakthrough

Cave propagation rate	Reference	Caving condition	Preconditioning technique
538 mm/day	CE PC1	Cave back reached the block height design	Intensive preconditioning
120 to 135 mm/day	Cave 5	The cave back reached an exhausted area	Without preconditioning
35 to 50 mm/day	Cave 6	The cave back reached the bottom of an open pit	Without preconditioning

Experiences to date have shown that intensive preconditioning has been beneficial not only on aspects associated with seismicity management, cave initiation and propagation; but also shown to achieve clear improvements in secondary fragmentation and thus overall mine productivity.

5. NEED FOR RESEARCH PARTNERSHIPS

In this paper we have focused on intensive preconditioning case studies but also summarized learnings from applied research which were driven by strong partnerships between industry and academia. Clearly, improvements in the implementation of preconditioning techniques as well as objective quantification of key performance metrics will require partnerships to continue. The work to date still points to a number of questions that limit our ability to develop robust guidelines that can be applied in a wider range of conditions, including:

- What is the true impact of hydraulic fracture initiation, blast induced stresses and gas loading on rock material and rock mass properties? and how does the in-situ stress state influence this impact?
- Can acoustic emission or optical fibre technology effectively capture the cumulative effects arising from external and internal forces throughout the preconditioning process?
- What type of novel active instrumentation could help us capture and better quantify fracture initiation and propagation both in hydraulic fracturing and confined blasting preconditioning processes?
- What specific constitutive modelling parameters are essential for accurately analysing and quantifying cave performance and the response of rock masses in cave behaviour modelling?"

At the time of writing this paper, Rio Tinto and The School of Mechanical and Mining Engineering of the University of Queensland had embarked on a new three year research partnership to tackle the above questions. The project entitled "Leading Practice in Hard Rock Preconditioning - Fundamentals and Engineering Design Guidelines" is currently underway. The aim of this project is to develop the know-how necessary to define a consistent and transferable set of the engineering design guidelines for preconditioning applications involving both hydraulic fracturing and confined blasting.

This involves the development of a methodology to appropriately quantify the impact of preconditioning on the targeted rock mass and thus derive a constitutive model to evaluate caving mechanics and its overall performance. This is critical, so that an objective definition of metrics associated with the successful design and implementation of hydraulic fracturing and confined blasting techniques:

Figure 19 shows the preconditioning research strategy to achieve the main objectives of the program.

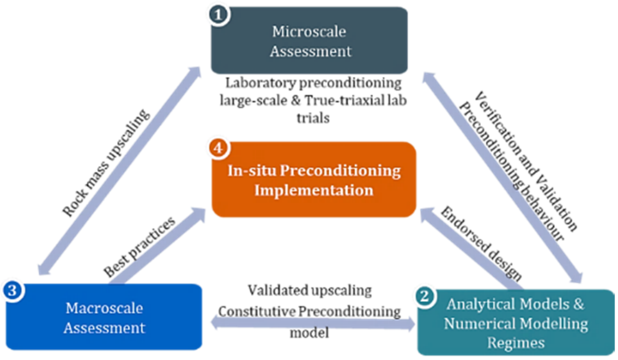

Figure 19 Preconditioning research strategy.

6. CONCLUSIONS

This paper has summarised the authors' experience in the implementation of intensive preconditioning techniques in two major caving operations. It has captured the processes implemented to define key design parameters supported by applied research efforts.

Given the wide range of geotechnical conditions and constraints including project and production requirements, it is envisaged that every future Caving operation may need different ways to incorporate preconditioning techniques. There is therefore a need to further develop, consolidate know-how through controlled experiments, advanced computational modelling and in-situ trials using new and emerging procedures to evaluate preconditioning techniques.

Preconditioning in competent hard rock masses continues to be a challenge due to the complex mechanisms at play, the engineering design and implementation process currently involves a combination of modelling techniques and site-specific trials that can be costly and only applicable to the geotechnical domains under consideration.

A more transferrable and repeatable process is needed to develop engineering guidelines that could be consistently applied across a range of conditions, including deep and complex geotechnical environments. Site implementation and monitoring will still be a key part of the validation process and there are a number of historical and current case studies that can support this; however, there is still a knowledge gap associated with the poor quantification of the impact that one or two forms of preconditioning may have on the rock mass of interest.

Currently, certain assumptions are made regarding the potential effects of preconditioning on the overall stiffness and strength of the rock mass; and these “modified” properties are used as input into subsequent models to simulate the potential impact on cave propagation and/or primary fragmentation, these initial assumptions and the process that follows lack rigour and are not based on sound scientific analysis. In addition, there is limited research on the potential benefits associated with downstream comminution energy requirements and potential reductions on the energy footprint of large caving operation.

ACKNOWLEDGEMENTS

The authors extend their heartfelt appreciation to the late Prof. Gideon Chitombo, whose visionary leadership was the cornerstone of the International Caving Studies. His dedication to fostering research-industry partnerships was instrumental in shaping the trajectory of our work. We are also grateful to the commitment of underground operators and engineers whose tireless efforts contributed to the trials, and operational success of intensive preconditioning implementation at Cadia East and Chuquicamata Underground. Their ingenuity and professionalism were pivotal in overcoming the challenges encountered during these endeavours. Finally, we also express our gratitude to Rio Tinto and the University of Queensland for their commitment to fostering collaborative research and allowing the publication of this paper.

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