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Evolution of ground support practices within the development cycle at Perseverance Mine

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Abstract

As underground mining is undertaken at an ever increasing depth, there is an ongoing need to optimise ground support practices to ensure the safety of the workforce and continuity of production. The ground support systems applied at Perseverance Mine in Western Australia have evolved over several years and have involved refinement of well established support techniques for the challenging ground conditions encountered elsewhere, as well as the testing of several innovative products and support practices. This paper provides an overview of ground support at Perseverance Mine as it relates to the development cycle, as well as presenting the results of several ground support trials undertaken at the mine over recent years. These trials have aimed to manage the risk associated with challenging ground conditions encountered at the mine, particularly relating to mining induced seismicity and squeezing ground.

1 Introduction

1.1 Perseverance Mine

The Perseverance Nickel Mine is located 15 km north of Leinster and 645 km northeast of Perth, Western Australia. The mine has been wholly owned by BHP Billiton's Nickel West division since 2005. The orebody was initially mined for ten years by the Agnew Mining Company using a variety of underground mining methods (Table 1) with mixed success due to difficult ground conditions. The mine was closed in August 1986. The lease was purchased by WMC Resources Ltd in 1989 and an open cut was established above the existing mine workings whilst underground development and rehabilitation continued in preparation for full-scale underground mining (Tyler and Werner, 2004).

Table 1 History of mining methods at Perseverance Mine

Date	Depth (m)	Reduced Level (mRL)	Mining Method
1978 to 1986	190 to 375	10330 to 10145	Underground — various
1989 to 1995	0 to 190	Surface to 10330	Surface open cut
1994 to 1998	375 to 520	10145 to 10000	Underground sublevel cave
	520 to 600	10000 to 9920	Unmined pillar
1997 to 2008	600 to 1030	9920 to 9490	Underground sublevel cave and narrow vein open stoping

The vast majority of nickel in the Perseverance Mine resource is contained in the ultramafic hosted disseminated Perseverance orebody which, apart from remnant mining around old stopes, has been mined underground almost exclusively by sublevel cave (SLC, Figure 1) since 1994. The hangingwall limb (HWL) extends north from the main disseminated orebody and is also mined using the SLC method. A small footprint orebody further north of the main disseminated orebody (Progress) is also mined via SLC. A narrow vein ore zone (the 1A orebody) has been mined using long-hole open stoping higher in the mine than current production activities. The various ore zones at Perseverance Mine and the depths of mining are shown in Figure 2.

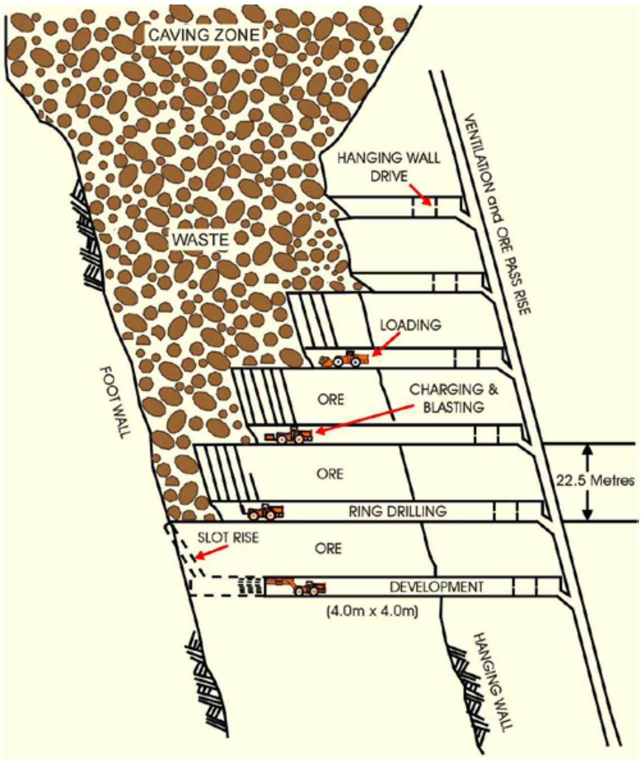


Figure 1 Schematic of the sublevel caving mining method used at Perseverance Mine

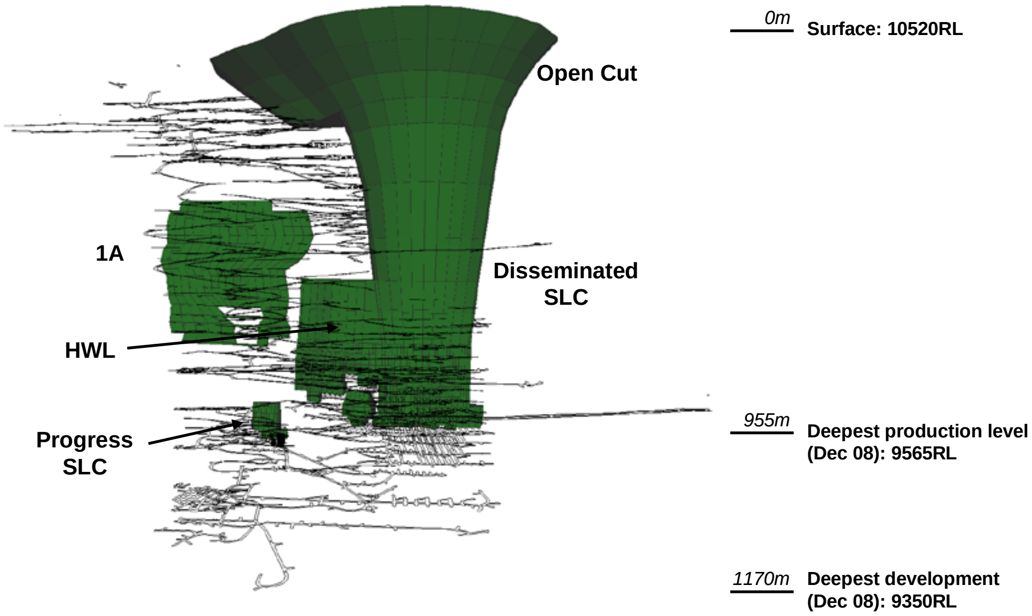


Figure 2 Longitudinal view of Perseverance Mine showing the mined void and development

Two distinct strategies have been used to implement the sublevel caving method (Wood et al., 2000). The first was to mine the upper levels, at 375–520 m depths below surface, and provide draw control by mining to a cut-off grade. However, deteriorating ground conditions experienced with depth and more disturbed geological conditions forced a redesign of the area. The second strategy was to drop down below the affected area at approximately 600 m depth and to recommence the cave. A temporary 80 m pillar was left below the previous mined level and extraction on the lower levels was controlled by tonnage in order to evenly draw the column of ore in the pillar and limit dilution entry. The orebody continues below the drop down levels to around 1120 m depth, where it inflects to the north. Modifications to the mining strategy are being analysed to cope with greater depths as part of a continuous improvement philosophy.

The mining layout for the Perseverance Mine SLC is shown in Figure 3. The orebody is accessed via a number of crosscuts connecting to a hangingwall drive on each level. Ore crosscuts are 5.5 m wide and 4.8 m high. Production levels are 25 m apart, floor to floor. The ore crosscuts are set on 14.5 m centres, leaving a notional 9 m wide pillar. As of December 2008, sublevel cave production was underway concurrently on the 9615, 9590 and 9565 levels (905 to 955 m below surface). Figure 3 shows a plan of the 9590 level, with the mined areas towards the top (east) of the plan hatched. Mining retreats towards the hangingwall drive. Production is staggered vertically to maintain brow stability (as shown in Figure 1) with draw carefully managed to maintain a dilution blanket above the caved ore and prevent preferential draw of waste material.

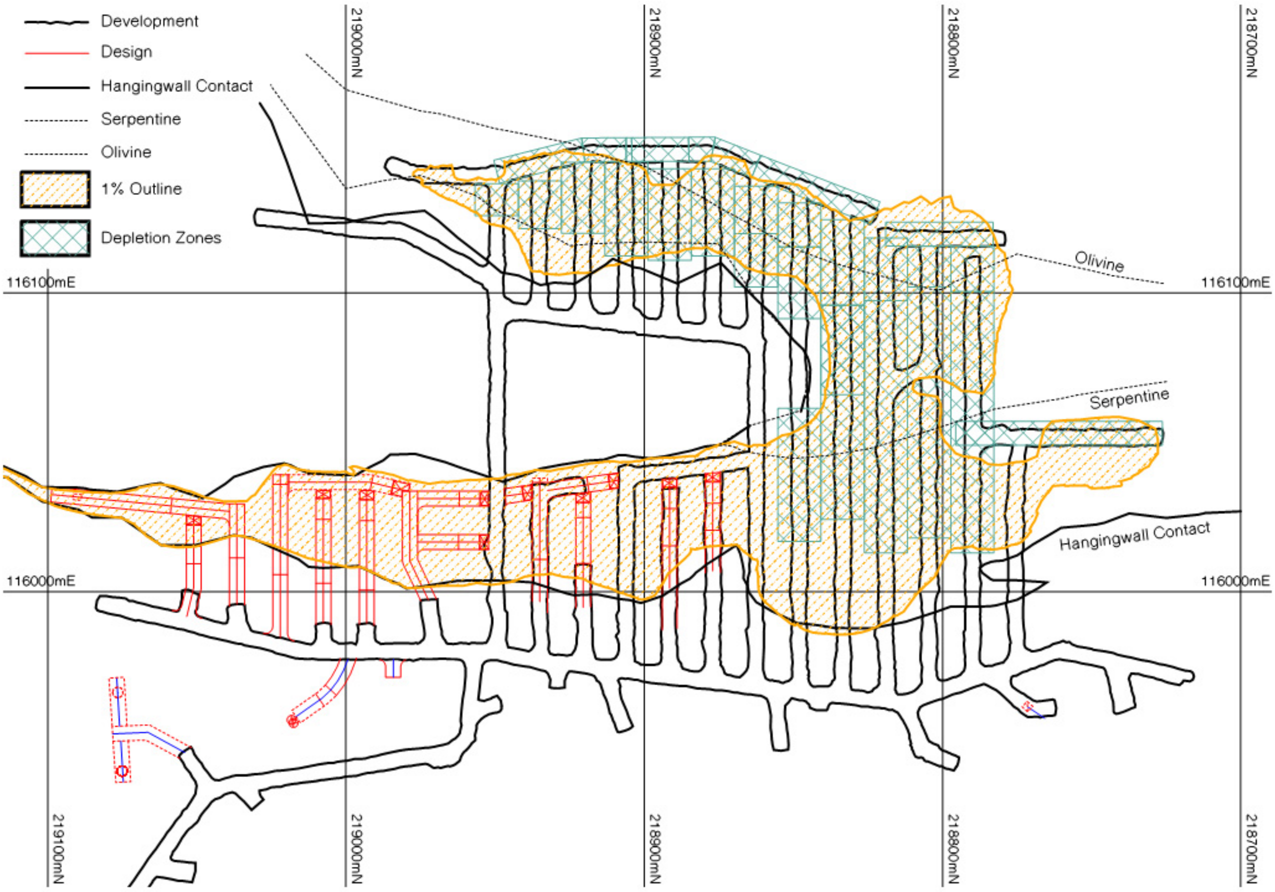


Figure 3 Plan view of the 9590 level showing mined voids (depletion zones), development and planned development. Important geological contacts and the 1% nickel grade boundary are also shown

Perseverance Mine's production rate is approximately 2 Mt of ore and 360 kt of waste per annum, with waste production expected to gradually diminish over the next few years with reduced development requirements. In order to achieve this production rate, 6600 m of development are required each year, with monthly development rates typically around 550 m. Table 2 lists the mining equipment currently used for tunnelling.

Table 2 Current equipment used for tunnelling at Perseverance Mine

Equipment Used for Tunnelling	Description
Development jumbos	6 Tamrock Axera D07-240 1 Tamrock Axera D06-226
Cable bolters	1 Tamrock Cabolter
Transmixers	2 Jaycon Transmix 500
Sprayers	1 Normet Spraymec 1 Jaycon Maxijet

1.2 Geology

The Perseverance nickel deposit is situated in the Archaean Yilgarn Block of Western Australia. The main disseminated orebody occurs within ultramafic rocks set in the intensively deformed eastern part of the Agnew-Wiluna greenstone belt, which is mainly composed of metamorphosed volcanic and sedimentary rocks. The nickel mineralisation occurs as massive and disseminated sulphides hosted by ultramafic-serpentinite lithologies (Barnes et al., 1988).

The Perseverance ultramafic is a lens-shaped body several kilometres long and up to one km wide in the vicinity of the mine. Within this, the disseminated orebody is located on the western margin and is approximately defined by a 1% nickel grade boundary. Typically the orebody is 80 m wide (east-west) and 150 m long (see the ore outline in Figure 3). The orebody is classified in the east-west direction according to variations in mineral assemblage of the host rock. Closer to the hangingwall drive, the orebody is colloquially known as the ‘serpentine ultramafic’, whereas further east the term ‘olivine ultramafic’ is used. The area between the two is known as the ‘transitional ultramafic’. The dip of the disseminated orebody is subvertical with an inflection zone between the 10100 and 9900 mRLs (420–620 m below surface) where the dip flattens to around 45° before steeping again below the 9900 mRL.

Local geology has a significant influence on ground support requirements at Perseverance Mine. The hangingwall rocks comprise metasediments and metabasic volcanics, with the dominant rock type a quartzo-feldspathic gneiss. These stiff units are known to be prone to mining induced seismicity and rockburst damage. The hangingwall contact with the ultramafic body is marked by a very prominent shear zone containing a mixed assemblage of extremely low shear strength metamorphic minerals (e.g. tochillonite, antigorite). This area is often subjected to significant squeezing, where wall displacements can often exceed 0.5 m. The shear zone is a regional feature that extends to the north of the disseminated orebody to form the hangingwall contact of the HWL and 1A orebodies. It thickens in the inflection area of the disseminated orebody. The disseminated orebody wraps around a portion of the hangingwall metasediments to form what is termed the ‘felsic nose’, as shown in Figure 3.

1.3 Geotechnical considerations

The geotechnical conditions encountered at the mine are summarised here (Wood et al., 2000; Struthers et al., 2000; Oddie, 2002; Thin et al., 2006).

A number of in situ stress measurements have been undertaken at Perseverance Mine using HI cells, hydraulic fracturing and acoustic emission. These cover a range of operating depths down to around 1300 m below surface. The results for the measurements show high stresses at shallow depth when compared to other mining districts around the world, however similar to other mines within the eastern Yilgarn Craton. The latest HI cell measurements were done on 9590 level in 2006 and are indicated in Table 3 (Litterbach, 2006). The measurements were done to quantify the magnitude and orientation of ground stresses on current mining horizons and in addition to other measurements for future deep mining areas.

Table 3 Perseverance Mine rock stress at 9540 mRL

Principal Stresses	Magnitude (MPa)	Dip (deg)	Bearing (deg)
Major	79.0	16	118
Intermediate	59.9	1	208
Minor	41.5	74	302

All development headings underground are normally covered with fibrecrete within 24 hours of exposure to maintain the integrity of the excavation. Mapping of joint structures is done by geotechnicians prior to fibrecreting. Induced stress fractures are also quite prominent around tunnels below the 9760 mRL horizon and ground support systems are designed to cope with this additional fracturing. This explains the fairly intense ground support schemes used at Perseverance Mine and described later in this paper.

Laboratory tests have been conducted on a number of samples of the major rock types at Perseverance Mine. The results for the dominant rock types (host ultramafics and hangingwall felsics) are shown in Table 4. The location of these tests is biased by a relatively large number of tests for the Southern Vent Shaft and for 9920 mRL. The results are indicative of reasonable property values that are expected for these rock types (Tyler and Werner, 2004).

Table 4 Perseverance Mine intact rock properties

		Density (t/m^3)	UCS 50 (MPa)	UTS (MPa)	E (GPa)	ν
Ultramafic (Talc-Chlorite, ‘shear zone’)	Mean	2.7	46	4.3	33.7	0.32
	Std Dev	0.14	17	1.3	5.0	0.03
	Count	139	9	5		
Ultramafic (Serpentine-Talc, ‘serpentine ultramafic’)	Mean	2.78	90	7.1	38.8	0.31
	Std Dev	0.18	23	1.4	7.8	0.07
	Count	109	50	41		
Ultramafic (Olivine-Serpentine, ‘olivine ultramafic’)	Mean	3.1	126	12.1	79.7	0.33
	Std Dev	0.4	35	4.3	34.3	0.09
	Count	85	14	11		
Metasediments (felsics)	Mean	2.45	142	13.3	80.5	0.27
	Std Dev	0.16	61	6.1	11.4	0.06
	Count	72	54	59		

Tunnels driven through the shear zone are particularly prone to generating squeezing ground conditions. Struthers et al. (2000) discussed ground behaviour in the SLC, particularly the depth of rock damage in the pillar walls and the rate of associated floor heave, and offered a widely accepted model for the phenomenon (Tyler and Werner, 2004). According to Struthers et al. (2000), the relative timing between different stages of failure along crosscuts does vary depending on local ground conditions, but the basic sequence of failure is generally the same. An extreme case of squeezing ground within the shear zone is shown in Figure 4.

Figure 4 Squeezing ground, 9665 XC17, November 18, 2004

Gaudreau (2005) notes that patterns of induced stress fractures around excavations have been studied in detail mainly through tunnel rehabilitation exercises but also through some probe drilling. For instance, many observations were done during 2004 and 2005, throughout a series of rehabilitation jobs in the SLC area especially in the southern end of the orebody. The pulverised and bulged rock mass that squeezed into the tunnel was found, once stripped, to be resting against a fractured but solid rock mass. This demonstrated that the pillar between the crosscuts in squeezing ground was in fact fractured but not yielded, for tunnels that had squeezed from a nominal width of 5 m to one of 2.5 m in about 18 months in extreme cases. It demonstrated that the rock mass at the periphery of the tunnel was most affected by damage and swell. The rock mass that bulged in the heading did not have the same fracture characteristics as the one taking its place and forming the new wall.

In July 2005, some diamond drill holes were driven through adjacent crosscuts on 9640 level and the core was analysed and found to be fractured but not pulverised. The definition of a yielded pillar core or its mechanical status and its influence on tunnel engineering is sure to generate more debate for the engineering of mining methods at depth for Perseverance Mine. For the moment, efforts are concentrated to trial various tunnel shapes and ground support systems that are likely to generate less ground deformation and prove to be more sustainable over long time periods.

Given the depth of mining, high stresses at relatively shallow depth, large mined out voids and a number of large scale geological structures, mining induced seismicity and rockbursts are an important consideration at Perseverance Mine. The seismic risk management strategy at Perseverance Mine relies on data from high resolution seismic monitoring using both ESG and ISS seismic monitoring systems. Coverage for the combined systems extends throughout the entire mine, however an upgrade to the system is underway at the time of writing to vastly improve the sensitivity of the seismic network. Seismic data is analysed daily to identify time trends in activity and take the appropriate measures to reduce risk through access restrictions, re-entry protocols following blasting or evacuations. Over the medium to long-term, seismic sources are identified and their seismic hazard assessed to plan risk reduction strategies such as improvements to ground support, changes in mine design and revised mining schedules. Seismicity recorded in 2008 is shown in Figure 5.

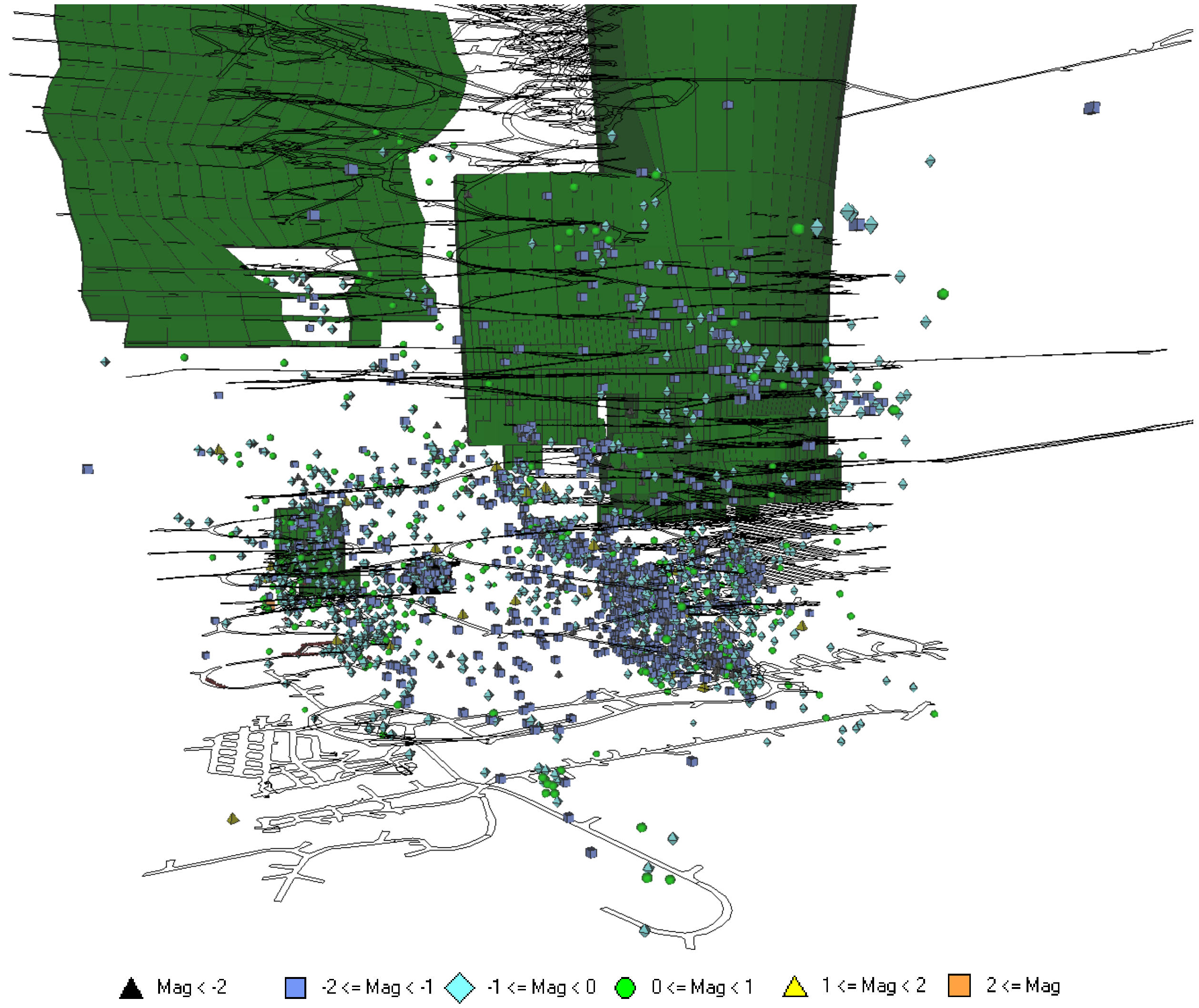


Figure 5 Seismicity recorded at Perseverance Mine in 2008 (approximate Richter Magnitude shown)

The main sources of seismicity at Perseverance Mine are:

- Intact rock fracturing and shearing on geological structures below the sublevel cave. This is thought to be driven by a highly stressed abutment zone which exists about 50 m below the current production level and advances down as mining progresses. Several large events (Richter Magnitude greater than +1) have been generated in this area, however, do not typically cause damage as they occur at some distance from existing mine development. These events typically occur in the stiffer 'felsic nose' rather than in the ultramafics.
- Localised strain bursting around development headings. These are typically lower magnitude events which can result in damage to unsupported development headings, soon after the development blast occurs. Again, these are more typical in the felsic rock unit.
- Cave propagation. These are typically small events associated with the upwards migration of a fractured zone above the cave void as caved material is drawn from production levels below.

- Abutment and pillar affects. Stress concentrations between individual orebodies and at the boundaries of mined voids have resulted in significant seismicity, although this was more of an issue several years ago when mining the upper 1A orebody, close to the HWL (as shown in Figure 2).
- Shearing on seismically active major structures. These structures have been responsible for some of the largest magnitude seismic events which have occurred at Perseverance Mine. The largest event recorded to date (Richter Magnitude approximately +3, January 1st, 2008) occurred as a result of slip on a fault north of the Progress orebody.

2 Ground support

This section describes the evolution of ground support practices at Perseverance as well as the current standards. A brief history is presented first, modified from Tyler and Werner (2004).

2.1 Brief history of ground support systems

Prior to 1995 the ground support in the SLC ore crosscuts consisted of Split Sets and mesh installed routinely several cuts behind the development face. However, on the 10130 and 10115 mRLs (390 and 405 m below surface) there were two 20–30 t falls of ground within the unsupported section of the drive. These falls of ground resulted in the decision to install the mesh and Split Sets right up to the face and support within the development cycle. In early 1995 it was recognised that cable bolts would be required in intersections and spot bolting of badly sheared hangingwall contact areas where required. By mid 1995 the results of initial stoping on the 10130 and 10115 mRLs indicated that the production brows were not sufficiently reinforced to prevent brow break off. By mid 1995 there was a plan to routinely cable bolt the backs of drives and within six months the worsening ground conditions below the 10100 mRL (405 m below surface) made it apparent that the walls would require cabling as well. The cable bolt rings were initially installed on a 2.5 m spacing, which was subsequently reduced to a 1.25 m spacing within a year. Post 1995, numerous changes and modifications to the ground support systems used in the SLC ore crosscuts have occurred, as shown in Table 5. The table refers mostly to ground support in the more challenging serpentine ultramafic and hangingwall shear zone.

Table 5 Ground support history in SLC crosscuts at Perseverance Mine

Date	Ground Reinforcement	Surface Support	Sequence	Comment
Pre 1995	2.4 m friction bolts	Weld mesh	Mesh and bolts installed several cuts behind face	Several large rockfalls occurred
Early 1995	2.4 m friction bolts and birdcage cable bolts (backs only) at 2.5 m ring spacing	Weld mesh	In-cycle bolting with cable bolts installed in campaign	
Mid 1995	2.4 m friction bolts and birdcage cable bolts at 1.25 m ring spacing	Weld mesh	In-cycle bolting with cable bolts installed in campaign	Review by consultant indicated requirement for shotcrete. Used in rehabilitated areas
Mid 1996	2.4 m friction bolts and plain cable bolts at 1.25 m ring spacing	Weld mesh with fibrecrete (steel fibres)	In-cycle bolting with cable bolts installed in campaign and post grouting of friction bolts	Non-meshed areas deformed intensely. Changed cable bolt system to plain strand from birdcage

Table 5 Ground support history in SLC crosscuts at Perseverance Mine (cont…)

Mid 1997	2.4 m friction bolts in backs and walls with debonded gewi bolts on a 1.25 m ring spacing	Weld mesh and fibrecrete (125 mm thick composite sandwich)	75 mm fibrecrete layer, bolting and mesh, 50 mm fibrecrete layer. Debonded gewi bolts installed in campaign	First attempts to generate a yielding reinforcement system, which improved with time
Dec 2002	2.4 m friction bolts, backs and walls with debonded gewi bolts on a 1.25 m ring spacing	Weld mesh and fibrecrete (125 mm thick composite sandwich)	75 mm fibrecrete layer, bolting and mesh with gewi bolts in-cycle, 50 mm fibrecrete layer	First attempts at in-cycle bolting in hangingwall shear zone areas
Jul 2003	Modified drive profile in hangingwall shear zone to an arch back			
Aug 2003	2.4 m friction bolts in backs and walls with debonded 3 m gewi bolts on a 1.25 m ring spacing	Fibrecrete and weld mesh (75 mm fibrecrete post mesh)		Introduction of stage 1 high toughness fibrecrete
Late 2004	Introduction of reinforced shotcrete arches in rehab areas			
Mid 2006	Commenced trials of inflatable Swellex bolts, using a Boltec Rockbolter			
Jun 2007	2.4 m friction bolts in backs and walls, with 2.4 m Swellex on a 1.25 m ring spacing, plain strand cables installed in shear zone	Weld mesh and fibrecrete (125 mm thick composite sandwich)	75 mm fibrecrete layer, bolting and mesh with Swellex in-cycle, 50 mm fibrecrete layer. Plain strand cables installed in campaign	Swellex installed with bolter. Spiles (4 m friction bolts) installed for each cut in shear zone
Sep 2007	2.4 m Swellex in backs and walls. Plain strand cables installed in shear zone	Weld mesh and fibrecrete (125 mm thick composite sandwich)	75 mm fibrecrete layer, bolting and mesh with Swellex in-cycle, 50 mm fibrecrete layer. Plain strand cables installed in campaign	Swellex installed with a jumbo (pins mesh). Jumbo fleet has Swellex pumps installed
Late 2008	Trialling the use of W-plates on all rockbolts (in addition to standard 150 mm plate), with a thicker initial spray of fibrecrete (~90 mm) and no second spray			

2.2 Current ground support standards

As the previous section has demonstrated, ground support practices at Perseverance Mine have evolved over several years, and continue to evolve today. The current ground support standards in use at Perseverance Mine have been designed based on several methodologies:

- Mechanistic and probabilistic design assessment.
- Empirical relationships between rock mass quality and ground support/stand-up time.
- Historical data and performance observations.
- Predicted deformation or loading from elastic 2D (Examine2D and Phases) and 3D stress modelling (Map3D, Abaqus).

- The life and serviceability of the excavation.
- In some particular cases discrete structure analysis using Rocscience programmes such as DIPS and Unwedge might also be conducted.

Eight ground support standards are currently in use at the mine (Table 7). The large number of standards reflects the variety of ground conditions encountered at the mine, from rockburst prone stiff felsic units to softer ultramafic rock types prone to squeezing in the SLC crosscuts.

Table 6 Current ground support systems in use at Perseverance Mine

Support System	Total Fibrecrete Thickness	Back Support	Pattern	Wall Support	Pattern	Application and Tunnel Profile
GS01	125 mm	Swellex and mesh	7 bolts per ring, 1.5 m ring spacing	Swellex and mesh	8 bolts per ring, 1.5 m ring spacing	Serpentine ultramafic (flat arch) and HWL (full arch)
GS02	50 mm	Resin anchored Securabolts and mesh	7 bolts per ring, 1.5 m ring spacing	Resin anchored Securabolts	8 bolts per ring, 1.5 m ring spacing	Olivine ultramafic, slight arch
GS03	50 mm	Resin anchored Securabolts and mesh	7 bolts per ring, 1.5 m ring spacing	Resin anchored Securabolts on SLC side. Friction bolts on footwall side	4 bolts per ring, 1.5 m ring spacing for thread bar, 3 bolts per ring, 1.5 m ring spacing for friction bolts	SLC ore footwall, full arch
GS04	125 mm	Swellex and mesh. Campaign 5 m cablebolts	8 bolts per ring, 1.2 m ring spacing, cable bolts at 1.5 x 1.5 m	Swellex and mesh	8 bolts per ring, 1.25 m ring spacing	Shear zone, full arch
GS05	50 mm	Resin anchored Securabolts and mesh	7 bolts per ring, 1.5 m ring spacing	Resin bars and mesh	4 bolts per ring, 1.5 m ring spacing	Felsics, full arch, deep mining
GS06	50 mm	Resin anchored Securabolts and mesh	5 bolts per ring, 1.5 m ring spacing	Friction bolts	6 bolts per ring, 1.5 m ring spacing	1A, slight arch, narrow and short drives
GS07	-	Resin anchored Securabolts and mesh	7 bolts per ring, 1.5 m ring spacing	Friction bolts and mesh	6 bolts per ring, 1.5 m ring spacing	Felsics, full arch, decline bypass in shallow mining depth
GS08	75 mm	Resin anchored Securabolts and mesh	7 bolts per ring, 1.5 m ring spacing	Resin anchored Securabolts and mesh	10 bolts per ring, diamond pattern	Felsics, full arch, deep mining where higher seismic potential

Squeezing ground conditions are the cause for most of the rehabilitation requirements at Perseverance Mine. None of the ground support systems in use at the mine are capable of completely preventing these large deformations. The key is to install the primary support as soon as possible to limit and manage the amount of squeezing that occurs. Introducing the primary support bolt (now Swellex) in-cycle has resulted in a marked improvement in excavation performance in difficult ground conditions. Rehabilitation is inevitable in extreme cases of drive closure, however, recently the number of passes of rehabilitation has been reduced. This is due to the improved ground support systems in use as well as careful management of lead and lag across SLC levels. The ground support system used in the shear zone, the area of most severe deformation, is shown in Figure 6.

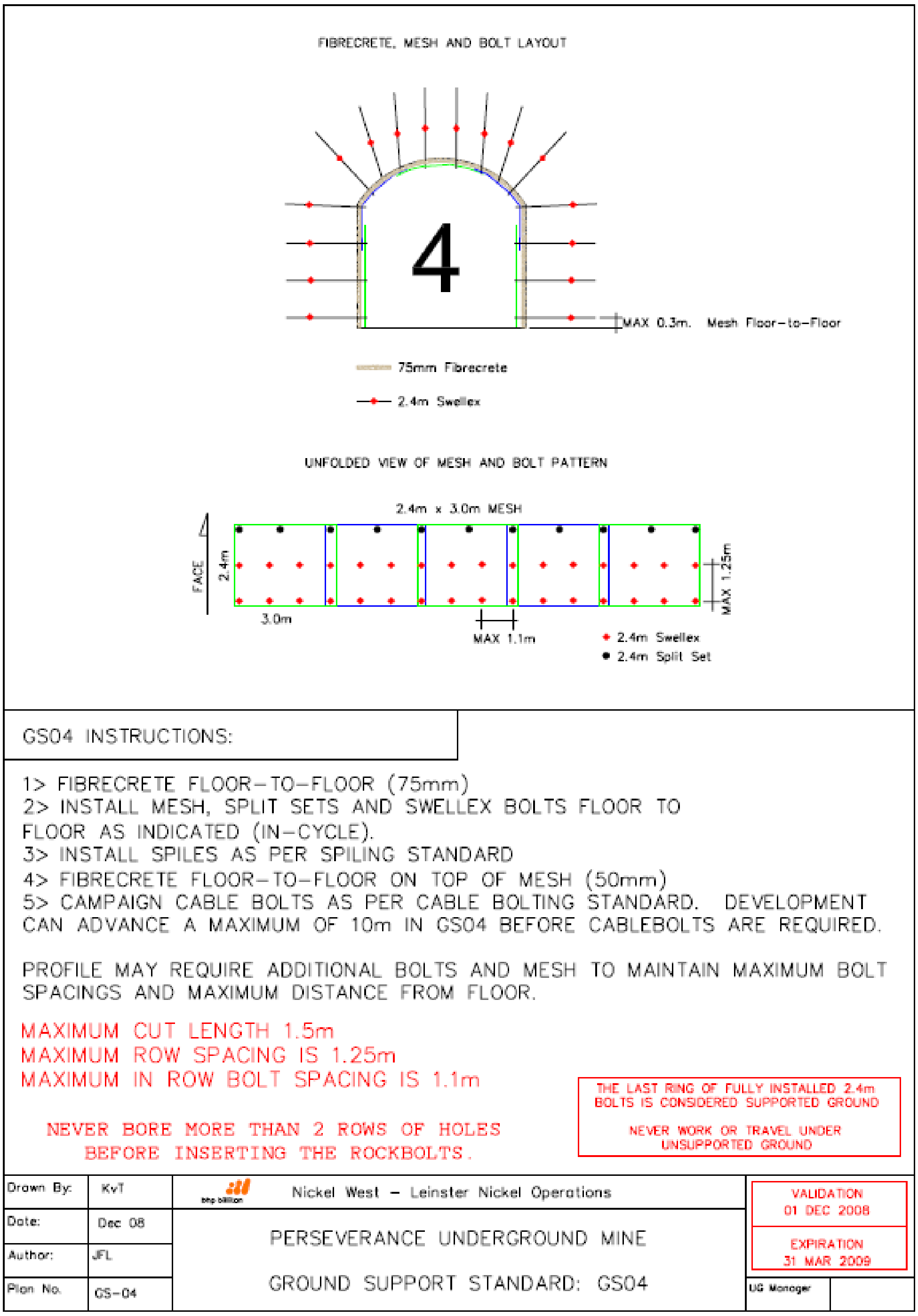


Figure 6 Ground support standard GS04 used in squeezing ground conditions (the shear zone)

Experience has shown that a tight pattern of strong rockbolts, strong surface support and mesh to the floor provides good support in seismically active conditions at Perseverance Mine. This may be because the larger and potentially damaging seismic events which occur at the mine often occur remotely to mine development.

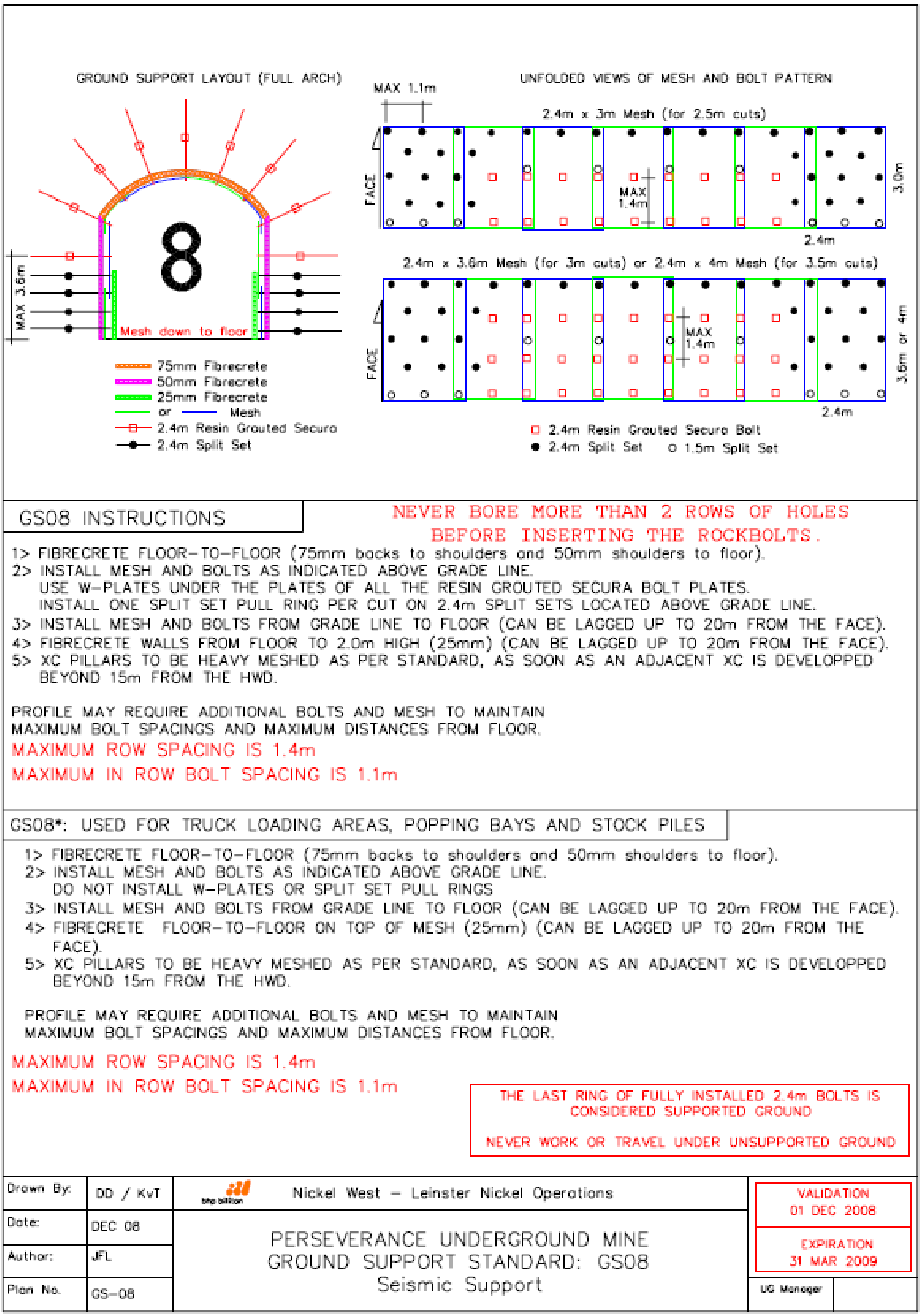


Figure 7 Ground support standard GS08 used in areas prone to mine seismicity

Severe rockburst damage which may be more typical in highly stressed regions in narrow vein mines in Western Australia (e.g. brows or pillars) is rare at Perseverance Mine, perhaps due in part to the fact that the majority of production areas at Perseverance Mine lie within the softer ultramafic rock types, which are not as prone to rockburst damage. The support system applied in areas where seismicity is expected is shown in Figure 8. All development faces are also meshed in-cycle in areas where seismicity is possible.

3 Trials and innovation

This section provides details on some recent and in progress trials which have been carried out as part of the ongoing efforts to better manage ground control challenges at Perseverance Mine.

3.1 Fibrecrete

In-cycle application of fibrecrete is considered vital in difficult ground conditions at Perseverance Mine since failure to apply it soon after development has been found to result in rapid deterioration of walls. It is accepted that the fibrecrete will eventually crack as the walls converge, however mesh is in place to retain the broken slabs of material. The second layer of fibrecrete is applied as a protective layer for the lower walls and largely to allow cleaner collaring of production holes in the backs. Gaudreau (2005) describes how between 2003 and 2004, trials were carried out on the use of synthetic fibres, whereby fibrecrete was sprayed as a single layer of 75 mm pre-mesh. The performance of the fibrecrete was deemed unsatisfactory. Once yielded, the fibrecrete panels would disintegrate entirely and the entire drive profile would have to be resprayed. A decision was taken to revert back to steel fibre and to use two layers of fibrecrete. This approach has been successful since then, however has resulted in the use of large volumes of fibrecrete. At the time of writing the use of W-plates behind the conventional 150 mm plates is being tried to facilitate better load transfer between the surface support and primary rockbolts, with a view to reverting to a thinner fibrecrete profile and reducing the amount of fibrecrete used on-site.

Reinforced shotcrete arches were first trialled at Perseverance Mine in 2004 and have since been used for brow support and for rehabilitation in wide span crosscuts where stripping has been required. The arches are considered a passive external support and prove useful if the tendon support has reduced effectiveness in heavily broken ground. Photographs of arch reinforcement and of completed arches are shown in Figure 8. Profile members are pre-fabricated and assembled underground to fit the application requirements.

Figure 8 Reinforced shotcrete arches at Perseverance Mine in construction (left) and completed (right)

3.2 Swellex

The inflatable Swellex bolt has been used effectively at Perseverance Mine for some time now, is relatively simple to install and has been embraced by our operators. It eliminates some of the problems associated with using resin anchored, mechanised bolts in highly stressed or broken ground and has a high axial capacity (24 t) when compared to other commercially available rockbolts. At Perseverance Mine, these bolts are now installed by development jumbo. Their ease of installation makes them ideal for use in broken ground and have allowed for more rapid support installation in these areas.

There are however, some concerns with the longer term performance of the bolts:

- The shear capacity of the bolt is less than that of a solid bar bolt (such as a Securabolt). Shear capacity is an important consideration in our ground conditions as rock mass dilation in the SLC crosscuts can result in guillotining of rockbolts without enough steel in cross-section, particularly in the walls.

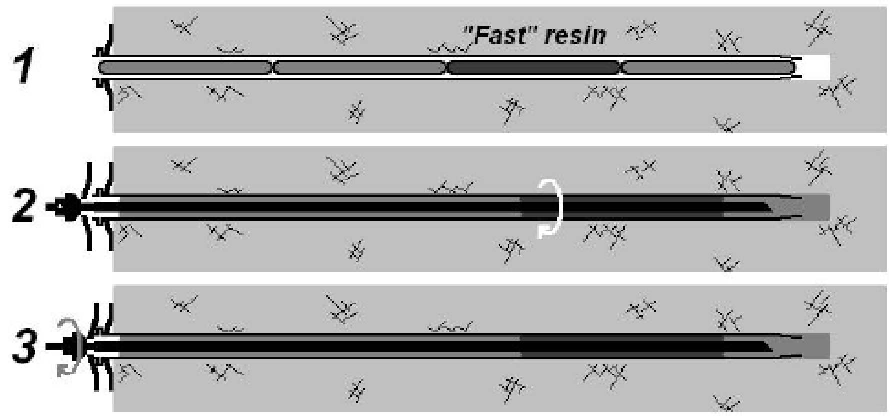
- We have encountered logistical issues with the supply of the bolt, with a shortage in late 2008.
- They are an expensive rockbolt.
- There may be issues with corrosion resistance of the bolt, although only a few cases of this occurring have been noted. Coating is being investigated as an option to improve the corrosion resistance however this will significantly add to the cost of the already expensive bolt.

It can be said that all ground support elements have their benefits and shortcomings. Whilst these issues are a concern and are being addressed, their ease of application means that Swellex will continue to be used for now at Perseverance Mine, coupled with continuous quality control testing by the geomechanics department in an effort to locate areas where the bolts may be sheared or corroded and reinforce these areas as necessary. We are continuing to work with the suppliers of the bolt to improve their corrosion performance, as well as investigating other options, such as the hybrid bolt.

3.3 Hybrid bolts

The hybrid bolt concept was identified as a candidate for use at Perseverance Mine with the potential for use as the primary rockbolt in difficult ground conditions after its successful application was reported from the Laronde Mine in Canada (Mercier-Langevin and Turcotte, 2006). The hybrid bolting system involves the installation of a resin bolt inside a pre-installed friction bolt which has the resin cartridge placed inside prior to installation. The use of a galvanised friction bolt and fully encapsulated solid bar means that this bolt should exhibit good corrosion resistance and perform well under shear loading.

Figure 11 illustrates the technique for this bolting system as it is applied in squeezing ground conditions at the Laronde Mine in Canada. Note that the fast resin as shown in Figure 9 is not necessary for the system to work and other resin arrangements can be used. A full column of medium set resin is successfully used on a regular basis for solid bar installation at Perseverance Mine.



Step 1	Friction bolt installed with resin cartridge inside.
Step 2	Resin bolt installed inside friction bolt, spun to mix resin.
Step 3	Once resin has set, nut is spun up tight to provide plate load.

Figure 9 Illustration of hybrid bolting system (Mercier-Langevin and Turcotte, 2006)

Three variants of the hybrid bolt concept have been trialled at Perseverance Mine:

- A 46 mm SS46 Friction Bolt with an R27 Securabolt installed using 26 mm medium set resin.
- A 46 mm SS46 Friction Bolt with an R27 Securabolt installed using 30 mm medium set resin.
- A 39 mm SS39 Friction Bolt with a 22 mm Reobolt installed using 26 mm medium set resin.

Several installation difficulties were encountered during the trial. Success of the concept relies on the ability of the operator to place the resin in the friction bolt prior to installing, otherwise resin must be installed individually, adding significant time to the development cycle. In around half the cases, broken rock fragments would either split the resin cartridge during installation or force it out through the split. For the trial, resin was installed separately to allow pull tests to be conducted to assess the performance of the hybrid bolts. This was not an issue in the case of the third variant trialled (where smaller SS39 friction bolts were used), however several of these buckled during installation in the difficult ground conditions, again due to the presence of broken fragments in the borehole or an uneven borehole and the reduced buckling capacity of the SS39 friction bolts due to a lesser amount of steel in the cross section.

For the bolts which were installed successfully, pull test results on all three variants were very encouraging, with several of the bolts achieving 25 t axial load. However, the practicalities of installation meant that none of the three hybrid bolt variants trialled at Perseverance Mine were considered suitable for routine use within the development cycle. Difficulties encountered during the installation of the most successful version (variant three) mean that there would be significant increases in development time if it were to be adopted, not to mention operator frustration, particularly in difficult ground conditions encountered in the shear zone. Furthermore, the number of failed installations was almost half the total number of bolts installed. A fourth variant was being trialled at the time of writing which was intended to address the problems associated with the first three:

- A 46 mm Stiff Split Set (fully enclosed), with an R27 Securabolt installed using 26 mm medium set resin.

It is hoped this fully enclosed Split Set will prevent the resin from being damaged during installation or being pushed out of the friction bolt.

3.4 High energy absorption mesh

HEA Mesh™ is a recent development (Potvin and Giles, 2008). The product is standard or crinkled weld mesh which incorporates high tensile steel cable lacing. The intention of the cable lacing is to provide vastly improved load transfer from a squeezing or dynamically loaded rock mass to the individual rockbolt units. By incorporating the lacing into the mesh, the entire system can be installed mechanically. The lacing also acts to reinforce the mesh overlap, since the lacing from adjacent HEA Mesh sheets cross over. The mesh overlap area has been identified as a weak point in most ground support systems underground and failure at the mesh overlap has been the cause of many falls of ground in underground mines (Heal and Potvin, 2007). The product is shown in Figure 10 and in its installed form in Figure 11.

Figure 10 HEA Mesh prior to installation (Potvin and Giles, 2008)

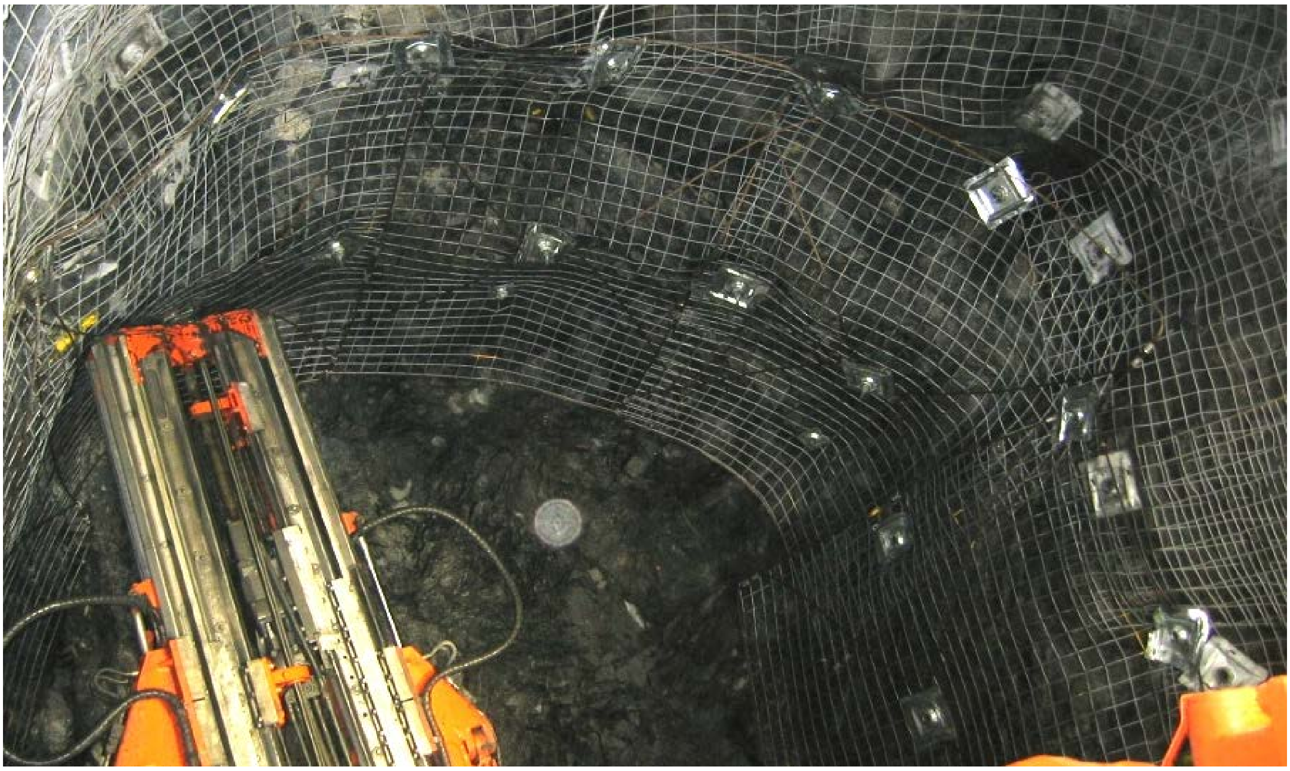


Figure 11 HEA Mesh sheets installed in a development heading (Potvin and Giles, 2008)

The HEA Mesh will be trialled at Perseverance Mine in 2009 and preparations were underway at the time of writing. The mesh will be trialled in both seismically active conditions and in squeezing ground conditions.

4 Conclusions

The ground support systems in use at Perseverance Mine have evolved over a number of years. Over the last two years, significant progress has been made in improving ground support performance in seismically active areas and in the areas of squeezing ground with the introduction of GS08 and GS04. Important gains in the development cycle in poor ground have been achieved using Swellex bolts.

The current focus is being placed on finding an appropriate rockbolt suitable for use in squeezing ground conditions. The hybrid bolt, a combination of a resin grouted rebar inside a Split Set type friction bolt, is a promising candidate if the practical issues associated with installation can be resolved. The aims of some of the changes have also been to improve the interaction of the entire ground support system. Over the next six months, an emphasis will be placed on experimenting with a new type of surface support, the HEA Mesh.

The ongoing efforts to improve the ground support systems in use have resulted in a continuous reduction in the number of falls of ground recorded at Perseverance Mine over recent years, despite the depth of mining increasing significantly over that time. These improvements have related to both the types of reinforcement and surface support elements used as well as the timing of their installation within the development cycle. We believe we can achieve further improvements as the depth of mining at Perseverance Mine continues to increase.

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