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The B11 support methodologies and QAQC systems: creating and implementing a traceable support system

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Abstract

The B11 block cave at BHP Leinster mine is a mini block cave located below and adjacent to the historic Perseverance sublevel cave. The host environment is characterised by high stress conditions (due to both regional stress and previous mining) as well as localised zones of poor rock mass.

The history of the Perseverance cave and the expected high levels of stress conditions and stress changes that the B11 excavations were anticipated to undergo required a development methodology that would provide a high level of assurance, both from the design as well as from the implementation points of view.

This paper describes the QAQC systems developed and implemented, as well as the practical implementation difficulties and gaps encountered between design and implementation.

Variations from the original mine design and scheduling, as well as its impacts are described and evaluated.

Keywords: *Leinster, monitoring, seismicity, permit, cave, development*

1 Overall setting

Leinster Underground mine is situated within the Mt Keith–Perseverance Greenstone Belt in the Eastern Goldfields Province of the Archaean Yilgarn Craton. Granitoid and gneiss separate the numerous (north–northwest) 20°–335° trending greenstone belts of the region with the subparallel contacts usually faulted or sheared as shown in Figure 1. Regional faults and shears include the (north–northeast to northwest) trending faults (Perseverance and Ninnis, with trends varying from 20°–65° to 335°) as well as the Ockerburry Fault Zone and the Miranda, Emu and Mount Mclure faults; (north to north–northeast) trending faults, with trends varying between 20° to 20°–65°. Most faults are found to be steep or near-vertical at the surface. The Mt Keith–Perseverance Greenstone Belt trends (north–northwest) 20°–335° and extends for at least 150 km from the north of Wiluna to Perseverance in the south (Figure 1) (Thin et al. 2006.).

The Perseverance Fault is part of the 'crustal scale' Keith–Kilkenny Lineament which extends over 400 km. The foliation on the Perseverance Fault is steep to sub-vertical. To the immediate east of Perseverance Fault lies a zone of highly deformed granitic rocks from 1 to 6 km wide. To the immediate west of the Perseverance Fault lies a 1 km wide zone of amphibolite with lenses of highly deformed granitic rocks. Liu et al. (2002) suggests that the Perseverance Fault is better termed a shear zone (Thin et al. 2006).

The Perseverance orebodies occur within ultramafic rocks in the intensively deformed eastern part of the Agnew–Wiluna greenstone belt. This belt is mainly composed of metamorphosed volcanics and sedimentary rocks. The nickel mineralisation occurs in massive and disseminated sulphides hosted by dunite–serpentinite lithologies (Barnes et al. 1988).

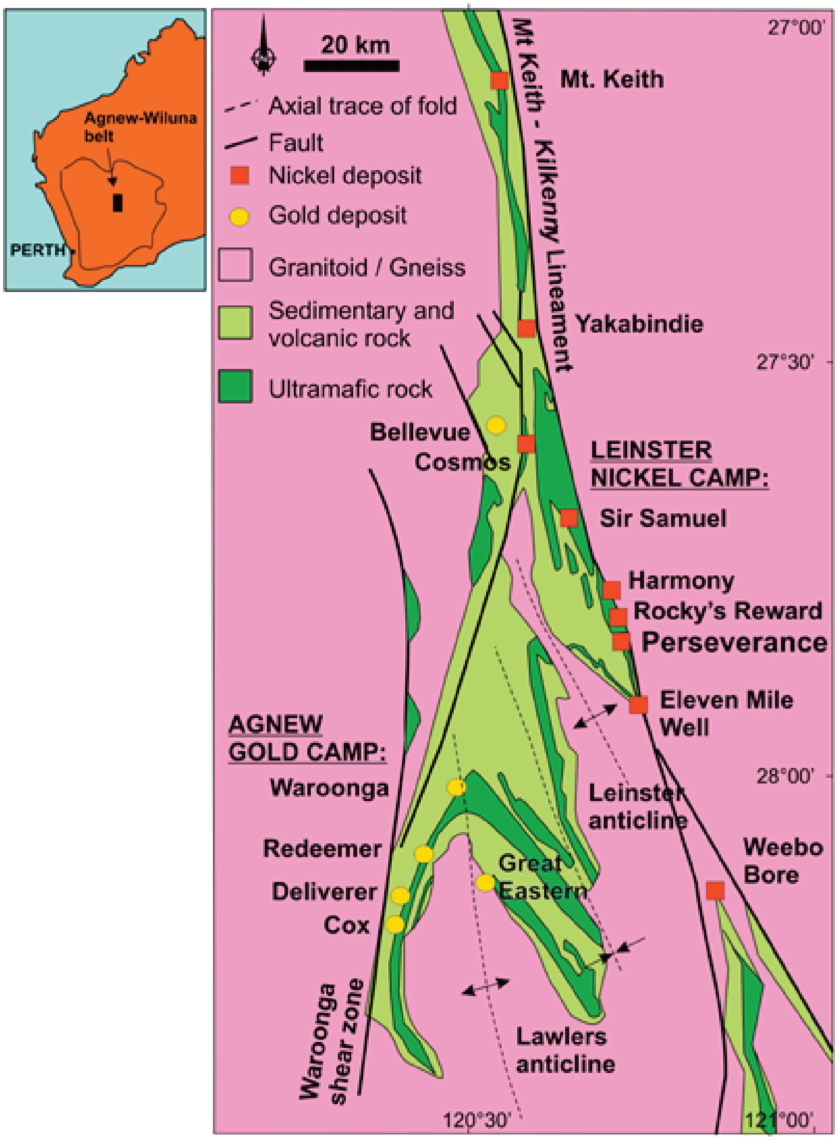


Figure 1 **Plan of Mt Keith–Perseverance Greenstone Belt regional geology (after Hill et al. 1995; Trofimovs et al. 2003)**

2 Mining environment

2.1 Mining setting

The B11 cave is located at Leinster mine, below and adjacent to the previously mined Perseverance sublevel cave (Figure 2). While mining the sublevel cave since the mid-late 1990s, poor ground conditions were experienced associated with stress related rock mass damage. Initially this was associated with the hanging wall shear where poor ground condition combined with high horizontal stresses caused ductile squeezing in the sublevel cave cross cuts. Later the mine developed stress related fracturing and rock bursting in the more competent rock types within which the hanging wall infrastructure was developed (BHP 2018).

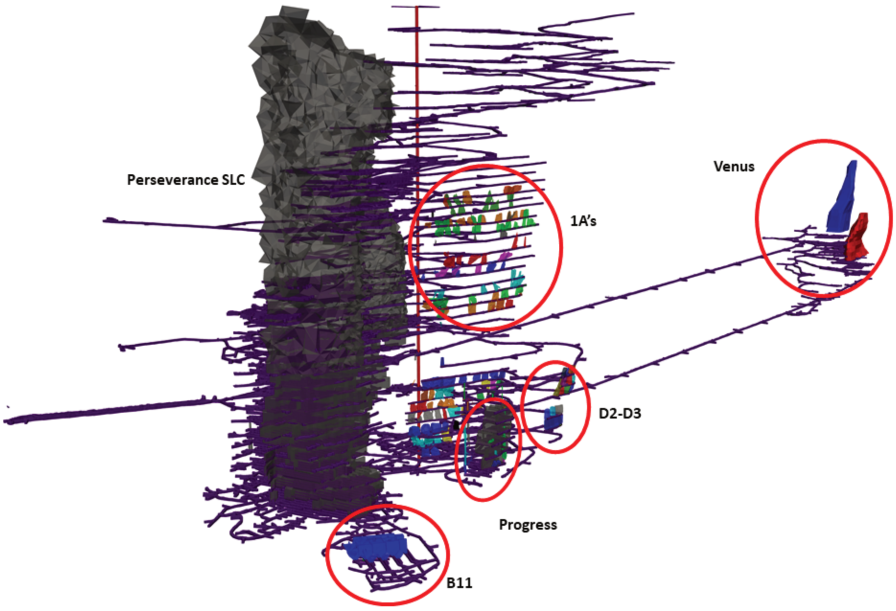


Figure 2 Overall view of Leinster mine orebodies

The B11 cave footprint is located in a highly faulted zone, with access to the footprint being made from the north side (Figure 3). From west to east, the footprint progresses from the felsic host rock to a shear zone, followed by a transition zone and finally the Olivine zone, which constitutes the large majority of the cave material by volume.

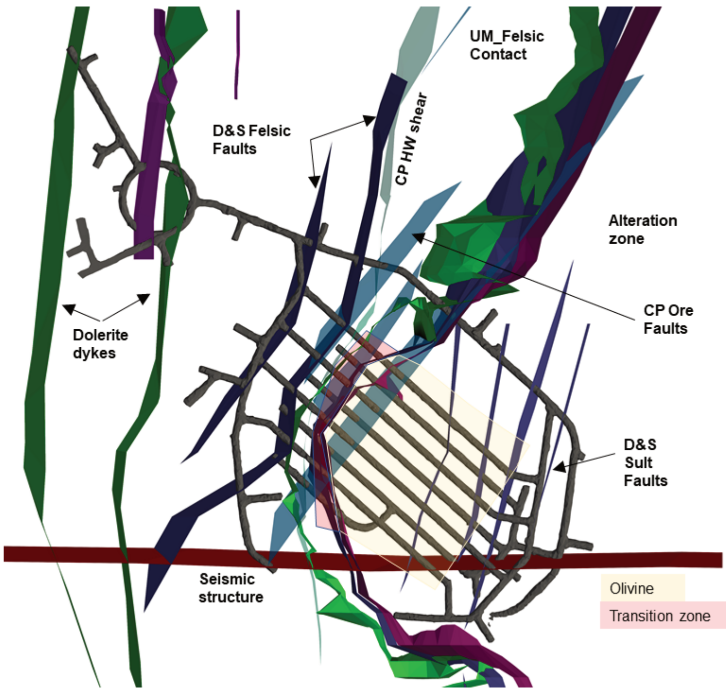


Figure 3 Plan view of B11 footprint detailing simplified geology

2.2 Stress environment

The stress environment for B11 cave can be seen as an extension of the conditions experienced in the Perseverance sublevel cave. The stress gradient for Perseverance mining area is seen in Figure 4, with the main principal stress oriented approximately in the east–west direction (Vidal da Silva 2022a).

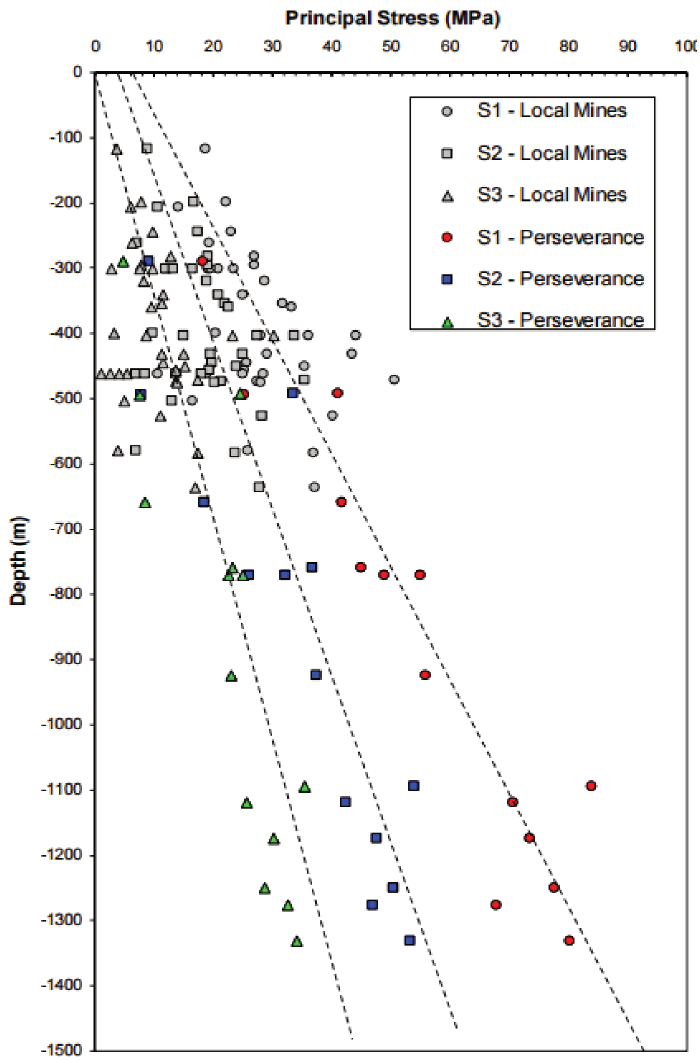


Figure 4 Stress variation with depth, Perseverance and nearby mines

The design work for the project indicated that the highest seismic energy potential would occur where fault slip events could occur.

2.3 Seismicity

Over the years, Leinster mine's seismic system was extended to keep pace with the mining operation. B11 was expected to be a highly seismic area and further expansion is planned and will be implemented as a response to the mining operation demands (Figure 5).

Trigger action response plans (TARPs) were also developed and are subject to an ongoing review process. This ensured that an appropriate response to the risk associated with varying levels of seismicity was available from the initial stages of the cave, and that the response evolves to match the changing risk.

Seismic monitoring is conducted to ensure personnel safety and monitor the rock mass response to mining both ongoing as well as immediately post firing. The target sensitivity levels are -1.5 ML (Hopkins 2018) (and location error of 10 m. The system expansion is ongoing, with current sensitivity shown in Figure 6.

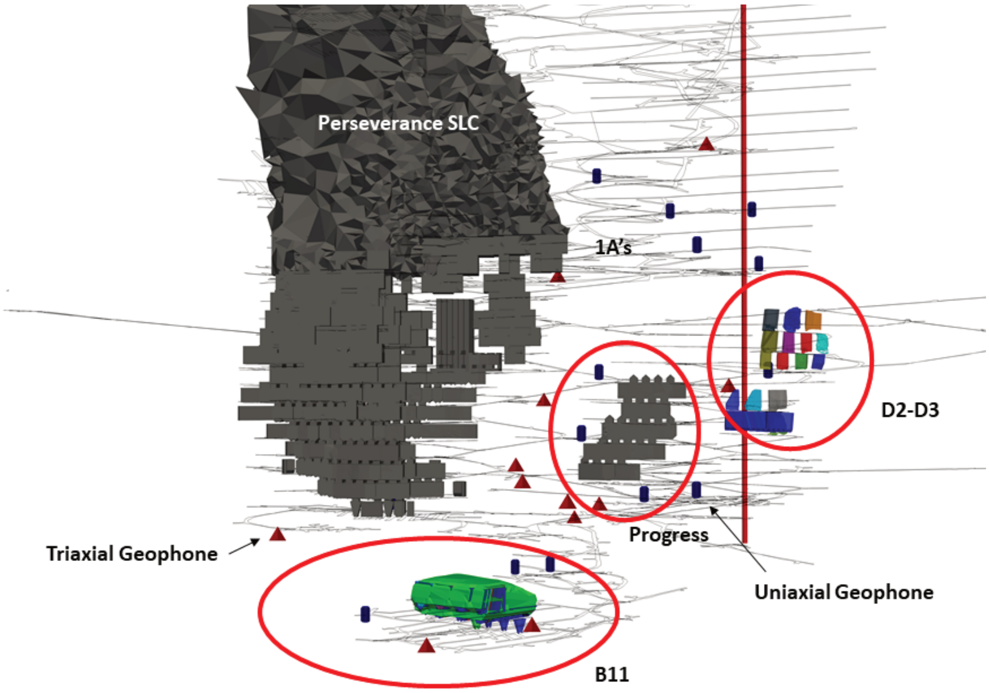


Figure 5 Sensor location in the vicinity of the B11 orebody

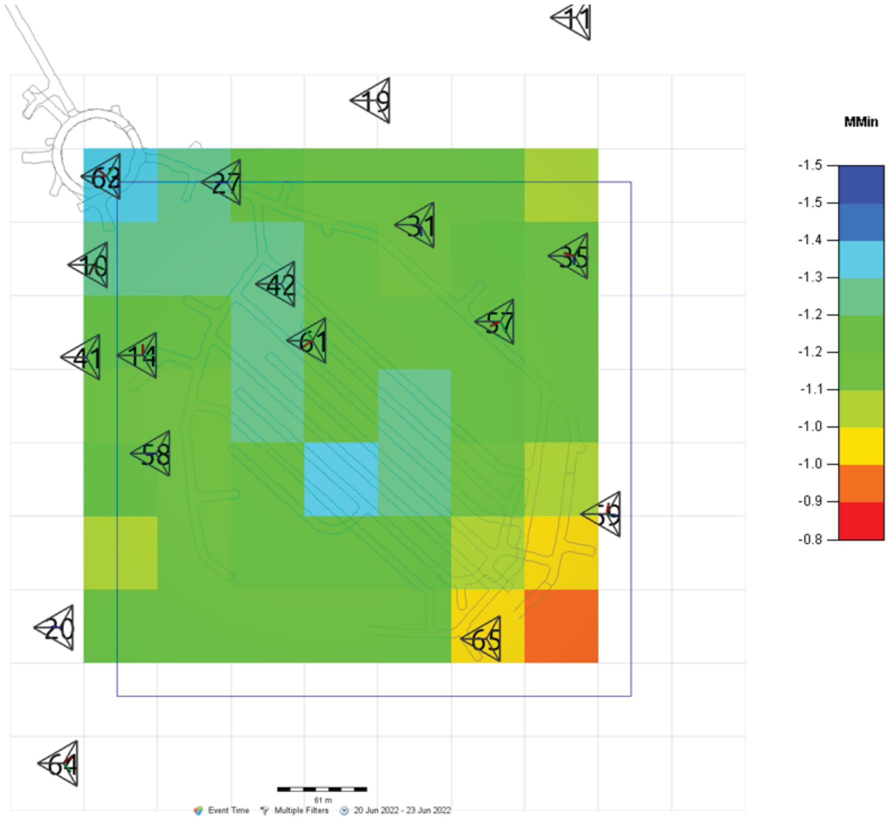
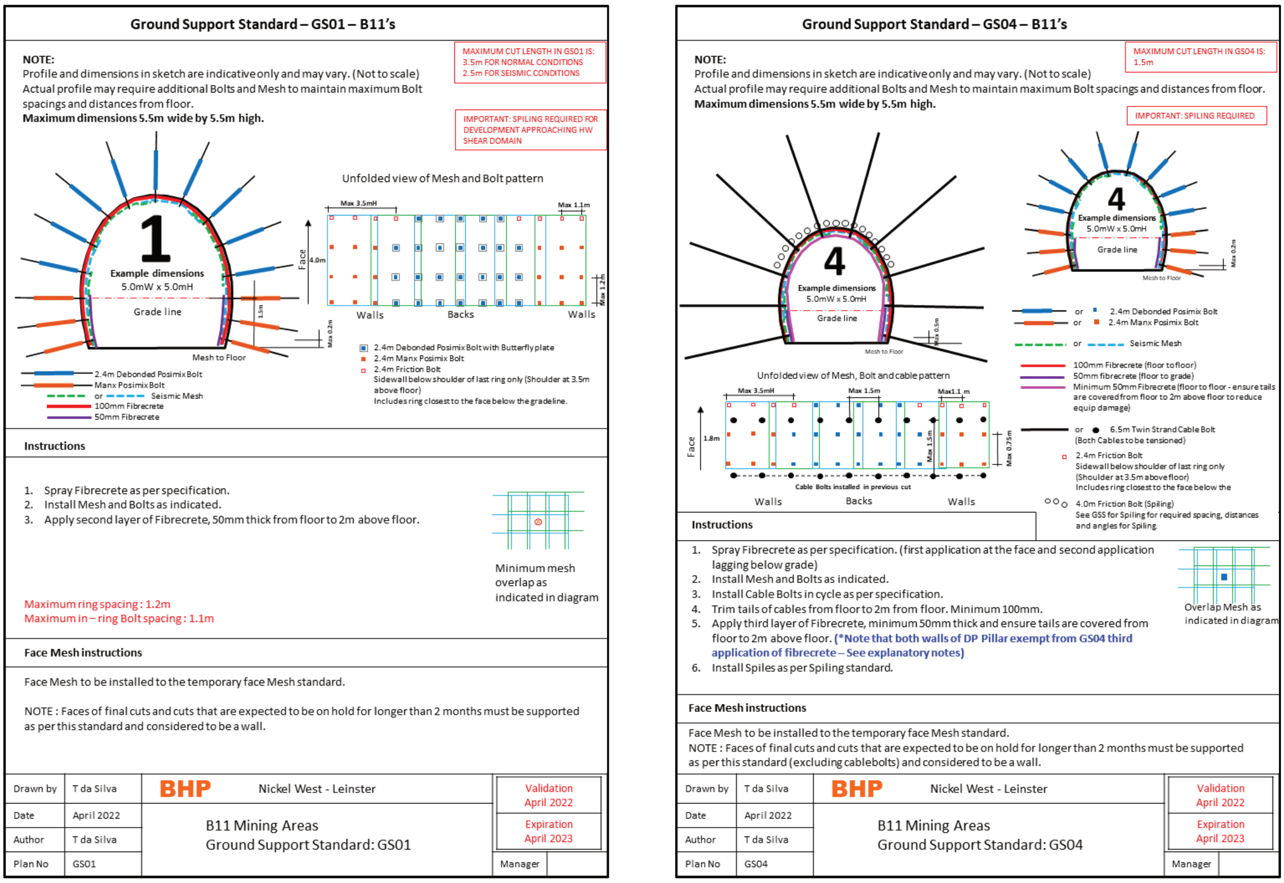


Figure 6 B11 Seismic system sensitivity

3 Support design

High energy demands (35 kJ – very high) are expected in some areas of the B11 footprint during its lifetime. Adequate support systems were developed, with examples shown in Figure 7.

Overall, the B11 support system design is separated into two main zones. The higher capacity support system (GS04) is used in the shear zone and immediately adjacent transition zone. GS01, which is a somewhat less demanding support requirement is used in the Olivine zone (Vidal da Silva 2022a).



(a) (b)

Figure 7 B11 Support standards. (a) GS01; (b) GS04

4 Quality control

From the onset, it was clear that a very high level of quality control would be a requirement in B11. The quality control cycle shown in Figure 8 was developed.

The quality control process begins by scanning immediately after the bogging to control the overbreak of the excavation, followed by scanning to determine the thickness of the applied fibrecrete. The location of all bolts is recorded by the survey team, as well as data associated with the installation itself.

Tolerances for the B11 excavation were 100 mm for bolt collar installation, 200 mm for cable installation and 200 mm for overbreak. No underbreak was accepted.

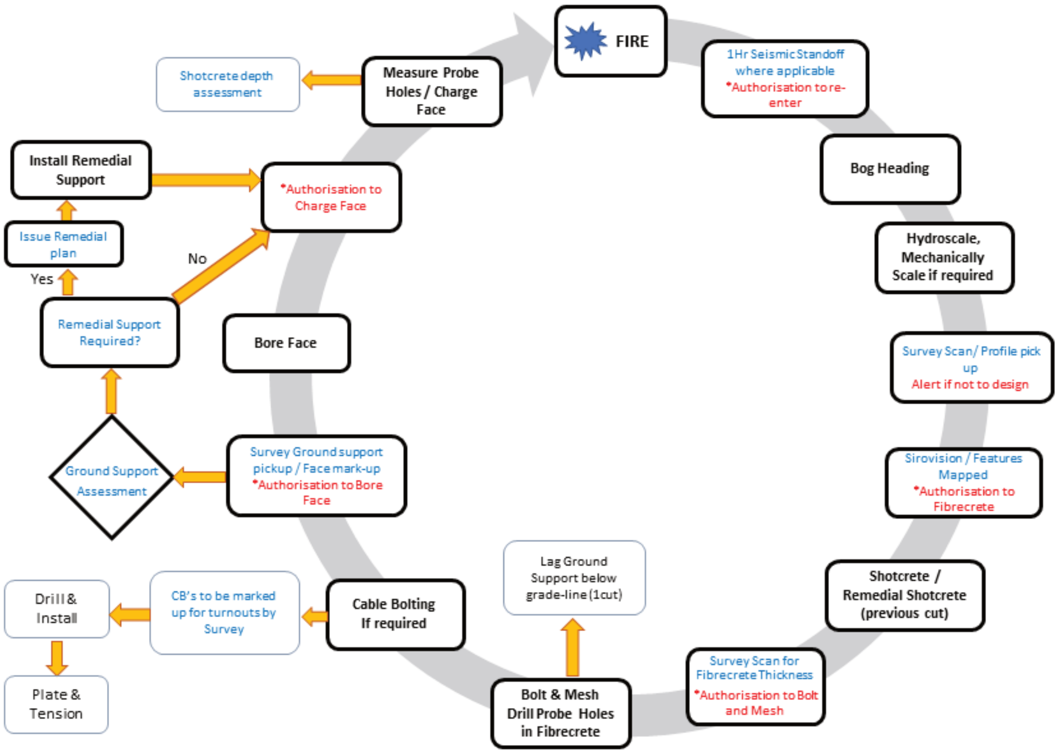


Figure 8 B11 QAQC development cycle, Leinster mine

4.1 Staffing levels

It became apparent that high staffing levels would be required due to the importance of ground support quality control. The mine was staffed with surveyors, geologists, geotechnical engineers and technicians on both day shift and night shift, in a departure of common working practice for technical services.

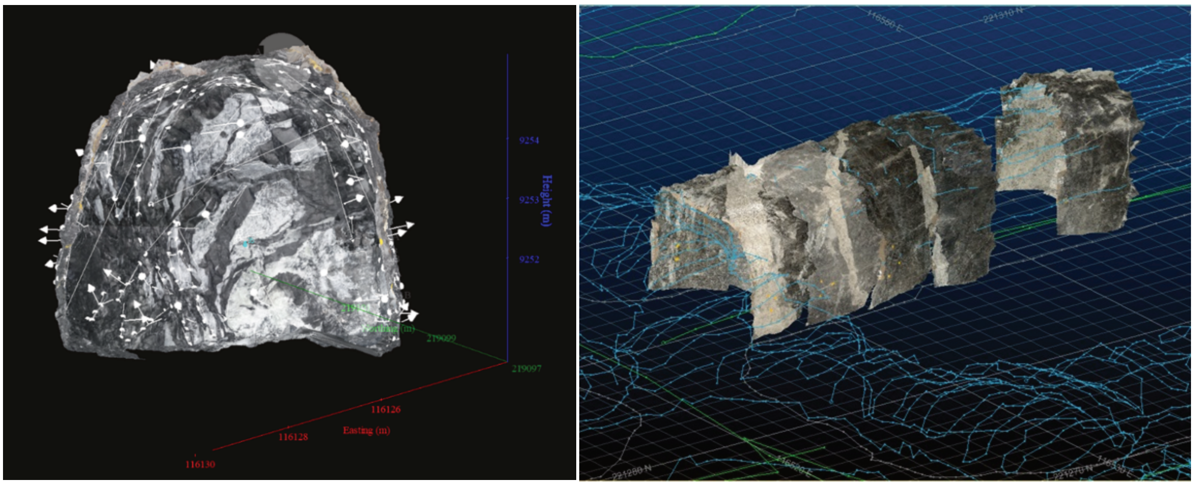
The requirements were that Sirovision and face mapping would be done on all B11 faces after each firing. It was also a requirement that scanning by means of a LIDAR or another type of spatially referenced point cloud generating system would be done at frequent intervals to monitor convergence.

4.2 Post-blast scanning

Survey performed post-blast scanning of the excavations. This served the purpose of verifying that the fired excavation was of adequate size, as well as maintaining a record of the initial shape of the created void.

4.3 Geology and geotechnical mapping

Once the heading was bogged clean and hydro-scaled, the geology and geotechnical teams would map the heading. The geotechnical technician would at this stage make a Sirovision scan of the heading. The scans were required to be spatially loaded to create an accurate dataset of the intercepted structures, as shown in Figure 9.



(a) (b)

Figure 9 Sirovision scanning. (a) Simple heading; (b) Combined scans

4.4 Fibrecrete thickness scanning

Once the geologist and the geotechnical technician had cleared the heading for access, fibrecrete would be applied in the heading. Survey would access the heading after the fibrecrete application to record the thickness of fibrecrete installed and identify any areas where it was still required. As part of a test, scanning units mounted in fibrecreting equipment were used with varied degrees of success. The equipment was fairly successful in monitoring the variation in thickness in the fibrecrete being applied, as long as the position of equipment itself was not changed. There was some progress in obtaining a usable result if small range equipment changes took place, but the results could not easily be positioned within the overall mine survey grid.

4.5 Bolting QAQC

4.5.1 Operator QAQC

The requirement was that a record be kept of the performance of each bolt installed. This was achieved by requesting operators to provide data regarding the drill bit. Hold time, resin batch date, etc, for each ring drilled. This was probably the most difficult part of the process to achieve compliance with.

4.5.2 Post-bolting QAQC

Once the bolting of the heading was completed, Survey was notified of its availability for QAQC to be done. At this stage the surveyor picks up the position of each bolt in the heading. This information is then transferred to a survey file and added to a general project file. The geotechnical team is notified once the data has been saved to the project, to access and perform QAQC.

Initially, measuring between bolts was done one bolt at a time, but this was proved to be a time consuming and error prone process. Deswik was commissioned to develop a sub routine that would allow for the input of the desired spacings between bolts and automate the measuring of distances both in between rings as well as within the ring itself. The output is a classification sheet, detailing which bolts are compliant with requirements and if remedial bolts are required (Figure 10).

The same process was applicable for cable installations.

While the heading face could be drilled after survey picked up the bolts, it could only be charged up after verification was obtained from the geotechnical team that the support was compliant with the required standard, or upon completion of a remedial plan when required.

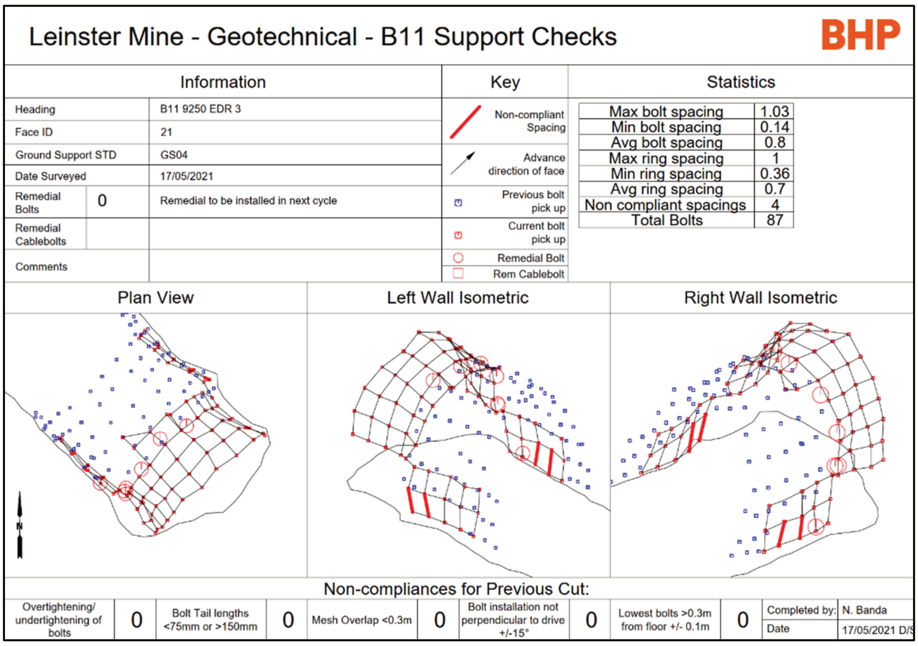


Figure 10 B11 Development Bolt check sheet showing required additional bolts

4.6 Post-firing seismic monitoring

Post-firing seismic monitoring and exclusion was implemented from the first firing of the B11 Project headings. From its application, it quickly become apparent that a case-by-case approach was required. The basic rule was implemented that, while a minimum exclusion time was required to be set, it was only after reaching background levels that it was safe to re-enter the working areas. This exclusion time increased once the undercut(s) were initiated, reaching up to 56 hours during the undercut firings. Expected high stress levels manifested into high seismicity levels, and frequent occurrence of significant events (above 1.5 local magnitude).

4.7 Convergence monitoring

Convergence monitoring is a very important part of the B11 QAQC process. Initially done using a 3D scanning solution, it was later upgraded to a LIDAR scanning system, due to better results.

The process works in two phases. The first phase includes scanning of the excavation to generate a series of point clouds, which are compared and interpreted in the second phase of the process. The difference between the two point clouds can be interpreted by a heat map or by sections (Figures 11 and 12).

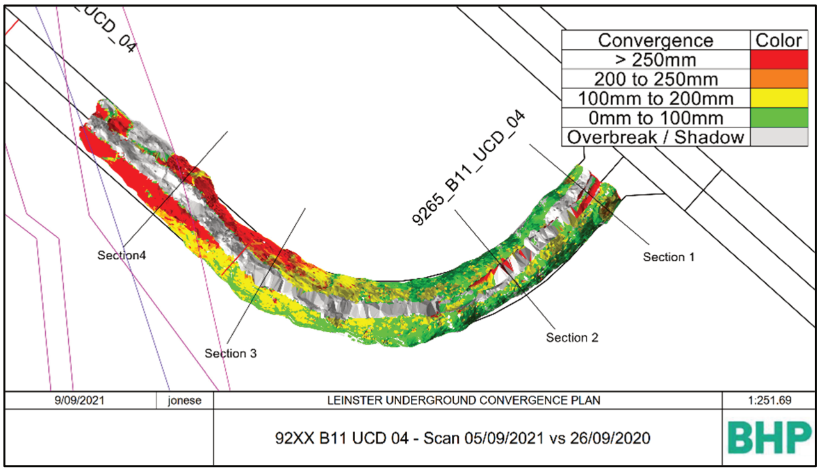


Figure 11 LIDAR scanning – heat map

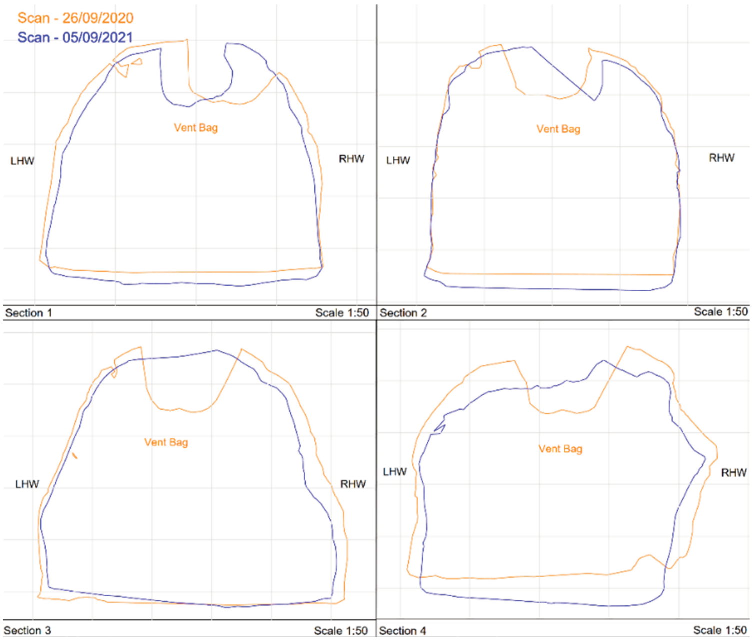


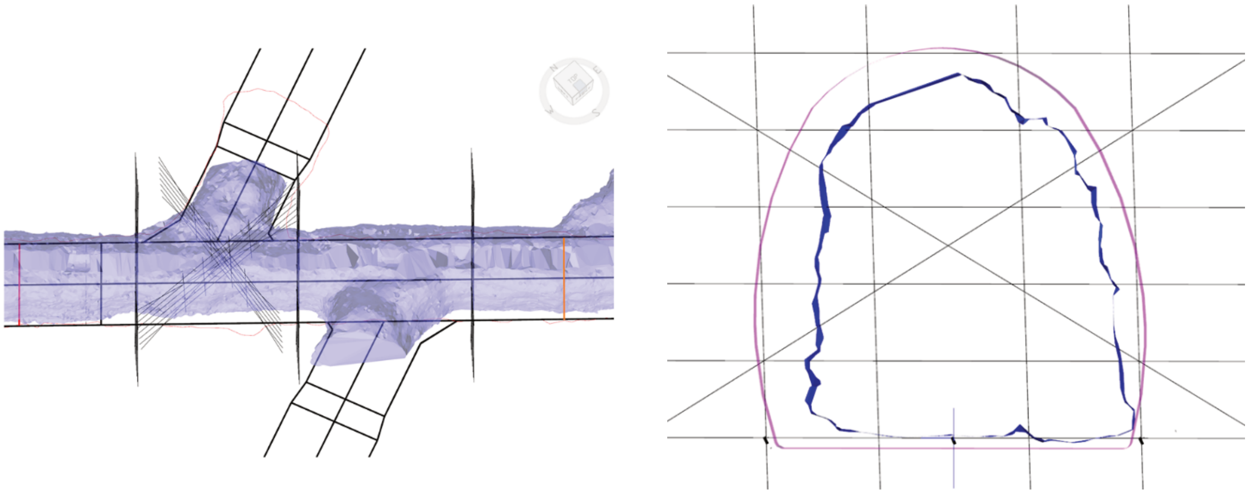
Figure 12 Sirovision scanning sections

The way the point clouds were created made it difficult to generate convergence rates over time for specific sections. A system was developed within the geotechnical team to establish a system of gates to ensure repeatable measurements at defined locations.

The gates were created and placed along the excavations design shapes (Figure 13a). Within each gate six horizontal measurement lines, two diagonal measurements lines and two vertical measurement lines were created (Figure 13b).

Measurements are taken by reading this distance along the lines between the intersection of each shape with the lines. As the gates themselves do not change, the readings could be relied upon to establish values like rates of convergence over time and variations in convergence between areas of the same excavation (i.e. hanging wall against sidewalls).

At a later stage, Deswik was commissioned to develop a routine automating the data collection for different shapes of the same excavation, making the process both less time consuming and less prone to human error.



(a) (b)

Figure 13 Scanning gates placement (a) Oblique view; (b) Section view showing gate

5 Implementation

5.1 Ground conditions

Ground conditions in B11 were closely associated with lithology and geological structures. In the shear zone and transition zone, poor ground conditions experienced were the base for the creation of a requirement that, in addition to reduced cut lengths, headings could not be fired if there was a possibility of no availability of fibrecrete post the firing. In the worse cases, fibrecrete was applied to the backs above the muck pile before bogging was initiated, as a means of consolidating the ground.

Once the undercut started and it was evident that extended exclusion periods were required, it was decided that headings in the shear zone would not be fired together with the undercut, as there was a possibility of uncontrolled unravelling starting during the exclusion period.

5.2 Mining sequence

The development and mining sequence of the B11 cave was as follows:

- Development of apex level.
- Development of undercut level.
- Development of extraction level.

The undercut was developed from the west to the east. A few months after the undercut in 9250 level had been initiated, it was proposed and endorsed that a double undercut be established. The purpose of the double undercut was to increase the height of broken rock in the cave during the initial phase of its establishment, and as such allow for an increased fragmentation level.

The ongoing seismic analysis identified that the seismicity levels experienced in the extraction level elevation were below what was expected. Once that was demonstrated to be an ongoing characteristic, advance of the extraction level drives from the east side was initiated, subject to a permit system as well.

5.3 Exclusion zones and permit systems

5.3.1 Undercut exclusion times and exclusion zones

The minimum exclusion interval following firing of the undercut and apex extraction rings was initially placed at 12 hours, and progressively increased to 24 hours. Authorisation to re-enter the area is subject to background seismicity levels being reached.

5.3.2 Initial development

It was clear from the outset that the system was too complex to be efficiently implemented by means of conventional communication. It was also necessary to ensure accountability and identify gaps in the system.

It was decided to create a permit system that would allow for a high level of control of each of the mining steps, as well as ensuring a high level of accountability. This is done by being able to demonstrate the adherence to support and QAQC requirements at any stage of the life of the excavation. This can become a rather important feature in cases of failure during later stages of the excavation life, especially if back-analysis is required. The permit form below was developed and implemented to ensure these requirements were implemented (Figure 14).

Leinster Underground Mine
B11 Permit Form V2.6

Heading	
Cut	
Date and time fired	

Note : Shaded cells to be filled in only if non compliances are noted

Step	Item	Responsibility			Date	Time
		Department	Name	Shift boss		
1	Geotechnical Authority to Re-enter	Geotechnical				
Operations to re-enter, bog clean, scale and re-bog if necessary						
2	Pre-shotcrete scan/ profile pick up – ***Alert if non-compliant***	Survey				
3	Sirovision and Mapping	Geotechnician/ Geology				
4	Ground Support QAQC	Geotechnical Engineer				
Operations to shotcrete to standard						
5	Post-shotcrete scan for fibrecrete thickness	Survey				
Operations to bolt and/or cable heading to standard						
6	Installed bolt and/or cable pick-up and face mark-up	Survey				
Operations to bore cut						
7	Bolt spacing compliance confirmed ***Alert if remedial plan to be completed before firing or in next cut***	Geotechnical Engineer				
Operations to install additional bolts						
8	Check remedial bolts installed	Shiftboss				
9	Cable spacing compliance confirmed ***Alert if remedial plan to be completed before firing or in next cut***	Geotechnical Engineer				
Operations to install additional cable bolts						
10	Check remedial cable bolts installed	Shiftboss				
For EDR/DPT in GS04, operations to complete GS-RR Resin Reinforcement						
11	Check GS-RR completion sheet	Shiftboss				
Operations to charge and fire						

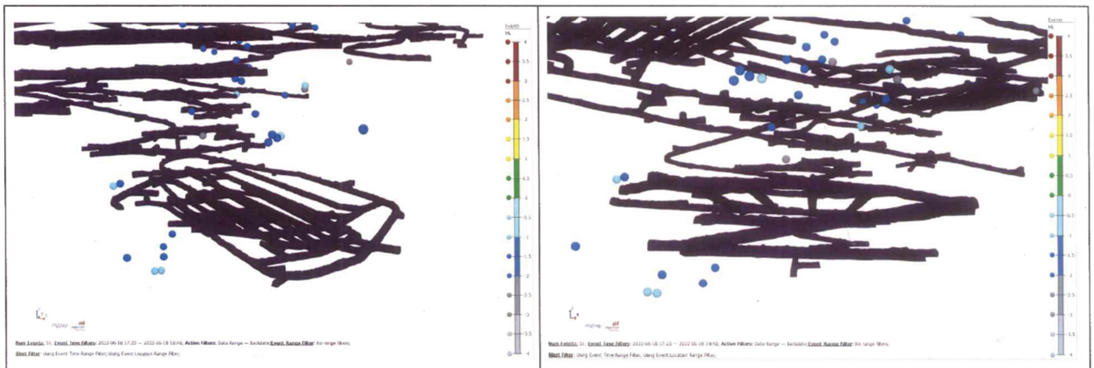
Figure 14 B11 Development permit re-entry form

5.3.3 Co-development

Originally, development of the 9250 level extraction drives was planned to occur from the west side to the east side only, following the undercut and protected by its stress shadow. However, seismicity levels in 9250 level were lower than originally anticipated, leading to the possibility of simultaneous development of the 9250 level extraction drives to occur from the east side. This was evaluated by taking into consideration not only its operational effects, but also the associated level of risk. The risk level evaluation was made by comparing the actual seismicity and deformation level against stress levels and expected deformation observed.

While it was observed that actual deformation and seismicity levels were below what was expected, it was decided that development from the east side be allowed, subject to implementation of a permit system that required the seismicity after the firing to be evaluated and minimum wait periods were established. An upgrade in the support system was also required. The form used for this particular permit is shown in Figure 15.

B11 EDR Seismic Re-entry	
Heading	B11 EDR33
Face ID	Cut 24
Ground Support Standard	GS03G
Date and Time Fired	18/06/2022 17:23:10
Date and Time Re-entered	18/06/2022 19:30:00
Shift supervisor authorisation given	Matthew Campbell
Comments	No considerable seismicity was noted following development firing in EDR33



B11 Seismic activities within the exclusion zone

B11 Seismic activities within the exclusion zone

Authorised by	
Geotechnical Engineer:	
Print name: Mehdi Najafi	
Date: 18,6,22 19:45:00	

Figure 15 B11 Development permit re-entry form

6 Lessons learned

A good QAQC system ensures that the installed ground support and work methods achieve the desired results and allow for a quantification of compliance. Developing and implementing the QAQC system was a cooperative effort between technical services and operations. The following lessons were learned during this process:

- The purpose of the system must be clearly defined before it is built and clear objectives established.
- The system must be built and communicated before any operational activities begin. It is very hard to change an established work method.
- It is never a completed process. It will evolve as practical issues are encountered and as the technical and operational priorities change. Be prepared to change it.
- It needs to be as simple as possible. Degree of complexity and error frequency go hand in hand.
- Ensure persons who will be affected by it or use it are familiar with both the purpose and implications of non-compliance.
- Adherence must not be optional and needs to be strictly enforced.

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