Deep Mining 2024 – P Andrieux & D Cumming-Potvin (eds)
© 2024 Australian Centre for Geomechanics, Perth, ISBN 978-0-6450938-9-6
doi:10.36487/ACG_repo/2465_83

Trialling the application of hydraulic preconditioning at Creighton Deep

Farid Malek [a,*], **Sean Maloney** [b], **Alex Hossack** [a], **Simon Nickson** [a]

[a] *Vale Base Metals, Canada*

[b] *MIRARCO Mining Innovation, Canada*

Abstract

Vale has completed several phases of work to explore the use of hydraulic preconditioning as a mechanism for the reduction of the maximum magnitude of mining-induced seismic events in highly stressed ground. Hydraulic preconditioning involves the isolation and pressurisation of diamond drillhole intervals to create additional fracture systems to reduce the seismic response by lowering the rock mass quality. The ultimate goal is to enable rotation of the major principal stress around future mining areas to reduce stress related interaction between adjacent orebodies.

The phased work plan was executed at Vale's Ontario Operations mines between 2017 and 2024. Phase 1 was designed around determining if fracture initiation could be executed under high-stress conditions in strong rock using a high-pressure, low flow rate pumping system at Copper Cliff Mine. Phase 2a involved the underground deployment of a prototype high-pressure, high flow rate pumping system at Creighton Mine to evaluate the ability to initiate and propagate fractures in rock mass at greater depth. Phase 2b involved a full-scale preconditioning curtain application, which was completed in early 2024, to trial stress shadowing between two different orebodies at Creighton Mine.

This paper will briefly review each of the phased work plans and results, with particular comment on the preparation logistics that evolved as the project advanced. Emphasis will be placed on the full-scale preconditioning curtain application (Phase 2b) and the associated results obtained so far. A review of the challenges and benefits of utilising a hydraulic preconditioning approach in deep mining applications will be presented.

Keywords: *hydraulic preconditioning, treatment, seismic, fracture, initiation, propagation*

1 Introduction

Vale supported an ultra deep mining network (UDMN) project managed by MIRARCO Mining Innovation between 2015 and 2018, through a contribution to the UDMN Hydraulic Preconditioning Project. The Geomechanics Research Centre at MIRARCO was the lead proponent of the project, which was funded by UDMN and focused on the issue of seismicity management in ultra deep mines (i.e. greater than 2,500 m in depth). The intent was to demonstrate that hydraulic fracturing can permanently alter the character of the rock mass on a regional scale, such that the hazards associated with larger scale seismic events could be mitigated. The first stage of the project, referenced as Phase 1 for this paper, was undertaken at Vale's Copper Cliff Mine where it was demonstrated that hydraulic fractures could be initiated at depth in the Canadian Shield rock mass (Altwegg 2017). A visit to Codelco's El Teniente Mine was also conducted at this time to benchmark the use of hydraulic preconditioning (Maloney et al. 2016) in the mining environment. A subsequent component of work aimed at trialling propagation of fractures, could not be completed within the UDMN time frame but was subsequently undertaken at Creighton Mine under Vale sponsorship. The first component of this effort, denoted Phase 2a, was successfully executed in November 2021 (Maloney 2022).

---

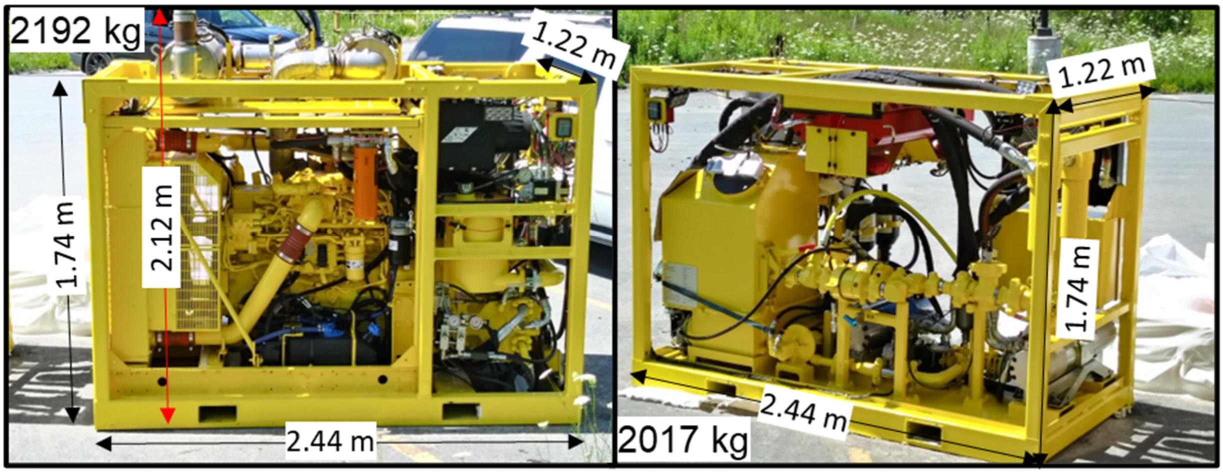
[*] Corresponding author. Email address: farid.malek@vale.com

Following up on the success of this trial, a full-scale Phase 2b treatment was undertaken at Creighton Mine and this paper details the results of this pilot application and anticipated next steps.

2 Phase 2 fracture propagation and full-scale trial

The Phase 1 fracture initiation trial confirmed the ability to initiate fractures in Sudbury conditions and was completed in 2017 at Copper Cliff Mine on 4425 Level. It is important to note that fracture initiation typically requires a high-pressure, low volume pumping system, whereas fracture propagation requires a high-pressure, high flow rate pumping system.

The fracture propagation work planned in Phase 2 required the use of a larger water volume pumping system to feed hydraulic fracturing apparatus within diamond drillholes. MIRARCO proceeded to work on the design of a modularised underground pumping system in 2017 to mimic a much larger system that might be applied in typical oil industry scenarios. The system design included consideration of typical cage dimensions and allowable loads in place at Vale's Ontario Operations and resulted in the fabrication of two separate modules that could be connected underground. The pumping system was ordered in 2018 and the final prototype was received by MIRARCO in June 2020 (Figure 1) after several unexpected delays associated with pump development.



(a) (b)

Figure 1 Prototype high volume pumping system. (a) Engine module; (b) Pump module

The Phase 2 program was split into two sub-phases, Phase 2a and Phase 2b. Phase 2a was designed to test the ability to initiate and propagate fractures with the prototype pumping system at depth. Phase 2b was directed at conducting a full-scale trial using the design parameters determined in Phase 2a.

The objectives of the Phase 2a component were to confirm the following:

- hydraulic fractures could be generated under higher in situ stress levels in competent rock
- fracture propagation could be conducted to assess future ground modification treatment potential
- establish the procedures (including enhanced safety protocols) necessary to effectively modify the behaviour of the rock mass.

The Phase 2a fracture propagation trial was completed at a trial site located at the 5150 Sandfill Station on the 8200 Level (2,500 metre below surface) of Creighton Mine, monitored by an IMS (Institute of Mine Seismology) seismic array. An initial trial was attempted in November and December of 2020 using an NQ treatment hole and 3 NQ observation holes to detect fracture propagation at 5 m and 10 m intervals from the treatment hole location. The treatment hole experienced borehole breakouts and setting the packer system at the correct depth proved difficult; consequently, an attempt to propagate a fracture at a shallower depth was initiated. Pressurisation progressed well until the packer pressure reached 56 MPa (8,000 psi) whereupon the lower packer element ruptured. At this time, the interval or injection pressure had only reached 31 MPa (4,500 psi) in relation to an expected pressure of more than 65 MPa for fracture initiation. The trial was immediately terminated and the downhole assembly successfully recovered without difficulty. There is always a risk that a ruptured bladder becomes entrapped in a breakout feature or open fracture, and assembly recovery becomes more difficult.

An alternate strategy for diamond drilling a new set of treatment and observation holes for a second trial attempt was adopted from observations of practices at Newcrest's (now Newmont) Cadia Operations. The required diamond drillholes were drilled, grouted with high strength grout, and subsequently redrilled while the drill remained on the same hole set-up. This practice allowed for some control of borehole breakout and permitted the trial to proceed at the required hole depths. Due to operational constraints, drill crew availability and Covid-19 related delays, resumption of the trial was delayed for a year and the second propagation trial was conducted in November 2021. Post test examination of the borehole wall with acoustic televiewing and careful analysis of the seismic record by IMS confirmed that a fracture had been initiated and propagated at least as far as the observation holes 5 m away.

3 Phase 2b full-scale preconditioning design

The Phase 2b work was designed around conducting a full-scale trial in an appropriate location at depth based on the conclusion from Phase 1 and 2 a that suggested a fracture can be created and propagated at depth to a 5 m radius within a 10-minute interval.

3.1 Objectives

The objectives of Phase 2b were:

1. To create a network of fractures between two adjacent orebodies, the 400 and the 400 Mid Orebodies, such that a stress shadow is created, limiting interaction between them (Figure 2).
2. To establish protocols and procedures for future applications of the hydraulic preconditioning technology.

The effectiveness of the approach will only be realised once mining occurs in the 400 Mid Orebodies.

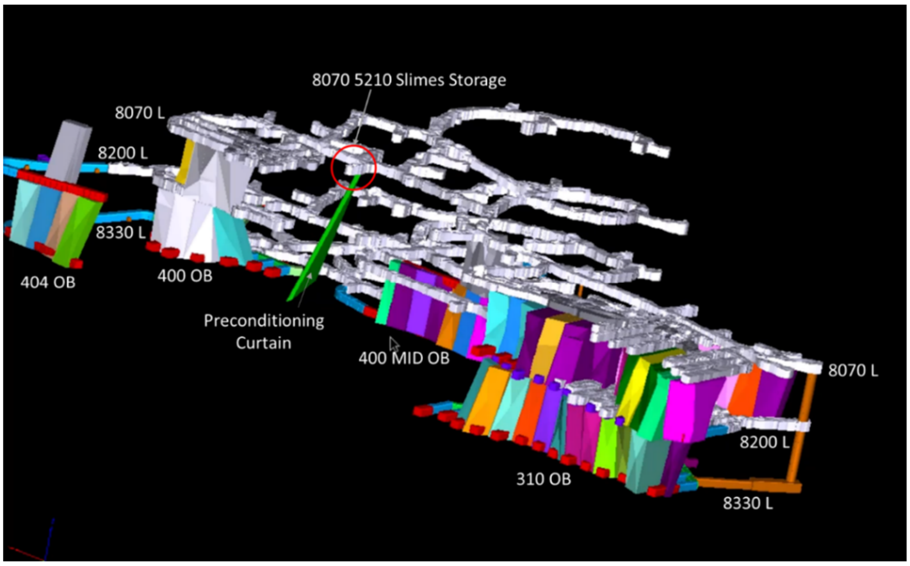


Figure 2 Planned location of preconditioning curtain between the 400 and 400 Mid Orebodies

3.2 Design approach

Much of the work in Phase 1 (fracture initiation) and Phase 2a (fracture propagation) was based on a semi-manual process of raising and lowering the packer assembly, utilising a tripod and winch system. Although this process worked well, it was determined that any future applications of hydraulic preconditioning would require a more mechanical process and plans were put in place to have a diamond drill permanently set-up on each treatment hole for the purposes of positioning the packer assembly.

3.2.1 Site selection and preparation

The treatment site selected was the 5210 Slimes Storage Bay on the 8070 Level (2,460 metre below surface) of Creighton Mine, as illustrated in plan view on Figure 3. Figure 3 also shows two lines (L1 and L2) representing the azimuth and extent of the planned treatment drillholes. Section views of the six treatment holes are presented in Figure 4. Observation holes were removed for Phase 2b but drilled treatment holes on the same line were used as observation holes. In addition to providing an optimal location for drilling of the treatment holes, the site offered ease of access, amenities (water, air and power) and minimal impact on mine operations.

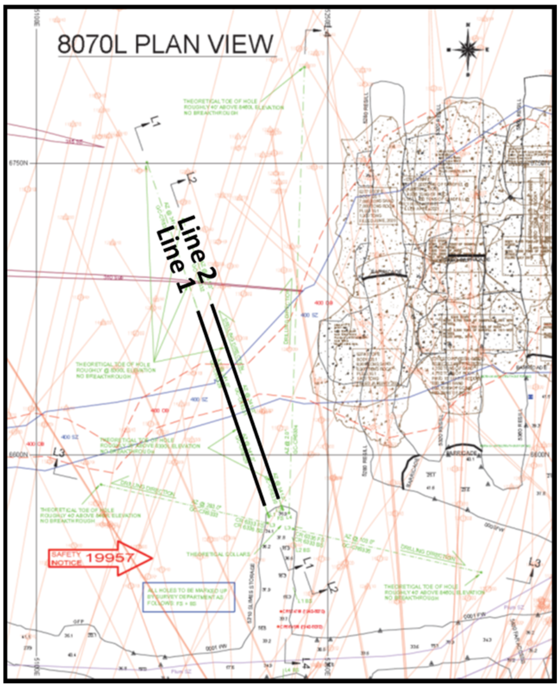


Figure 3 Plan view of treatment holes rings (Line 1 and Line 2) drilled on 8070 Level

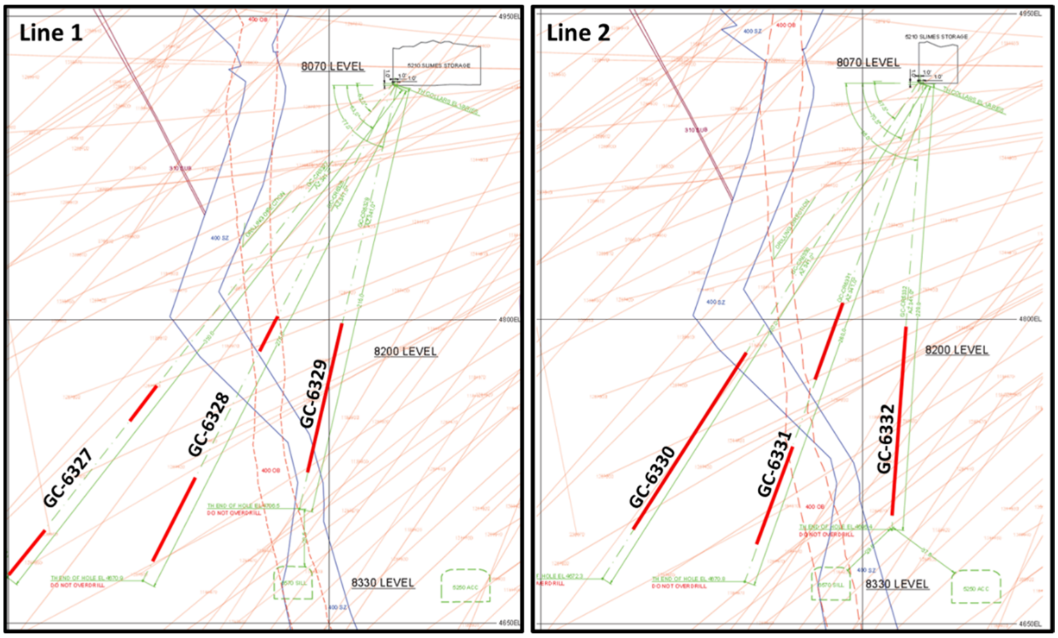


Figure 4 Line 1 and Line 2 section views of treatment holes drilled on 8070 Level with actual preconditioned intervals shown in red

Re-purposing of the 5210 Slimes Storage Bay involved setting up an alternate location for slimes storage and completing some required ground support rehabilitation. A concrete pad was also poured at this time to serve as a work platform and to facilitate positioning of diamond drill and preconditioning equipment. Prior to the commencement of activities at the selected site, both a management of change process and job hazard assessment analysis were undertaken in collaboration with associated stakeholders to identify and mitigate identified risks.

3.2.2 Equipment

The introduction of hydraulic preconditioning at Creighton Mine required the acquisition of specialised equipment, some that had seen prior use in Phase 2a and some new hardware that was better suited to an industrial application. These included a high-pressure/high flow pumping system, high-pressure BQ drill rods and a single feed, integrated straddle packer assembly. A photo of the Phase 2b set-up is provided in Figure 5.

Figure 5 Equipment set-up on 8070 Level for a preconditioning treatment

3.2.3 Treatment execution

The execution of the preconditioning treatment at any one of the site's six drillholes, including pre- and post-treatment processes, involved many steps. The treatment steps applied in this exercise are summarised:

1. Diamond drill HQ sized borehole to depth; box, photograph and log recovered core.
2. Log borehole with acoustic (ATV) and optical (OTV) televiewers (the latter is optional).
3. Fill borehole, from the bottom up, with high strength, no-shrink cement grout.
4. Re-drill grouted borehole (employing a previously used bit).
5. Re-log borehole with ATV to check hole integrity and capture pre-treatment data.
6. Based upon ATV records and treatment design objectives, select fracture intervals (current limitation of minimum 1.5 m fracture spacing is dictated by the inflatable packer length).
7. Attach integrated straddle packer assembly to custom, high-pressure BQ drill rods ensuring that O-ring washer is positioned properly and undamaged.
8. Add sufficient high-pressure rods with O-ring washers to position integrated tool at lowest desired fracture position in the borehole.
9. Install retention plate at top of drill string and chain to drill anchors.
10. Attach high-pressure hose to top of drill string ensuring that whip-checks are in place.

11. Connect high-pressure hose to pump and open valve.
12. Connect 76 mm water supply line from water storage tank to pump and complete pump priming process.
13. Start high-pressure pump and ramp flow up until pressure peaks, further increasing flow rate until desired injection time is achieved; record pressure and flow rates.
14. Stop pumping; open pressure relief valve if pressure is slow in reducing.
15. When pressures are relieved, release chains on retention plate and raise tool 1.5 m placing lower packer where upper had previously been located).
16. Repeat procedure for each fracture.
17. Upon completion of hole treatment, re-run ATV to validate fracture generation.

4 Phase 2b full-scale preconditioning results

4.1 Fracture monitoring

Since the purpose of rock mass hydraulic preconditioning is to create additional damage thereby facilitating adjustment to imposed stresses in a less violent manner, means of assessing its success, in the short-term, were adopted. These included real-time monitoring of pump performance and pre-treatment and post-treatment televiewer logging of the borehole.

4.1.1 Pressure and flow monitoring

The high-pressure pumping system allowed the pump operator fine control of the flow with real-time display of both discharge pressure and flow (see Figure 6). Actual pressure and flow values are logged to disk at 30 second intervals for archival purposes. In addition, a video camera, focused on the hole collar, permitted pump operator viewing of flow from the injection hole. This information was then subjectively assessed by the operator to determine if fracturing and propagation had been successfully achieved or if the interval sealing had been breached or a packer had ruptured (sudden, rapid pressure loss). The record from Hole CR6332 illustrated in Figure 7 clearly demonstrates this issue. On 6 December 2023, peak injection pressures around 60 MPa were consistently achieved with flows of 50 litres/minute. On 7 December 2024, the first attempt was unsuccessful due to packer failure and subsequent attempts were also deemed unsuccessful as pressures tended to top out around 40 MPa with substantial flow being noted from the treatment hole. These observations were subsequently confirmed by the post-treatment televiewer logging and seismic monitoring.

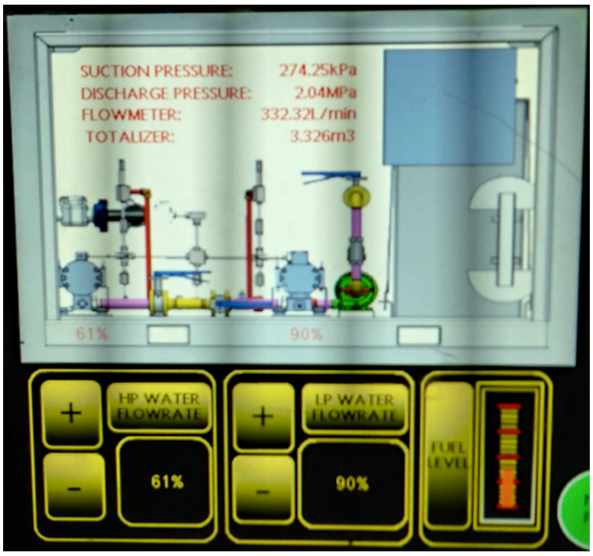
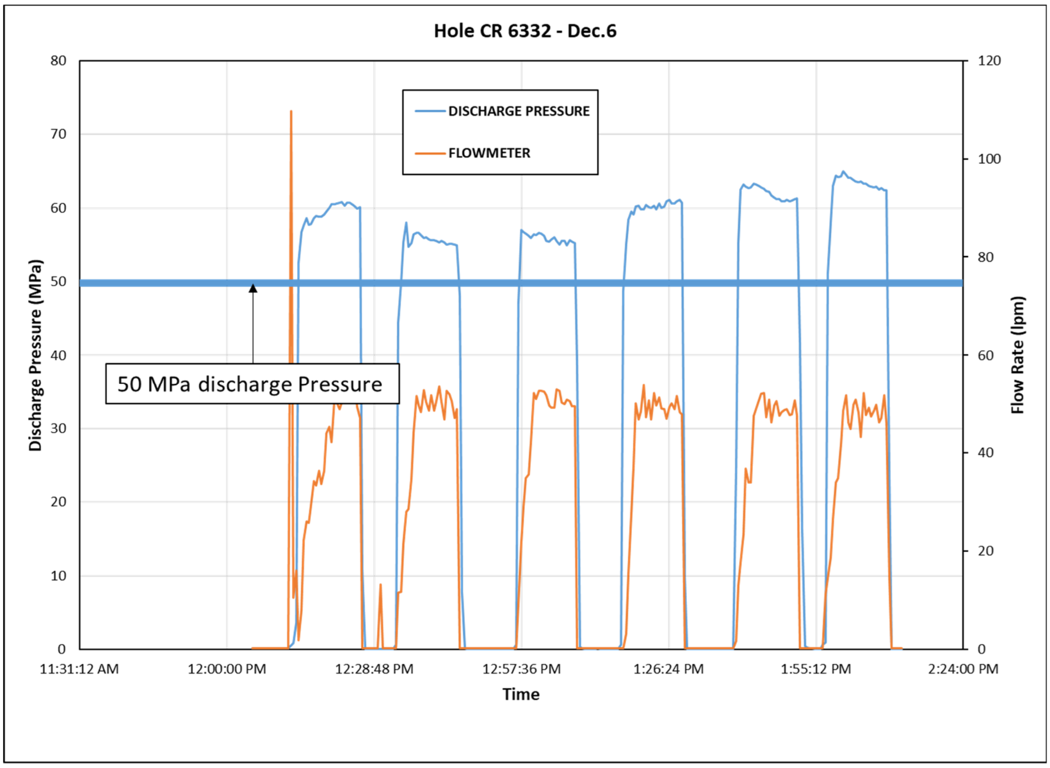
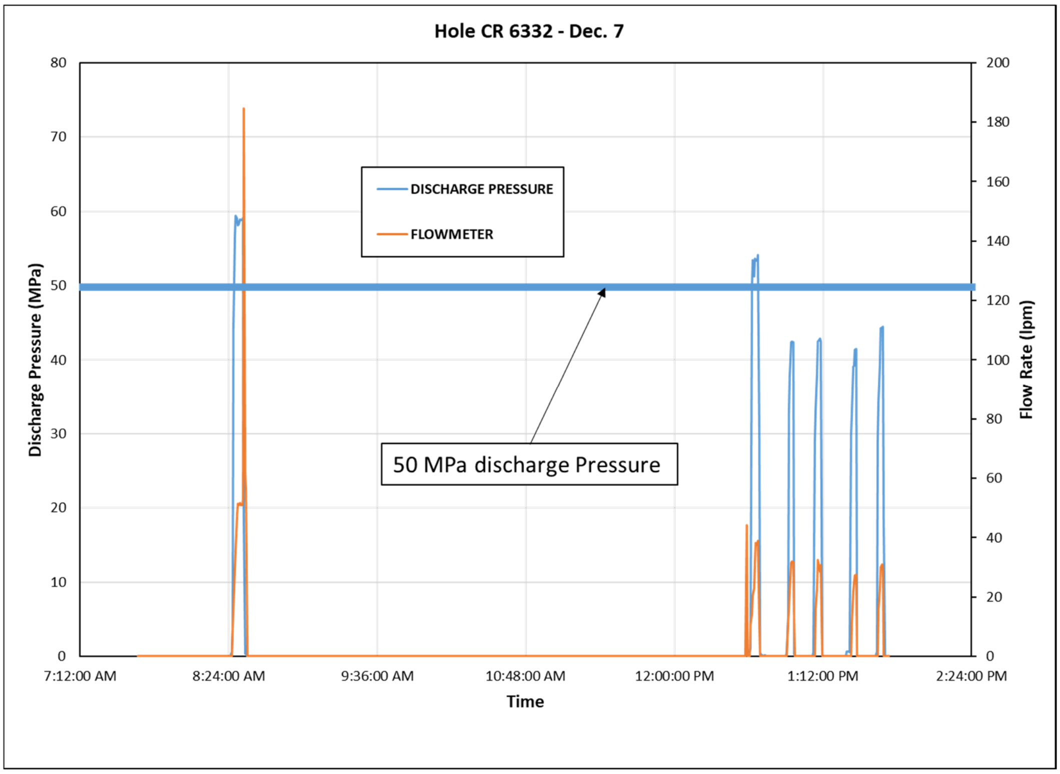

SUCTION PRESSURE: 274.25kPa
DISCHARGE PRESSURE: 2.04MPa
FLOWMETER: 332.32L/min
TOTALIZER: 3.326m3

Figure 6 Operator's pump control screen



(a)



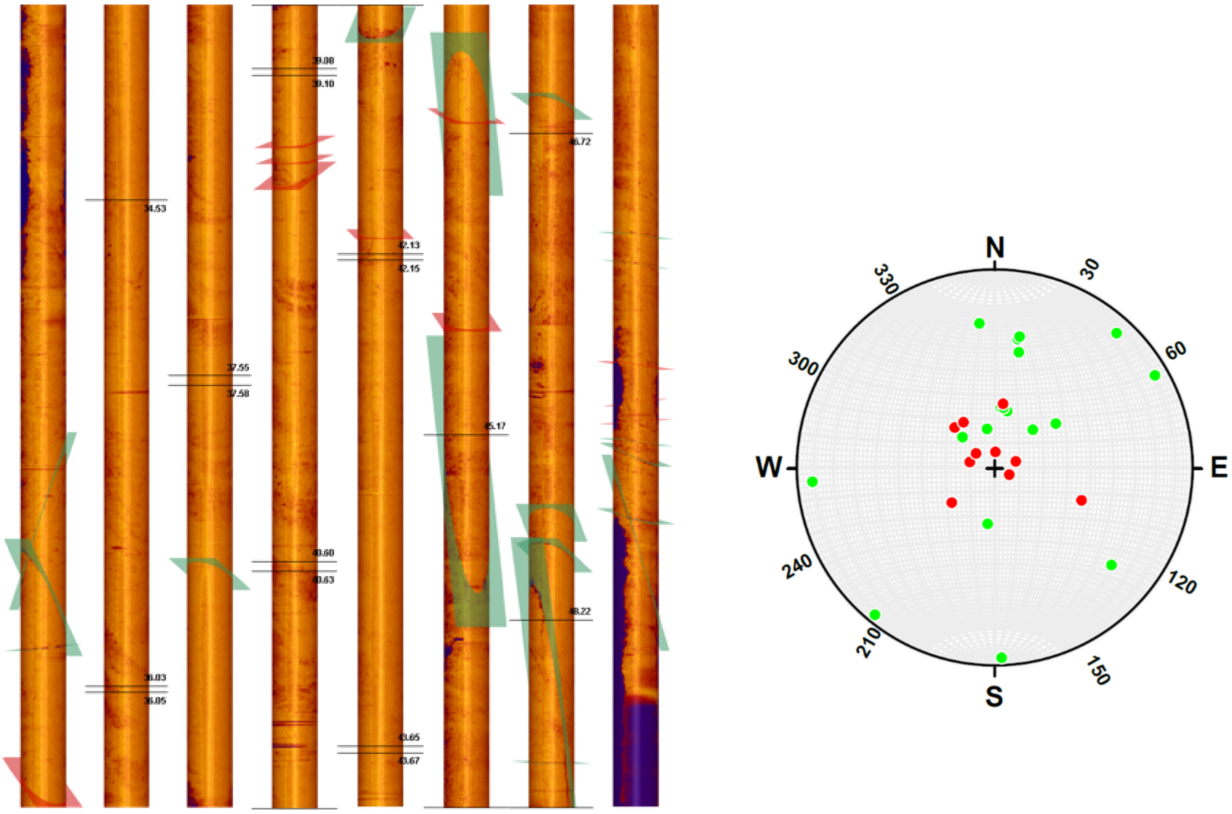
(b)

Figure 7 Pressure flow records from Hole CR6332. (a) 6 December 2023; (b) 7 December 2023

4.1.2 Host fracturing and success monitoring

The treatment holes were acoustically televiewed prior to grouting to establish the pre-existing fracture network and following treatment to identify any new fractures generated (i.e. location and orientation).

It should also be noted that the holes were logged after re-drilling through grout to ensure pre-treatment integrity. An example of this exercise is presented in Figure 8 for the upper interval of Hole CR6331. Prior to treatment, some 18 discrete fractures were logged within the interval and following treatment, the number had increased to 28 discrete fractures post treatment. For the most part, the induced fractures tend to be near horizontal as expected given the ambient stress condition ($\sigma_1 > \sigma_2 > \sigma_3 = \sigma_v$). Whether this proves sufficient to alter the rock's response to mining remains to be seen and will be evaluated as mining extraction advances.



(a) (b)

Figure 8 (a) Log of upper treated interval in Hole CR6331 (displayed in 2.5 m sections commencing at a depth of 31.45 m; pre-existing fractures are shown in green, the induced fractures in red); (b) Corresponding plot of poles to the fracture planes, corrected to account for hole inclination.

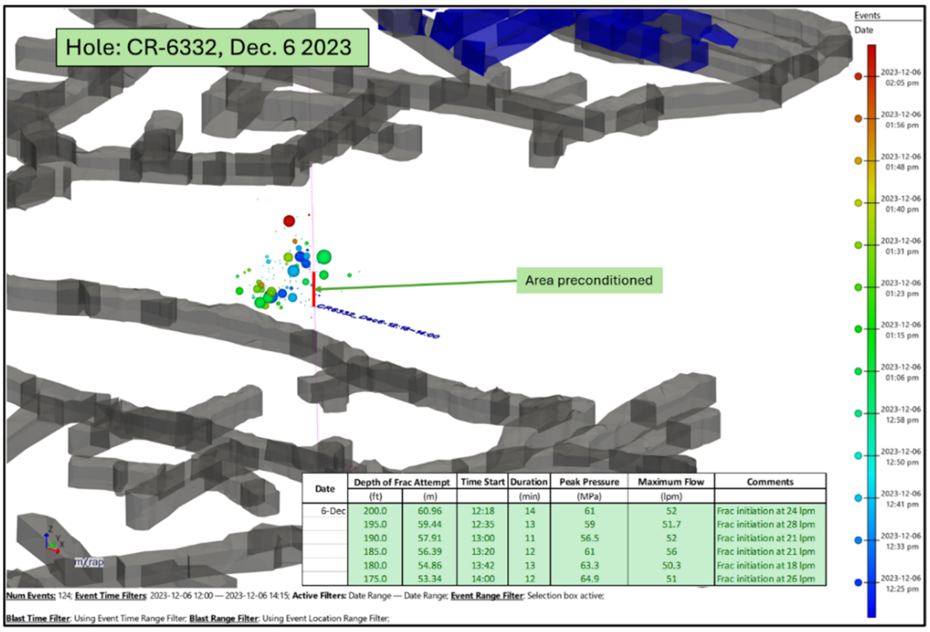
4.2 Seismic monitoring analysis

The basis for seismic monitoring for Phase 2b was the use of the existing Creighton Mine seismic system to source seismicity associated with the preconditioning treatments. Alternative monitoring technology was also trialled during this project but was not able to provide accurate event locations relative to the hydraulic preconditioning area. The results of the seismic monitoring analysis are summarised in this section.

4.2.1 Seismic monitoring system

The Creighton Mine seismic system (ESG Solutions) was used to monitor the seismic response during the preconditioning process. Data from the hydraulic preconditioning treatment time intervals was manually processed and analysed using mXrap software. In addition to the regular processing, ring buffer data from the Creighton Mine seismic system for the days when hydraulic preconditioning treatments occurred were saved for further detailed processing.

Figure 9 shows an example of a three-dimensional view locating Hole CR-6332 and the section preconditioned on 6 December 2023. The associated seismic response from the Creighton Mine seismic system is displayed in the graphic.



Date	Depth of Frac Attempt		Time Start	Duration	Peak Pressure	Maximum Flow	Comments
	(ft)	(m)		(min)	(MPa)	(lpm)	
6-Dec	200.0	60.96	12:18	14	61	52	Frac initiation at 24 lpm
	195.0	59.44	12:35	13	59	51.7	Frac initiation at 28 lpm
	190.0	57.91	13:00	11	56.5	52	Frac initiation at 21 lpm
	185.0	56.39	13:20	12	61	56	Frac initiation at 21 lpm
	180.0	54.86	13:42	13	63.3	50.3	Frac initiation at 18 lpm
	175.0	53.34	14:00	12	64.9	51	Frac initiation at 26 lpm

Num Events: 124; **Event Time Filters**: 2023-12-06 12:00 — 2023-12-06 14:15; **Active Filters:** Date Range — Date Range; **Event Range Filter**: Selection box active;

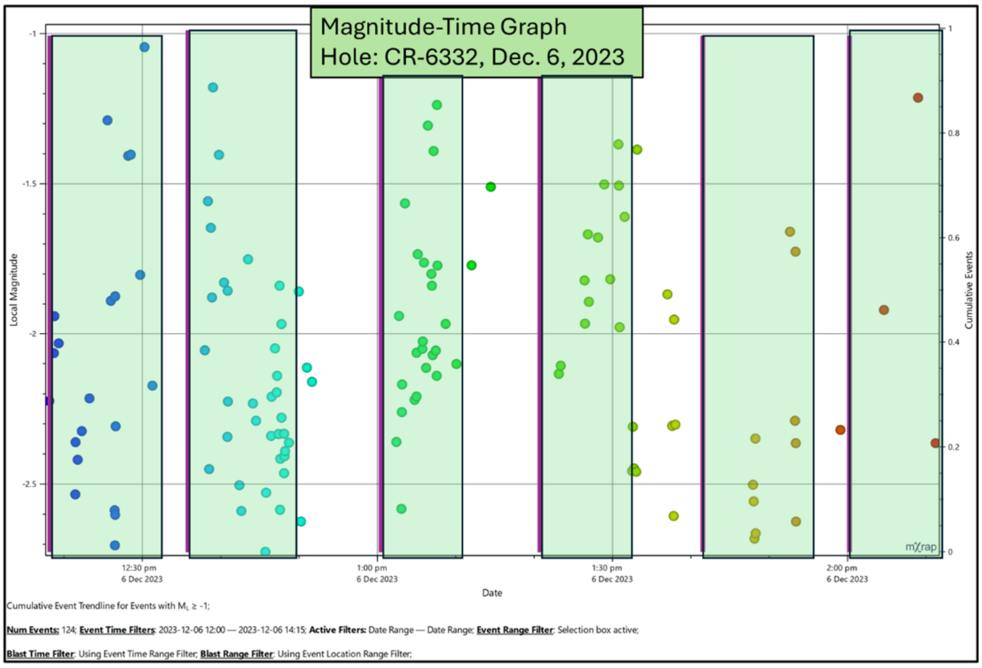
Blast Time Filter: Using Event Time Range Filter; **Blast Range Filter**: Using Event Location Range Filter;

Figure 9 Three-dimensional view showing Hole CR-6332, section preconditioned on 6 December 2023 and associated seismic response from Creighton Mine seismic system

4.2.2 *Seismic data analysis*

The seismic monitoring showed that seismic data was recorded when the peak pressure from the hydraulic preconditioning was above 50 MPa. For the holes where the pressure was below 50 MPa, fracture propagation likely did not occur and generally either the rock mass was weak (fault zone) or other issues caused reduced water pressure (e.g. flow from injection hole, packer rupture).

For holes where water pressure was consistently above 50 MPa during the hydraulic preconditioning process, the seismic data was evident for part or most of the preconditioning periods. Figure 10 illustrates an example of a magnitude-time graph (mXrap software) for Hole CR-6332 showing the start time of each treatment interval and associated seismicity from the Creighton Mine seismic system.



Cumulative Event Trendline for Events with $M_L \geq -1$;

Num Events: 124; **Event Time Filters**: 2023-12-06 12:00 — 2023-12-06 14:15; **Active Filters:** Date Range — Date Range; **Event Range Filter**: Selection box active;

Blast Time Filter: Using Event Time Range Filter; **Blast Range Filter**: Using Event Location Range Filter;

Figure 10 Magnitude-time graph (mXrap software) for Hole CR-6332 showing start and end times (in green) of each treatment and associated seismicity from Creighton Mine seismic system

4.3 Operational challenges

The introduction of a new process in mining brings a myriad of challenges that need to be surmounted. When introducing preconditioning at depth, the issues can be formidable, relating both to the operating environment and equipment limitations. Some of these issues are presented:

- Ground Conditions: At the depth of application (2,460 m), the high ambient stress field promotes failure of the borehole wall (dog-earing) creating sealing issues or, in extreme cases, rupture of the packer. Cementing and re-drilling of the treatment diamond drillhole was adopted to mitigate packer rupture following observation of a similar practice at Cadia East Mine. This had proven successful in the earlier Phase 2a trial. It was noted that conditions can still deteriorate due to mining-induced stress changes if treatment is not undertaken expeditiously following re-drilling.
- Flow Demand: Early on it was observed that direct connection via a 51 mm hose to the Creighton Mine water supply was insufficient to meet pumping demands. This was remedied by installing a 1,000 litre reservoir and connecting to the pump by a 76 mm diameter line. The 51 mm mine supply was then diverted to continuously recharge the reservoir during pumping.
- Pressure Limitation: The MIRARCO pumping system had been designed around the current pressure limits of the treatment hardware (packer/rods/hose). Hence, the system was hard coded to trip at a discharge pressure of 68 MPa (~10 ksi). Consequently, on several occasions, a fracture could not be generated due to tripping at the preset high limit. Despite assurances by the hardware suppliers that intermittent operation at higher pressures was allowable, the hard-coding of the pump precluded its implementation. The pump supplier had ceased operations since the prototype was built and time did not allow for revamping of the control system.
- Tool Installation/Positioning: The HQ integrated packer assembly, some 3.4 m long and weighing 80 kg, would not fit through the drill's rotation and foot clamp. Consequently, insertion and retrieval required removal of the jaws from both components and careful lowering of the packer assembly by the wireline cable until clear of both units. Safe procedures were developed for this process in conjunction with the drilling contractor. It was sometimes necessary to run the string beyond the rod interval, which made coupling to the supply hose challenging. To facilitate such procedures as well as to provide strain relief at the joint, scaffolding was erected as shown in Figure 5.
- Operating environment (Heat/Ventilation): High ambient temperatures (on the order of 30°C) and humidity at depth needed some consideration. The prototype pumping system was powered with a Tier 4 Final diesel engine to provide the flexibility needed to manage pump locations at different mines. Despite the pump run time being short, the system did add noise and heat generated by the diesel-powered engine. Although Tier 4 diesel engines are more environmentally friendly, they do tend to run hotter. The blind drift used for Phase 2b was serviced by an exhaust fan and ducting was effective in ventilating the area. A portable, booster fan positioned near the work area was added to provide sufficient airflow for evaporative cooling when physical exertion (e.g. during tool insertion) was required. In addition, it was necessary to ensure that adequate breaks were taken and hydration maintained during the course of each shift.

4.4 Next steps

The results of the Phase 2b application at Creighton Mine are still being evaluated and the ultimate conclusion will be referenced to mining conditions during extraction of the 400 Mid Orebody stoping sequence later in 2024. Creighton has adopted a top-down mining sequence which benefits from stress shadowing below the current mining horizon. Stress shadowing at the start of a new mining horizon is limited during the extraction of the first few stopes and typical operational issues include blasthole squeezing and seismicity, which will be monitored during the initial stope extraction from the 400 Mid Orebody.

The experience of hydraulic preconditioning at Creighton Mine has generated renewed interest in utilising this technology for operationalising full-scale preconditioning and investigating alternative options for minimising seismic activity during the mining cycle. A conceptual Phase 3 trial is being developed for deeper application at Creighton Mine that is based on the learnings from the Phase 2b work. It is anticipated that this work will follow the processes adopted for Phase 2b and will lead to a second high-stress application with a new pumping system. The prototype pumping system has performed well over the course of Phases 2a and 2b but has experienced challenges over its use that suggest that investigation of an alternate system would be prudent. Contact has been made with suppliers of such systems in a block caving environment to determine what might be possible in an open stoping application.

5 Conclusion

The Phase 1 and 2a work suggested that a fracture can be created and propagated at depth to a 5 m radius within a 10-minute interval. Phase 2a also determined that a diamond drill would need to be mobilised for full-scale application with multiple treatments.

The Phase 2b program determined that full-scale application is feasible from an operational perspective. Full validation of the impact of the preconditioning still needs to be completed as mining extraction advances. It is anticipated that reducing the rock mass quality will provide the ability to shadow areas between orebodies and minimise operational factors such as blasthole squeezing in initial stoping. The work was able to create multiple fractures at depth and the investigators are optimistic that rock mass quality has been changed sufficiently to alter the response to mining. In terms of timing, it was found that it was possible to successfully treat one hole in about a two-day time frame. The work was conducted with minimal impact on mining operations.

The Creighton Mine seismic system was a useful tool for monitoring treatment areas. The ring buffer data from the system for the days when hydraulic preconditioning treatments occurred proved useful in the analysis process.

This work suggests that hydraulic preconditioning can be used successfully but it has to be strategically applied to particular applications. Examples include stress shadowing and protection of permanent infrastructure. Vale is currently evaluating areas for additional full-scale treatment applications (Phase 3) in 2024 and 2025. Consideration for upgrading the pumping system used for Phases 2a and 2b and acquiring a new pumping system will be included in the evaluation.

Acknowledgement

The authors wish to thank Vale for the approval to publish and present the findings of this trial. Thanks also go to the many Copper Cliff (Phase 1) and Creighton Mine (Phase 2a and 2b) personnel for their support of the trials, testing, and defining the future vision for the new technologies to support underground hard rock mining operations. The authors also wish to express appreciation to the MIRARCO and several other enterprises that supported the campaign work through diamond drilling, hole logging, and monitoring systems. The collaboration shows an open willingness to support underground mining with new tools that satisfy safety, accuracy, and efficiency objectives.

References

Altwegg, P 2017, *Hydraulic Preconditioning of Highly Stressed Rock Masses: Phase 1 Report*, MIRARCO Ref. # MRM002-00105.
Maloney, S, Yao, M & Altwegg, P 2016, *Site visit: El Teniente, Chile. Hydraulic Preconditioning Project Summary Report*.
Maloney, S 2022, *Hydraulic Preconditioning of Highly Stressed Rock Masses at Creighton Mine,* MIRARCO Ref. # GRC-0404.