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A methodology for managing squeezing ground conditions at Mincor's Mariners Mine, Western Australia

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Abstract

The recent global downturn in the mineral industry bought about a re-structuring of the geotechnical services and resources within the Mincor Operations, with an emphasis on ensuring maximum utilisation of available resources.

A back-to-basics approach led to the development of goals and an action plan, whereby instrumentation and geotechnical resources were optimised. The action plan included the following:

- *The installation of SMART cables to monitor deep-seated movements of structures in drives of strategic importance, to understand failure mechanisms and ground support reaction.*
- *Review and validation of the structural and ground support data to ensure the minimum ground support requirements are met.*
- *Review and validate the geotechnical data to delineate a new domain that was often the source of significant rehabilitation costs.*
- *Maintain hazard mapping to establish a history of ground support deterioration over time and monitor bolt performance and rehabilitation requirements. These observations are utilised to validate numerical modelling outputs and determine mine design criteria.*
- *Use the Matthews/Potvin modified stability graph, numerical modelling and stope behaviour observations to determine a local design criterion, and predict future stope behaviour.*
- *Collation of data into REM3D to ensure all known geotechnical data and design criteria are available and presentable in a digital format. The three dimensional geotechnical models are used by mine planners and schedulers to gain an understanding of areas that will likely require additional ground support or design changes.*

The objective of this paper is to present the methodology that Mincor has used in order to optimise its resources and deliver sound geotechnical advice to operational and planning personnel.

It is important to note that some data and observations included in this paper are from Mincor's neighbouring Miitel and Redross mines, which are located approximately 5 km north and 10 km south of Mariners respectively. Because of the similarities in mining and geology of both mines the data, observations and methodologies are interchangeable between the operations.

1 Location and mine geology

Mariners Mine is located approximately 100 km south of Kalgoorlie, Western Australia. The mine was discovered and operated by WMC Resources from 1991 until 1999 when it was written off and flooded during a period of low nickel prices. Mincor acquired the project at no cost as part of its acquisition of the neighbouring Miitel Nickel Mine in 2001 and reopened Mariners in 2004. Until December 2009, Mincor has extracted 848,000 tonnes of ore at 2.47% nickel for 21,950 tonnes of contained nickel.

Mariners Mine is typical of mines found in the Kalgoorlie-Kambalda nickel district of Western Australia, consisting of a very competent basalt footwall and a poor talc-magnesite-chlorite ultramafic hangingwall. The ore body at Mariners grades from high-grade massive and matrix ore on the basalt footwall contact, to gradational disseminated mineralisation extending out into the hangingwall ultramafics. The ore body average width is 3 m with strike lengths ranging between 50 and 250 m, dipping at an average of 50°.

The former N07 and N08 orebodies were primarily a single inter-channel with a broadly disseminated mineralised profile. The current N09 ore body consists of a series of structurally controlled and thickened, south plunging primary pods with strike lengths of approximately 40 m. The ore body is bounded by a series of up to four deformational events. The recently discovered N10 ore body exhibits similar poddy characteristics to that of the N09, with the exception of gradually increasing dip.

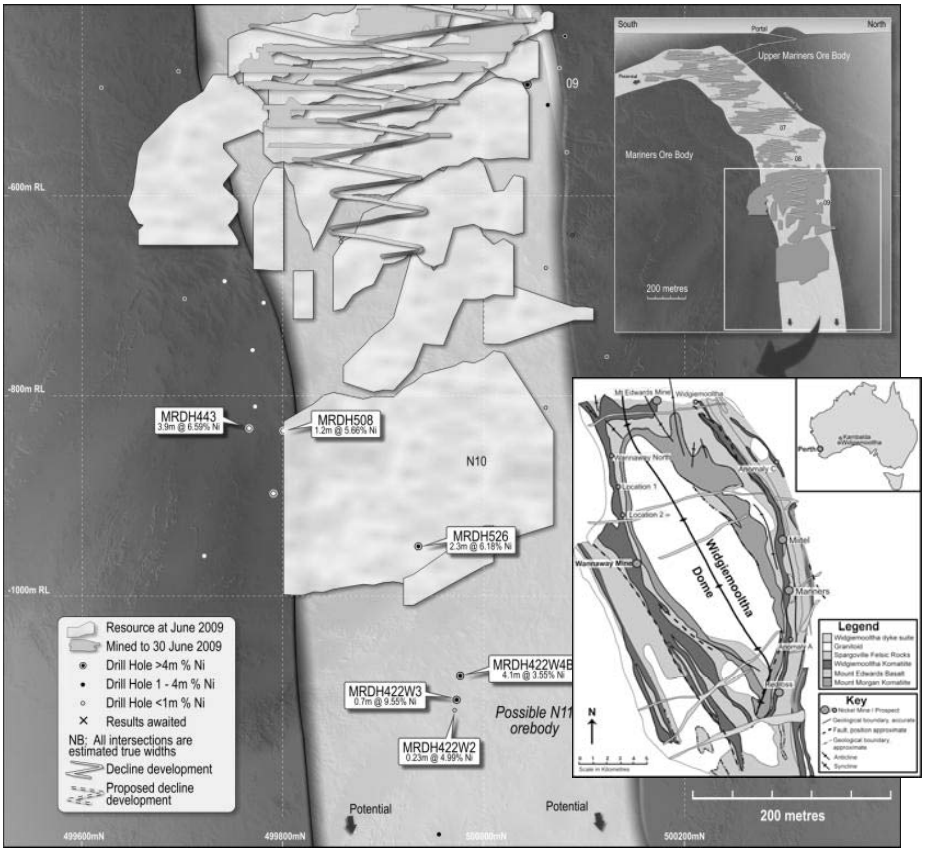


Figure 1 Mariners Mine orebodies and geology of Widgiemooltha Dome (insert)

2 Geotechnical setting

Mariners Mine has previously been divided into three geotechnical domains (namely basalt, ultramafic and ore), primarily based upon geology and the rock mass response to stress. Due to increasing depth and higher stress the competent footwall basalt is displaying signs of spalling with seismic activity increasing when driving perpendicular to the principal stress orientation.

The brittle and less competent massive and matrix ore displays a combination of spalling, some creep style behaviour and minor seismic activity. The least competent ultramafic material exhibits predominately creep style behaviour and minimal seismic activity.

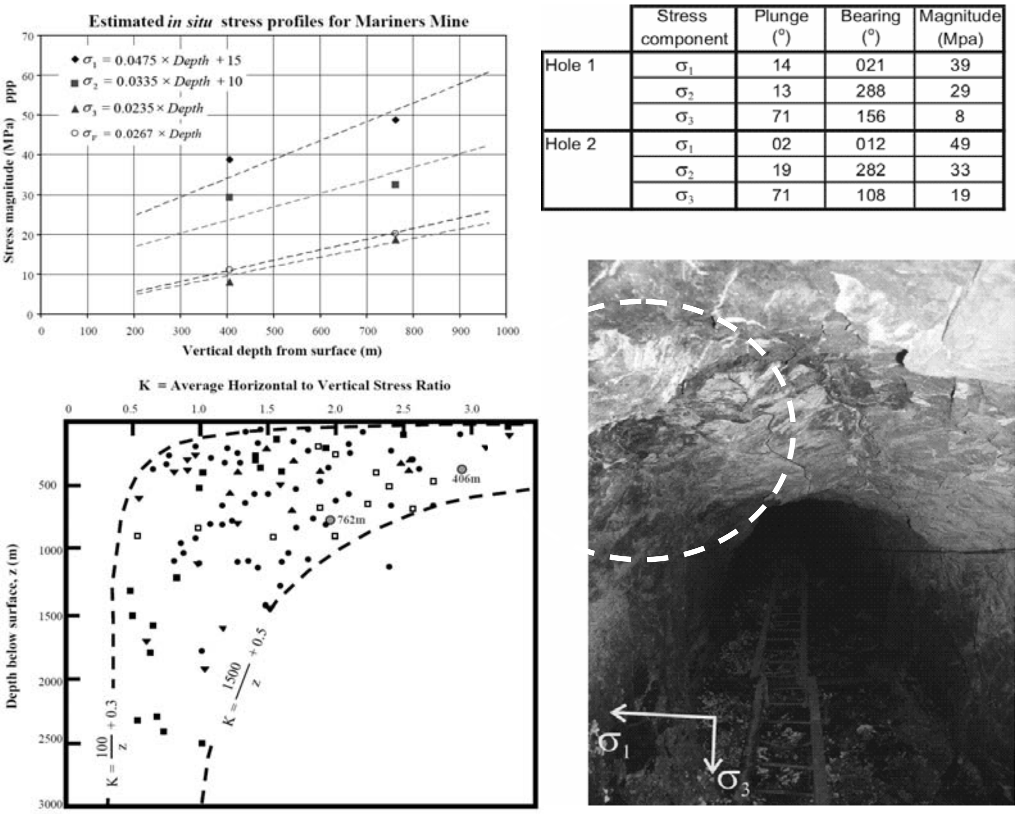
A recent re-evaluation of the geotechnical domains in conjunction with observational hazard mapping allowed the identification of a second ultramafic domain. This domain exhibits accelerated creep behaviour in the presence of a shear structure or fault. The absence of chlorite and mineralisation further exacerbates the creep behaviour. To date no laboratory testing has been completed to characterise the rock mass in this domain.

Table 1 Summary of geotechnical domains and rock mass properties

Rock Mass Property	Unit	Host Rock Domains		Ore Domains		
		Basalt	Ultramafic	Massive	Matrix	Disseminated
UCS	MPa	175	52	110	83	49
Density (ρ)	t/m^3	2.89	3.03			
Tensile strength	MPa	18	9			
Young's modulus	GPa	52	70	60	57	44
Poisson's ratio		0.27	0.33	0.24	0.3	0.36

3 Stress state

Two acoustic emission (AE) stress measurements have been conducted at Mariners at 406 m (June 2005) and 762 m (May 2008) below surface, with results displaying a high increase in stress state at depth, typical of the Kalgoorlie–Kambalda region (refer to Figure 2). A high degree of confidence can be placed in the acoustic emission results as the stress magnitude and direction can be calibrated against borehole breakout observed in airleg escape ways and rises. Localised areas of increased stress occur around the central pillars. These high stress concentrations are most evident where changes in geology are present.



	Stress component	Plunge (°)	Bearing (°)	Magnitude (Mpa)
Hole 1	σ_1	14	021	39
	σ_2	13	288	29
	σ_3	71	156	8
Hole 2	σ_1	02	012	49
	σ_2	19	282	33
	σ_3	71	108	19

Figure 2 Results of stress measurements from Acoustic Emission method (Villaescusa and Machuca, 2008) and breakout observed in an airleg rise

4 Mining method

The mining methodology employed at Mariners involves the development of primary ore drives along the strike of the orebody (strike drive). The ore drive backs are stripped by single flat back drives, followed by retreat modified Avoca or blind long hole stoping to a barren central pillar (refer to Figure 3). The vast majority of mining is via mechanised equipment with handheld mining limited to isolated, small high grade narrow vein areas of the mine.

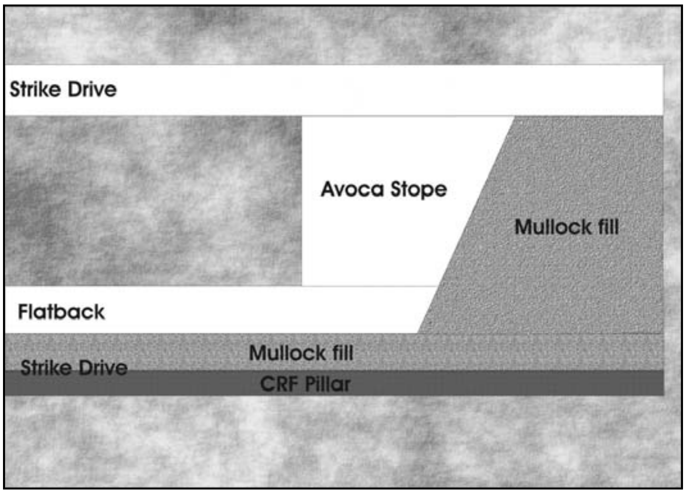


Figure 3 Schematic of Avoca style mining method used at Mariners

5 Instrumentation, observations and data collection

Increasing stress and seismicity at depth bring an increasing complexity to the geotechnical management of the Mariners Mine. The need to collect quantitative and observational data that is accurate and ordered with enough confidence to be the basis for the calibration of numerical modelling is essential.

The strategic, rather than blanket, use of instrumentation is paramount to balancing data acquisition and quality with cost. It is essential that all instrumentation installed have a specific purpose and that the data is rigorously analysed in order to ensure high quality geotechnical models.

5.1 SMART cables

SMART cables are installed in areas that are of strategic importance (e.g. intersections), geotechnical interest (structurally complex, or high closure areas) or where a non standard mining approach is being adopted. An example of the use of a SMART cable in a strategic role can be seen in Figure 4.

In this situation a final flat back had been completed, leaving the ore inaccessible to conventional long hole stoping machinery. A decision was made to extract the remaining ore via airleg stoping. Due to the length of time (greater than 12 months) required to complete mining on this level, a cable bolt pattern incorporating a SMART cable was installed through previously identified hangingwall structures.

Figure 4 suggests that movement occurs initially along the first structure, and later along a second deeper structure beyond the embedment length of rock bolts. The SMART cable is useful for validating the need for cable bolting but also has the ability to monitor cable loads. As twin strand cables have been installed in this region, it can be estimated from the SMART cable logging data that the cables embedded beyond geological structures are at approximately 63% of the design capacity.

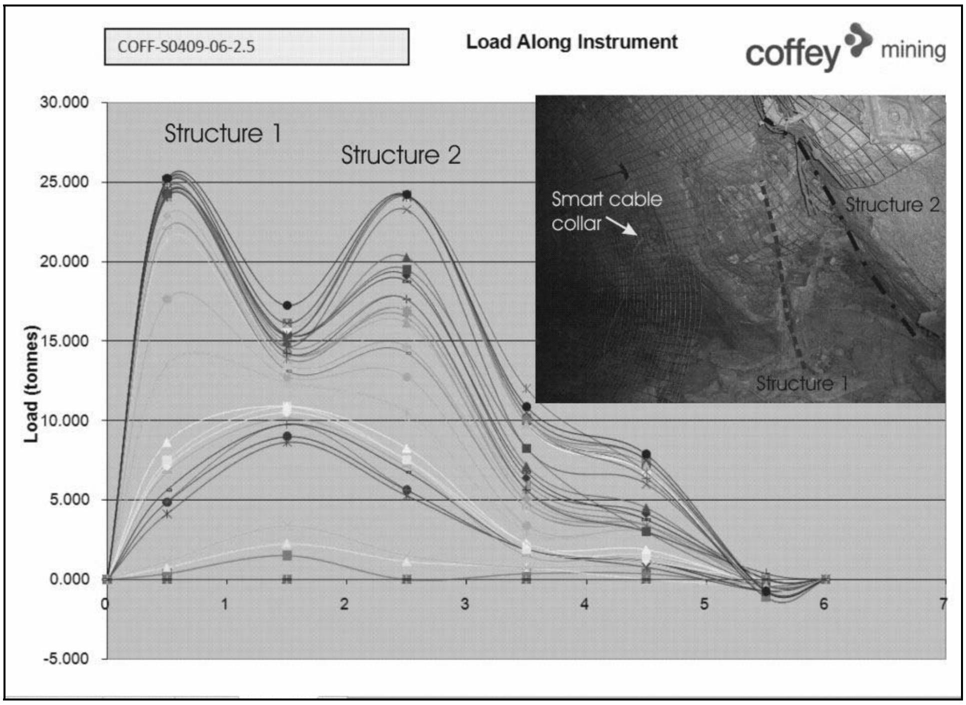


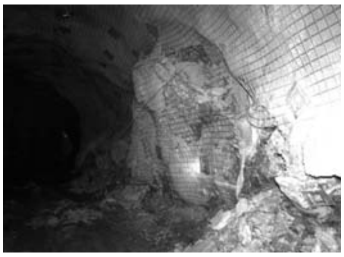
Figure 4 Load along SMART cable due to movement along two large structures in the 1600C hangingwall (plot produced by Excel macros supplied by Coffey Mining)

5.2 Mapping

Geologists and the geotechnical engineer collect structural data during routine underground visits. This data is collated into a central database and represented in both a digital format (Surpac) and on hazard maps. Rocscience DIPS software is used to analyse the structural data to identify specific structural/joint sets which in turn is used as input for wedge analyses to confirm ground control requirements.

Closure monitoring had previously been conducted on a regular basis at Mariners. However, due to this process being resource intensive it was suspended in favour of less quantitative and more observational drive damage mapping. Damage mapping, as shown in Figure 5, is completed on a regular basis and consists of observing the deterioration of the rock mass and ground support and identifying zones of anomalous jointing or structure. The hazard mapping damage scale, displayed in Table 2, is used to classify damage observed underground.

Table 2 Mariners damage mapping scale

Rock Mass Condition	Damage Rating	Description of Conditions
	0	No damage visible, all surface support and rock bolts intact
	1	Some spalling and cracking of exposed rock. Cracking of fibrecrete but majority of fibres intact across crack. Rock bolts intact. Split set plates buckling but not detached.
	2	Moderate amounts of spalling, moderate fibrecrete cracking (>20 mm) with majority of fibres broken across the crack. Some split set plates failed. Buckling of Omega bolt plates
	3	Severe deterioration. Large amounts of spalling, bucking or floor heave. Fibrecrete cracking (>50 mm) and detaching from rock. Numerous failed split set bolts, and some failed Omega bolt plates

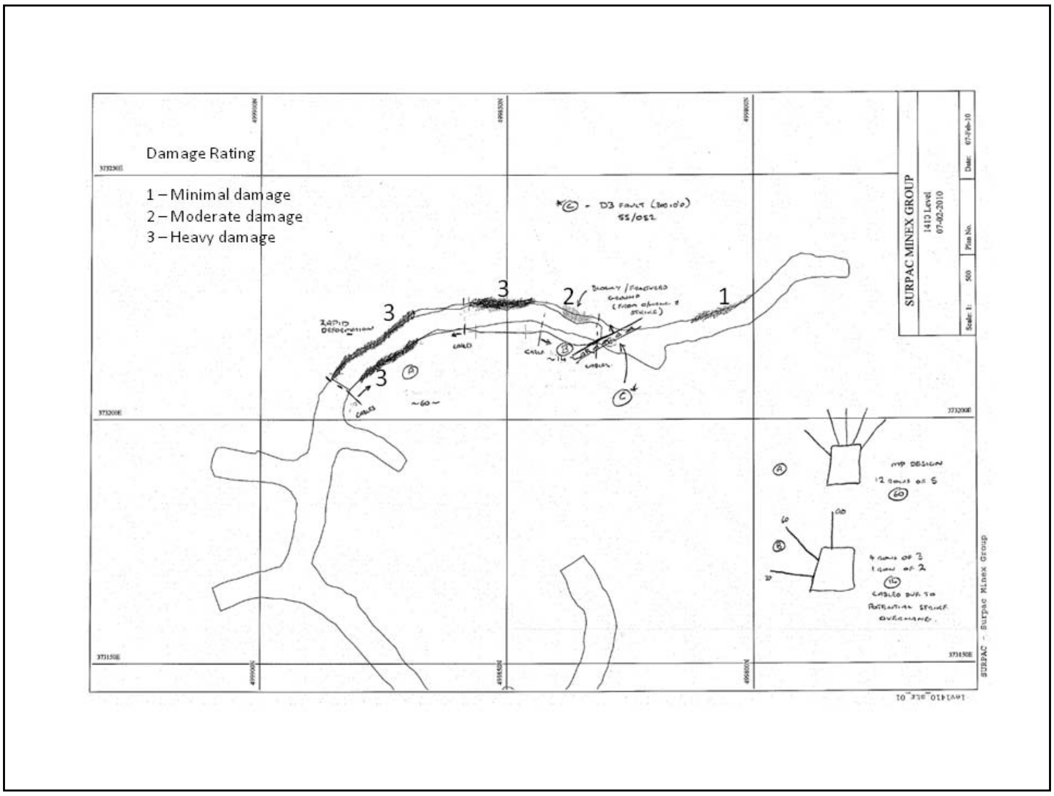


Figure 5 An example of hazard and damage mapping

An analysis of sequential damage maps highlighted a trend of accelerated deterioration within a specific zone in the ultramafic domain.

Previously no geotechnical distinction had been made between the mineralised and non-mineralised ultramafic hangingwall as both exhibited similar creep responses to stress. Relative to the non-mineralised ultramafic, the presence of the chloritic metamorphic halo and mineralisation, marginally increase the cohesion and strength of the mineralised ultramafic. In the presence of significant shearing or faulting these intrinsic strength differences become exaggerated and the rate of deformation of the non-mineralised ultramafic dramatically increases in direct comparison to the mineralised ultramafic. Further domain laboratory sampling and closure monitoring is warranted to quantify these behavioural differences.

Figure 5 shows an example of damage mapping across the mineralised and non-mineralised ultramafic domains over the same time period. In the absence of damage mapping showing this accelerated damage trend (repeated on several levels), this additional ultramafic domain may not have been identified.

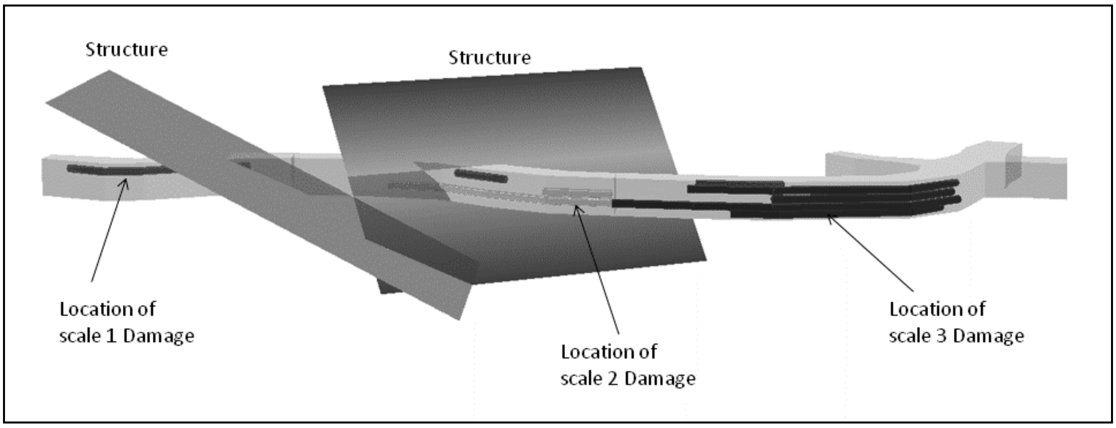


Figure 6 REM3D output for the 1410 Level at Mariners showing damage mapping over both ultramafic domains and structure projections

6 Stope stability performance

The performance of stope and pillar design versus actual behaviour is monitored and back analysed. Firstly the stope stability and rock mass data is accumulated in order to produce localised Matthews/Potvin modified stability graphs, and secondly the stope design and actual shape are back analysed in Map3D to produce stress and structural design criteria

6.1 Matthews/Potvin stability analysis

Although stope dimensions across the mine are relatively uniform the localised stability graphs are a valuable guideline for identifying the stability of non standard stope dimensions such as those mined at the top of the ore bodies where blind long hole stoping of varying dimensions is conducted. Where modified Avoca stoping is being conducted it can be difficult to determine a distinct hydraulic radius and modified stability number for stable stope design criteria. The sequential retreat nature of mining means that hangingwall damage and ground deterioration from creep initiated in the first stopes can have a cumulative effect on the latter stopes, despite the presence of backfill. This means that although stopes have similar hydraulic radius and stability number, one may be stable and the next may fail, hence graphically we end up with a tight cluster of good, transitional and failed stopes as seen in Figure 7.

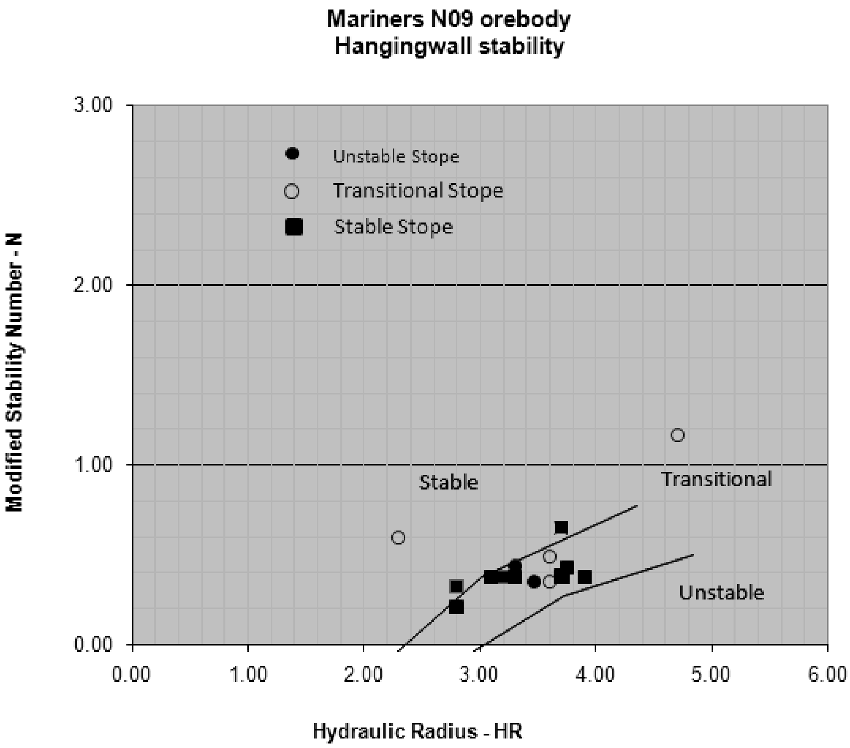


Figure 7 Localised Matthews/Potvin stability graphs for Mariners Mine

6.2 Numerical modelling

Until the recent downturn, operational demands lead to a majority of the numerical modelling (Map3D) being outsourced to consultants, with modelling being completed on a large campaign basis as a tool to assist changes to mining sequences. The outsourcing of this task was primarily due to a lack of resources, program familiarity, and time to perform this task in the operational role of the geotechnical engineer. Numerical modelling has now been returned to the operational role with mine wide modelling being constructed via a series of smaller models that are calibrated to certain or a series of observations during a mining cycle.

A stope design criterion has been established at the Redross mine using stope performance, hazard mapping, drive deterioration, over break and fracturing around the drives as a means of calibrating of numerical modelling against observations (Figure 8). Further work in refining the Map3D design criterion and ensuring calibration with ground conditions at Mariners is required prior to any determination of probability of failure being completed.

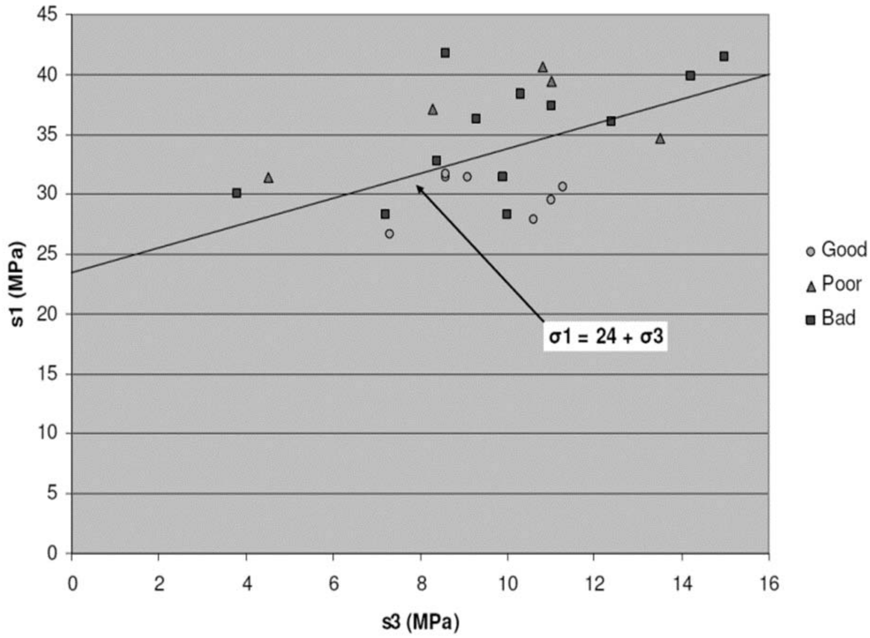


Figure 8 Map3D design criterion for 20 m strike length stopes with ultramafic hangingwall at Redross Mine (Green, 2008)

7 Seismicity

Seismic activity at Mariners has been monitored since mid-2007 via a small standalone ISSI system with data processing and monthly reporting being conducted by ISS International. The data collected by the system is used to perform a seismic hazard risk assessment, based upon the seismic hazard scale (SHS) produced by Hudyma (2007). The SHS process is used as a guideline for determining a relative seismic hazard and an approximate magnitude of the largest expected event, and for Mariners the SHS is determined to be moderate to high with a maximum Richter magnitude event of +2. The largest event to date is a Richter magnitude 1.6 event located on a known fault as stoping was being retreated. One example of strain bursting from a basalt capital development has been observed with the ejection being contained by mesh and split sets.

The SHS is updated monthly with the ISS reporting and the seismic hazard risk assessment process identifying that further work on understanding the origin of seismicity and dynamic loading of ground support needs to be completed.

8 Collation of data

Historically geotechnical data collected at Mariners was almost entirely observational, and although high quality data was collected, little history of the data is retained once an employee leaves, or without vast amounts of time spent deciphering notepads.

Although this trend continues at Mariners, albeit with more quantitative data from the use of instrumentation, a process was needed to capture observations over time. The initial solution to this was to capture all observations as hazard maps on level plans that were updated at regular intervals for each drive (every fortnight) as mining progressed.

Other data such as structural projections, numerical data analysis, failure analysis and majority of the seismic data lay buried in various formats from Excel spreadsheets, Rocscience programs, numerical modelling packages to mine design programs, and hence was unable to be added to the hazard maps.

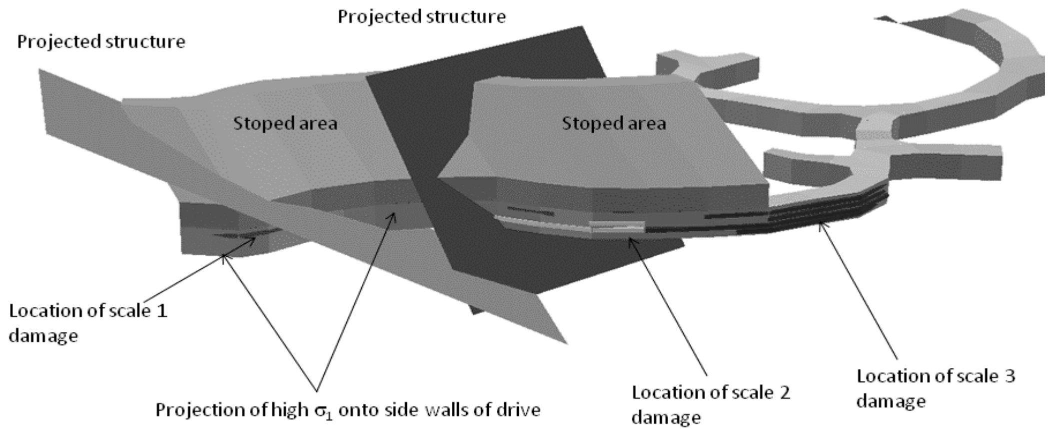


Figure 9 REM3D output for the 1410 Level at Mariners showing damage mapping, projected structures and σ_1 projected onto drive wall

One solution to data presentation was offered in the form of a small software package known as REM3D. Used primarily as a visualisation and presentation tool it allows the collation of data from various formats into a single three dimensional visualisation package. Figure 9 below shows an example of a stoped level displaying projected structures, drive damage and σ_1 projections from Map3D onto the hangingwall.

An additional benefit of using REM3D is that it allows non geotechnical staff access to known geotechnical data for the purpose of future mine planning.

Further projections, extrapolations and analysis can be completed by the geotechnical engineer using other more dedicated software but for a first pass process for analysing various mining possibilities and as a method for presenting future ground conditions to other professional staff it is ideal.

Conclusion

Mincor's methodology for managing squeezing ground is simple and robust, and focuses on using observational data in the form of damage and structural mapping as a basis for the calibration of more detailed analytical work such as numerical modelling, structural projections and empirical analysis.

Data collection and analysis is essential in rock mechanics. The collaboration and presentation of this data to other mining professionals in an easy and understandable manner is as equally important. The use of a program such as REM3D has allowed the centralisation and visualisation of geotechnical data in a user friendly format that provides a quick first pass process in analysing the geotechnical viability of various mining options.

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