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APPENDIX M

Geotechnical Assessment: Martha Underground Mine
(AMC)

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Report

Project Martha
Oceana Gold (New Zealand) Limited

AMC Project 217049_3
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Unearth a smarter way

Executive summary

Based on the current understanding of ground conditions, the planned ongoing investigation of conditions as suitable drilling positions become available, and the proposed cautious approach to development using close ground control techniques where required, AMC Consultants Pty Ltd (AMC) is confident that the proposed Martha underground mine can be developed and brought into production without any compromise to underground or surface stability. This is on the basis that:

- The proposed designs are appropriate and conservative.
- The planned development, drilling and interpretation as outlined in Section 5.4 will provide additional information at a detailed level and hence provide sufficient opportunity to adjust the design in response to encountered ground conditions.
- The proposed mining methods involve stope excavations that have a high level of assurance of stability, as discussed in Section 5.1. Stopes will be filled without delay on completion (Modified Avoca), or in the case of Avoca stoping, on a continuous basis with the fill being progressively advanced to follow the stope face and to maintain a minimal hangingwall/footwall exposed span. Where open stopes are encountered and it is intended to recover some of the adjacent resources, it is proposed that the voids will be filled with suitable materials before stoping commences.

The mining plan provides a high level of confidence that underground or surface stability will not be compromised throughout and following mining in the Martha Underground Mine.

In making this assessment, important considerations include:

- Extensive underground mining at Waihi (in the Favona, Trio and Correnso operations in particular) has allowed the collection of a large amount of knowledge and understanding of the geotechnical conditions that are likely to be encountered with Project Martha.
- Nonetheless, more detailed understanding of ground conditions can only be developed through further studies and analysis, some of which can only take place when the new areas to be mined are opened up, and as a result of further, progressive investigations including probe drilling and development.
- Martha is not unusual in this regard. Oceana Gold (New Zealand) Limited (OGNZL) has sufficient information and understanding now, based on experience gained locally and in other mining projects, to know with confidence that the ore will be able to be safely accessed and mined, and that the underground mining can be undertaken in a manner that will not cause major surface disturbance.
- Ground conditions influence the mining method, the means of access, and the design of stopes and access tunnels. A critical aspect of the current proposal is to undertake investigations to understand those conditions so that a safe and efficient mining method and well-informed approach to developing the mine is used.
- Factors that influence ground conditions are discussed in detail in the report and include the qualities (integrity, strength, rock mass quality etc.) of the various rock types, and proximity to old underground workings and the Martha pit.
- Based on the extensive information available to date in relation to these matters a preliminary, conceptual approach has been developed. This is consistent with mining industry practice at this stage of development. It will be able to be refined and adapted as mining proceeds.
- Monitoring will be implemented to ensure that the excavations are performing as expected and that the response to mining is within acceptable limits.

Quality control

The signing of this statement confirms this report has been prepared and checked in accordance with the AMC Peer Review Process.

Project Manager

The signatory has given permission to use their signature in this AMC document

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Appendix A Rock mass classification distribution plots

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1 Introduction

Oceana Gold (New Zealand) Limited (OGNZL) engaged AMC Consultants Pty Ltd (AMC) to assist in geotechnical aspects of permitting applications for proposed underground mining at Martha. The Martha Underground project is located at Waihi in New Zealand.

1.1 Scope of work

This report describes the work undertaken to complete the geotechnical analyses for the Martha Underground Mine (including development and stope stability) and includes recommendations for underground design parameters, monitoring, and requirements for additional investigations for input into further study. These investigations are part of the normal progression towards more complete understanding of the geotechnical conditions in a mine as development proceeds.

1.2 Supplied data

The following information was used as part of the geotechnical assessments:

- Previous geotechnical reports for Martha (SRK, 2012, SRK, 2016, and SRK, 2017).
- Previous geotechnical report and mining study for Correnso (SRK, 2014 and Newmont, 2014).
- Pit shell (martha_pit).
- Old workings of underground development and stoping (levels_allhistoric_merged).
- Underground stope and development designs (r dev wf v4_rotated, rex mine design).
- Resource drillhole locations, provided by OGNZL May 2017.
- Geological and geotechnical logging, provided by OGNZL May 2017.
- Core photographs, provided by OGNZL May 2017.
- Ground conditions cross sections of the Martha project provided by Pells Sullivan and Meynink (PSM), January, 2018.

1.3 Data confidence

The level of confidence in the geotechnical data available for this study is qualified in Table 1.1. The study is considered to be at scoping level. The level of data confidence can be expected to improve significantly as more information becomes available through further drilling and testing.

Table 1.1 Level of data confidence

Input Variable	Confidence Level	Comments
Geotechnical logging data quality	High	A site visit was undertaken, and QA/QC of logging data has been undertaken against core photographs and site observations.
Geotechnical data spatial distribution	Moderate	Drillhole spacing is appropriate for a scoping level of study. Rock quality designation (RQD) was collected for all drillholes but Rock Tunnelling Quality Index (Q) was only collected for 11 drillholes. In addition to RQD and Q logging data, PSM has reviewed all available core and core photographs and generated ground conditions sections throughout the Martha project. This work provides a comprehensive picture of the disturbance associated with historical mining at Waihi.
Rock property testing	Low	Rock property tests are not currently available for Martha and Rex. However, average values for strength and elastic properties are available from testing in the same lithologies at Correnso.
In situ stress	Low - moderate	Results are only available from the Acoustic Emission technique, which can be unreliable. An overcoring measurement should be considered when access is available, particularly if mining at depths greater than the recent experience at Correnso.
Storage of information	High	Geotechnical information is stored in databases.
Geological information	Low	Drillhole spacing is appropriate for a scoping level of study.
Structural model	Moderate	This is based on limited drillhole information, supported by pit mapping in some areas. The model can be improved with additional logging, and underground mapping once mining commences.

1.4 List of abbreviations

E	Young’s modulus (elastic constant)
GPa	Gigapascals (giga newtons per metre squared)
HR	Hydraulic radius
m	Metre
MPa	Megapascals (mega newtons per metre squared)
υ	Poisson’s ratio (elastic constant)
Q	Rock tunnelling quality index
Q’	Modified rock tunnelling quality index
QA/QC	Quality Assurance/Quality Control
RQD	Rock quality designation
SD	Standard deviation
SRF	Stress reduction factor
σ_1	Major principal stress
σ_2	Intermediate principal stress
σ_3	Minor principal stress
t	Tonnes (metric)
UCS	Uniaxial compressive strength for intact rock

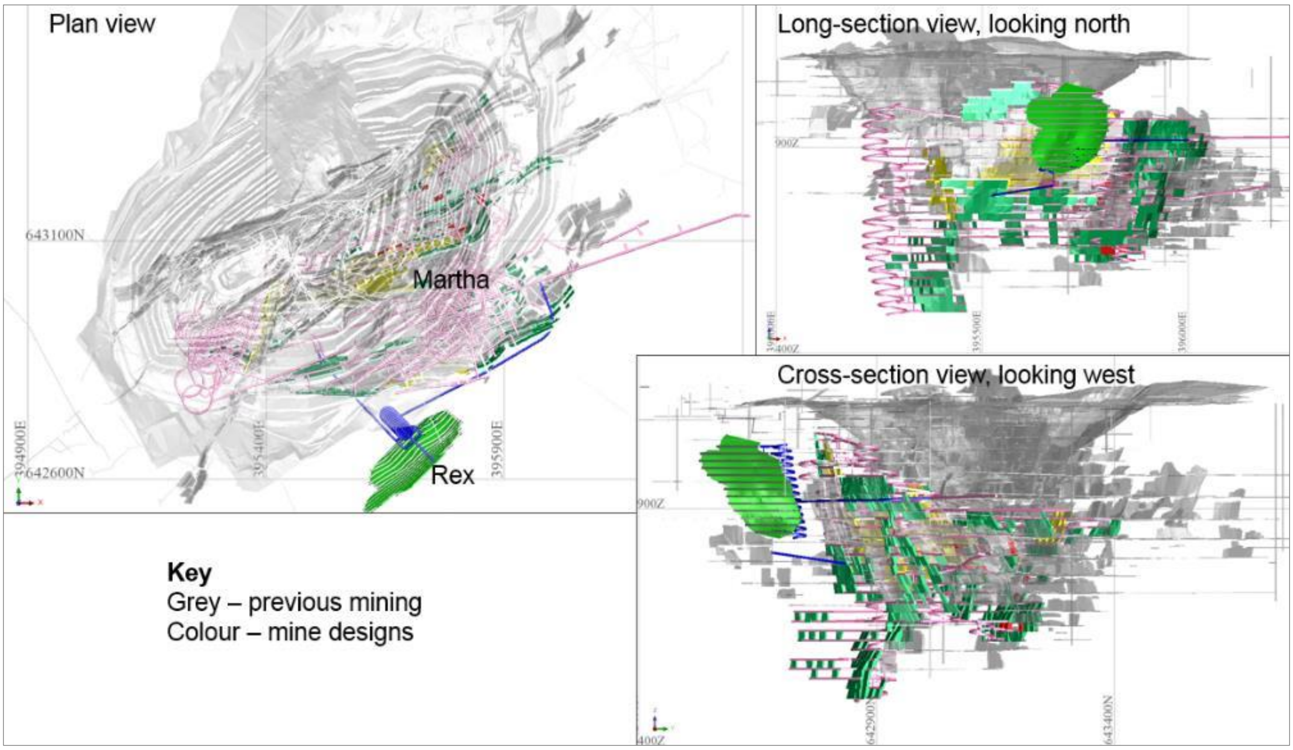
2 Background

2.1 Project setting

The existing mines at Waihi include the Martha open pit and a number of underground mines. Mining commenced during 1878, and the Correnso and SUPA underground mines are the currently active operations at the site.

The resource areas associated with the Martha Underground are located below or just south of the Martha open pit, as shown in Figure 2.1. Much of the resource is located in close proximity to old workings (pre-1990s). A void model of the old workings has been created from historical records, supplemented where possible with information from drilling and exposures in the Martha Pit.

Figure 2.1 Project setting



2.2 Geology

A summary of the geology is taken from Newmont, 2014.

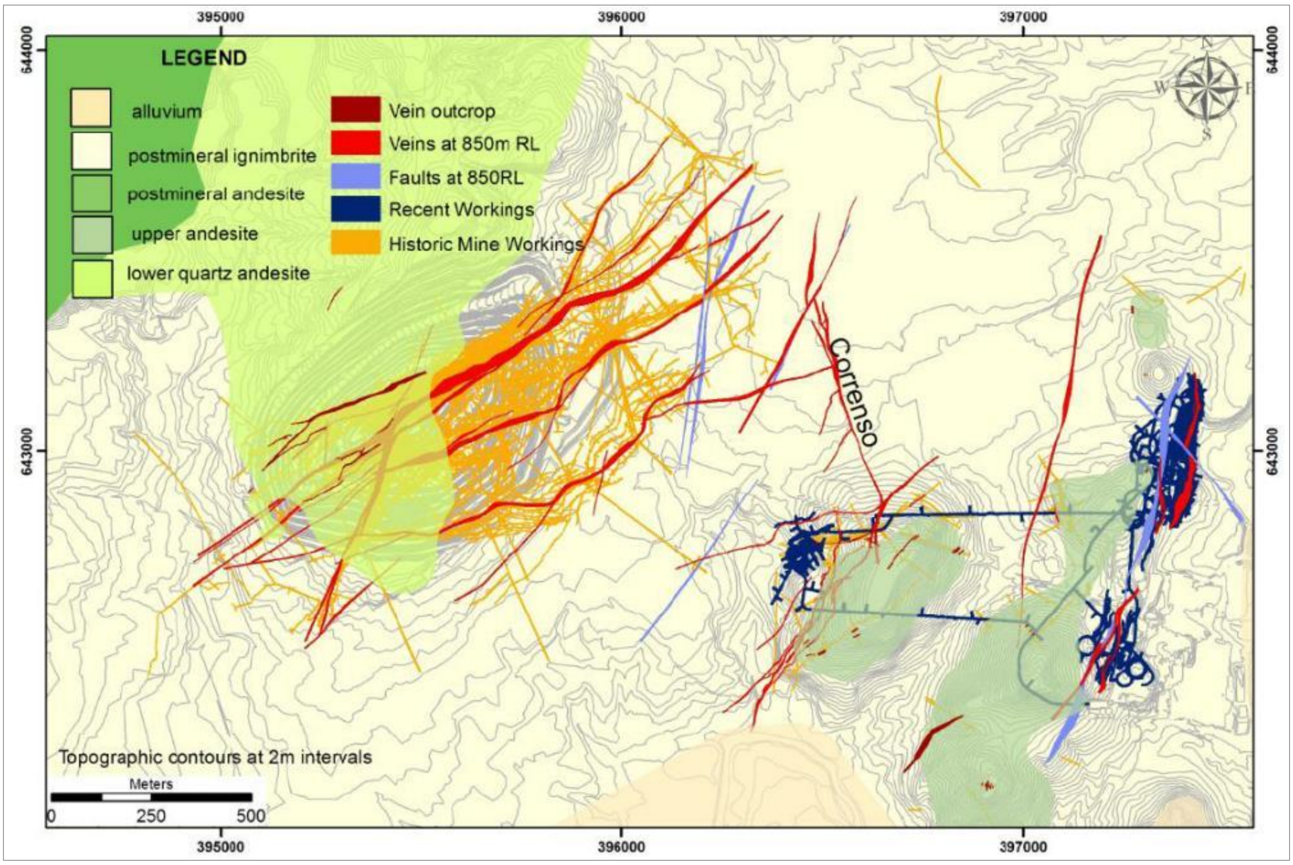
The dominant host lithology at Waihi is quartz-phyric andesite lava. This unit is over 400 m thick with minor variations in texture or modal composition. The quartz andesite is overlain by a series of feldspar-phyric andesite flows and volcaniclastics.

Host andesitic volcanics have undergone pervasive hydrothermal alteration, often with complete replacement of primary mineralogy. Characteristic alteration assemblages include quartz, albite, adularia, carbonate, pyrite, illite, chlorite, interlayered illite-smectite and chlorite-smectite clays extending over tens of metres laterally from major veins.

2.3 Previous mining

The Martha pit extends to about 270 m below surface and the old workings extend to about 620 m below surface. Current mining at Correnso is about 400 m below surface. The location of the Martha workings and Correnso mining area is shown in Figure 2.2.

Figure 2.2 Mining areas and geology (Newmont, 2014)



2.4 Previous studies

SRK undertook a geotechnical study for the Martha resource area during 2012 (SRK, 2012). The study included the Empire, Grace, Martha, Mary, Regina, Victoria and Edward orebodies but did not include the Rex orebody.

SRK and Newmont undertook a geotechnical and mining study for the nearby Correnso orebody during 2014 (SRK, 2014 and Newmont, 2014).

3 Geotechnical investigations

3.1 Drilling

Resource drilling for the Martha resource areas has been undertaken at Waihi. The locations of the drillholes used in assessments relative to the mine designs for these resource areas are presented in Figure 3.1 and Figure 3.2. The drillholes used in the SRK assessment are presented in Figure 3.3 for comparison. The dataset used by AMC is smaller than the dataset used by SRK. A significant proportion of the SRK drilling appears to be associated with resources that are not part of the current mining plans.

From the resource drilling programme, geotechnical data was collected from 2,362 m of drill core.

Figure 3.1 AMC dataset – plan view (RQD plotted along drillhole traces)

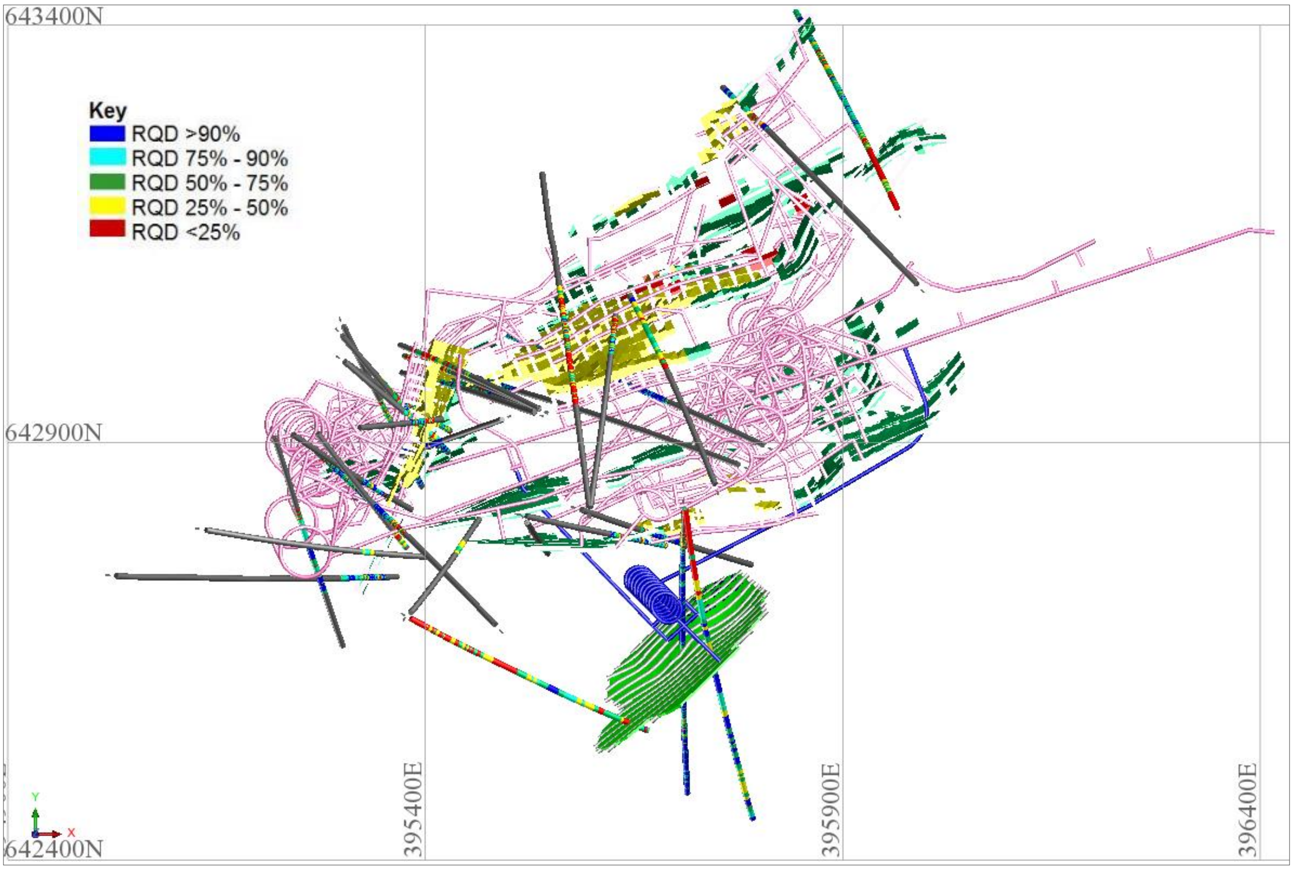


Figure 3.2 AMC dataset – isometric view (RQD plotted along drillhole traces)

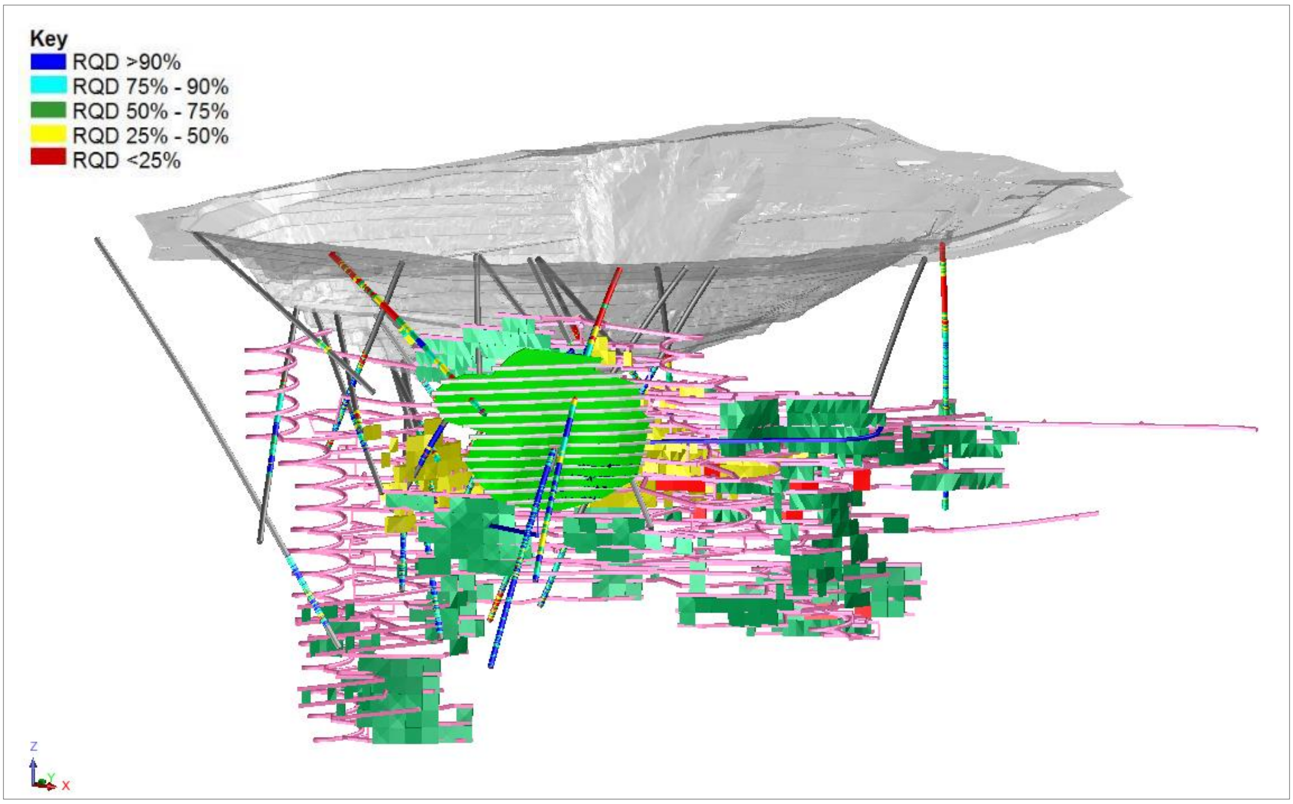
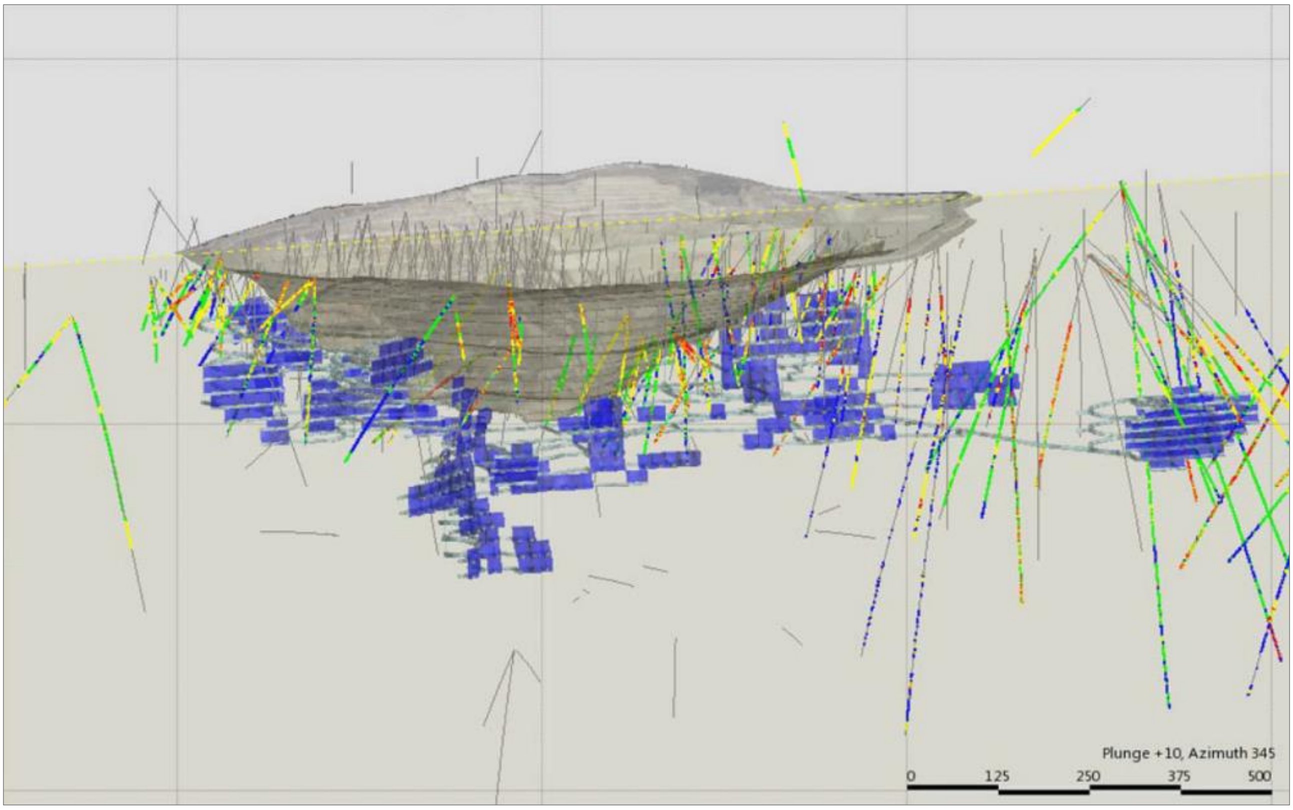


Figure 3.3 SRK dataset (RQD plotted along drillhole traces)



3.2 Core logging

Geotechnical information was collected by site personnel. RQD was collected for 2,362 m of drill core, and parameters for the assessment of the Norwegian Geotechnical Institute's Q system (Barton, Lien and Lunde, 1974) were collected from 1,052 m of drill core.

Structural measurements collected from drill core were not available to the AMC study. However, SRK's 2012 report includes analyses of structural data from Martha. AMC considers this to be sufficient for the current study, recognizing that additional data will be obtained as development and drilling are undertaken in Martha, assuming the project proceeds.

3.3 Rock properties

A description of the rock properties for the project area was available in SRK (2014), Parrott (2012) and Richards (2012). This information is summarized in Table 3.1 for uniaxial compressive strength (UCS), Young's Modulus (E), and Poisson's Ratio (υ).

Table 3.1 Summary of rock properties

Rock Type	UCS (MPa)		E (GPa)	υ	Description
	Average	SD[1]			
Ignimbrite	<20	–	–	–	Very weak to weak
Quartz andesite	69	27	47	0.27	Strong
Ore	80 – 100	–	–	–	Strong

[1] Standard deviation

3.4 In situ stress

Two acoustic emission (AE) tests were conducted at Western Australian School of Mines (WASM). The results are summarized in Table 3.2.

Table 3.2 In situ stress

Principal Stress Component	Gradient Magnitude (MPa/km)	Azimuth (°)	Dip (°)
σ_1	60.2	199	03
σ_2	39.6	289	02
σ_3	26.9	059	86

AMC notes that this technique has produced unreliable estimates of the stress field at some projects. Concerns regarding the reported AE stresses have also been expressed by an external peer reviewer (Brady, 2013).

AMC understands that no stress-related issues have been experienced to date in the nearby Correnso project. Nonetheless, some of the Martha resources lie at greater depth and consideration of stresses will be required for detailed planning. Such planning will occur at a later stage, when additional drilling has been undertaken and the stoping targets are better defined.

When suitable access becomes available at Martha, and if it is considered that mining of the resources at depths below 700 mRL is likely to proceed, an overcoring stress measurement should be considered. However, given the experience gained in other underground projects at Waihi, such as Correnso, AMC considers that the potential for stress-related issues is low in the bulk of the proposed Martha underground.

3.5 Seismic hazard

The seismic hazard map of New Zealand (Stirling et al, 2012) indicates that the peak ground acceleration in the project area is 0.1 g to 0.2 g with a 10% probability of exceedance in 50 years.

Damage to deep tunnels caused by natural earthquake events is likely to be restricted to lining distress, however mine infrastructure closer to surface could be susceptible to greater damage (Richards, 2012).

According to Ground Control Engineering (2012), there is no history of significant mining-induced seismicity in the Martha Underground area.

A microseismic system has been installed and is used to monitor the rock mass response to mining at Correnso. It is understood that the seismicity detected to date has been insignificant, with no events greater than -0.5 local magnitude.

Considering all of the above, AMC's assessment is that natural and mining-induced seismicity are not likely to be significant hazards for the underground operations.

4 Characterization of geotechnical conditions

4.1 Rock mass classification

The modified rock quality index Q', after Mathews et al (1981) and Potvin (1988), has application in stope stability assessments, at least for preliminary design. This system is widely used in the mining industry and was used as a basis for stability assessments at the Favona, Trio and Correnso projects.

Q' uses four of the same parameters as Q and is calculated as follows:

$$Q' = \frac{RQD}{Jn} \cdot \frac{Jr}{Ja}$$

Where:

RQD is the rock quality designation, a rock quality estimation technique developed by Deere et al (1967).

Jn is the joint set number, assigned based on the number of joint sets (values ranging from 0.5 to 20).

Jr is the joint roughness number, assigned based on the shape and roughness of joint surface (values ranging from 0.5 to 4.0).

Ja is the joint alteration number, assigned based on the mineral infill and alteration of the joint surface (values ranging from 0.75 to 20).

Table 4.1 provides a qualitative description of the rock mass quality based on the evaluation of Q (after Barton Lien and Lunde, 1974). It should be noted that the Q-system is a logarithmic scale, and that the Q' classifications are equivalent to the Q-system.

Table 4.1 Rock mass classification based on the Q-system (Barton Lien and Lunde, 1974)

Q value	Rock Mass Description
0.001 – 0.01	Exceptionally poor
0.01 – 0.1	Extremely poor
0.1 – 1	Very poor
1 – 4	Poor
4 – 10	Fair
10 – 40	Good
40 – 100	Very good
100 – 400	Extremely good
400 – 1000	Exceptionally good

The rock mass classification data from Martha was analysed according to the proximity of ground to the old workings, and the degree of weathering. The rock mass classification data based on Q' is presented in Table 4.2 and Table 4.3. Detailed plots showing the data distribution including the Q' parameters are presented in Appendix A.

Table 4.2 Rock mass classification based on Q' – proximity to old workings

Zone	Metres Logged (m)		RQD Percentile (%)			Q' Percentile		
	RQD	Q'	25	50	75	25	50	75
All data	2,632	1,052	38	63	85	2.3	5.0	11.7
Near old development	110	45	36	63	78	2.2	5.3	9.6
Within 10 m of old stopes	264	157	23	52	76	2.9	6.1	15.5
Old stopes	202	135	0	25	55	0.6	3.0	7.6
Not near old workings	2,056	715	43	67	88	2.3	5.0	12.0

Table 4.3 Rock mass classification based on Q' – weathering

Degree of Weathering	Metres Logged (m)		RQD Percentile (%)			Q' Percentile		
	RQD	**Q'**	**25**	**50**	**75**	**25**	**50**	**75**
Highly weathered	43	5	0	0	18	0.1	0.1	0.1
Moderately weathered	367	138	17	42	62	1.0	1.5	4.6
Slightly weathered	1,771	740	43	67	86	2.5	5.8	11.5
Fresh rock	448	169	40	76	100	2.75	6.9	25.0

Review of the data indicates that proximity to old workings has a negligible effect on rock mass quality as indicated by RQD and Q'. This would suggest that the zone of loosening around old stopes is generally quite limited.

With regard to weathering, there is a progressive improvement in rock mass quality as weathering effects decrease from 'moderately weathered' to 'fresh' rock. The core classified as 'highly weathered' rock shows some surprisingly high RQD and Q' values. Some of the intervals were checked against core photographs and the weathering rating was re-assigned, and in some cases the RQD was reduced.

4.2 Weathering

The degree of weathering is variable within the project area, and this has a considerable effect on the rock quality. Examples of the degree of weathering for each class presented in Section 4.1 are shown in Figure 4.1 to Figure 4.4. The term 'weathering' also refers to the degree of alteration for this assessment.

Figure 4.1 Example of highly weathered rock

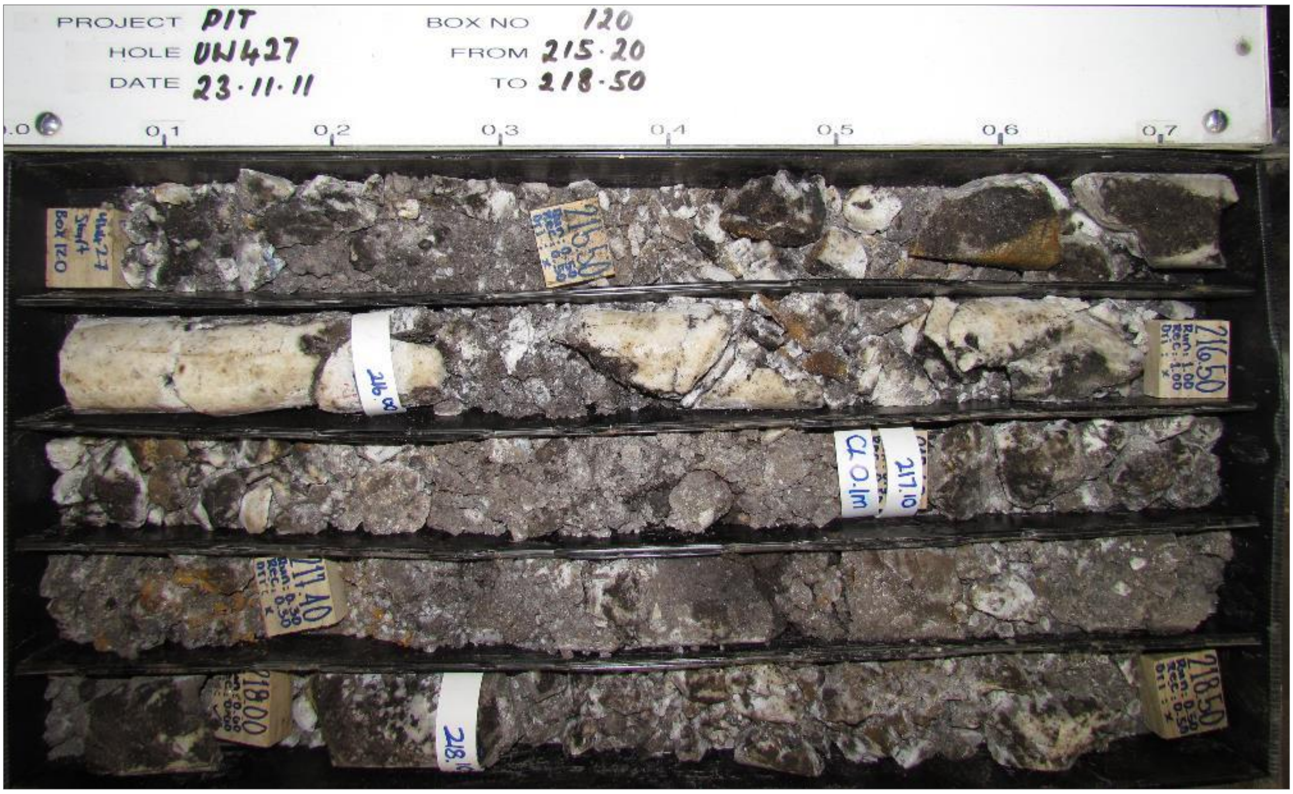


Figure 4.2 Example of moderately weathered rock

Figure 4.3 Example of slightly weathered rock

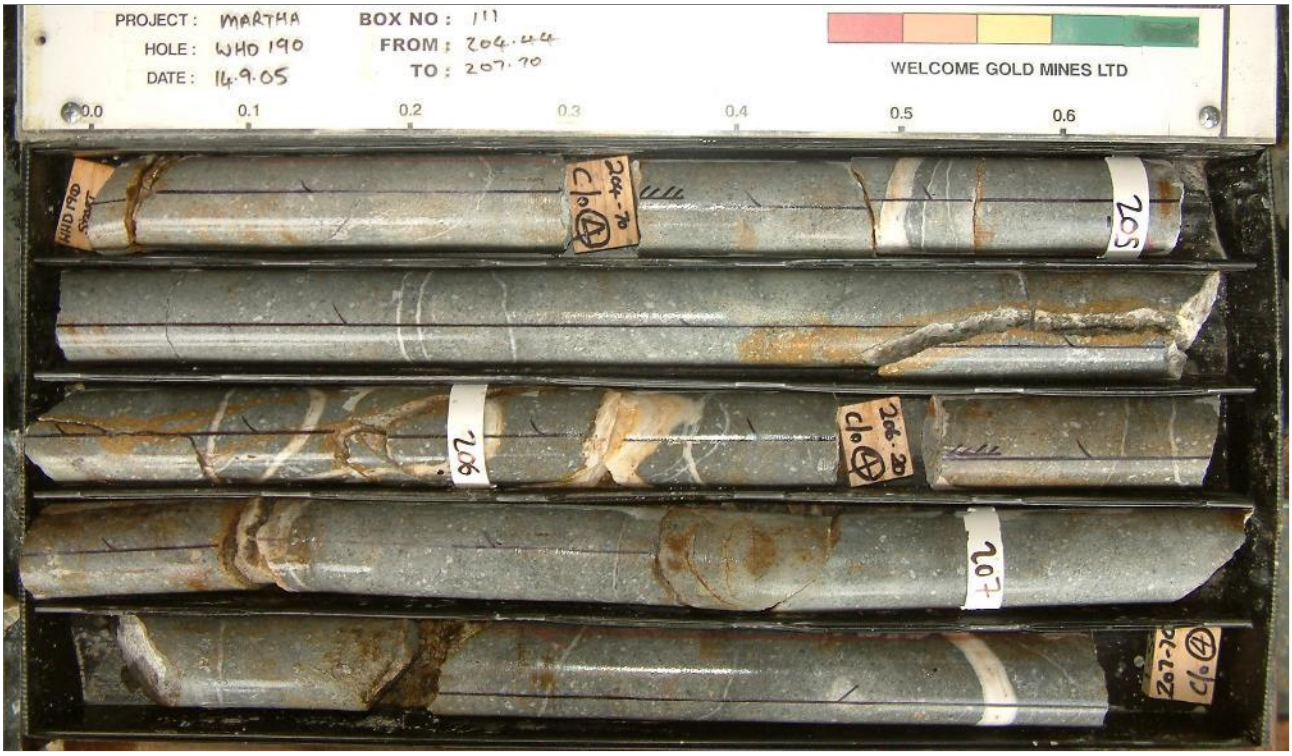


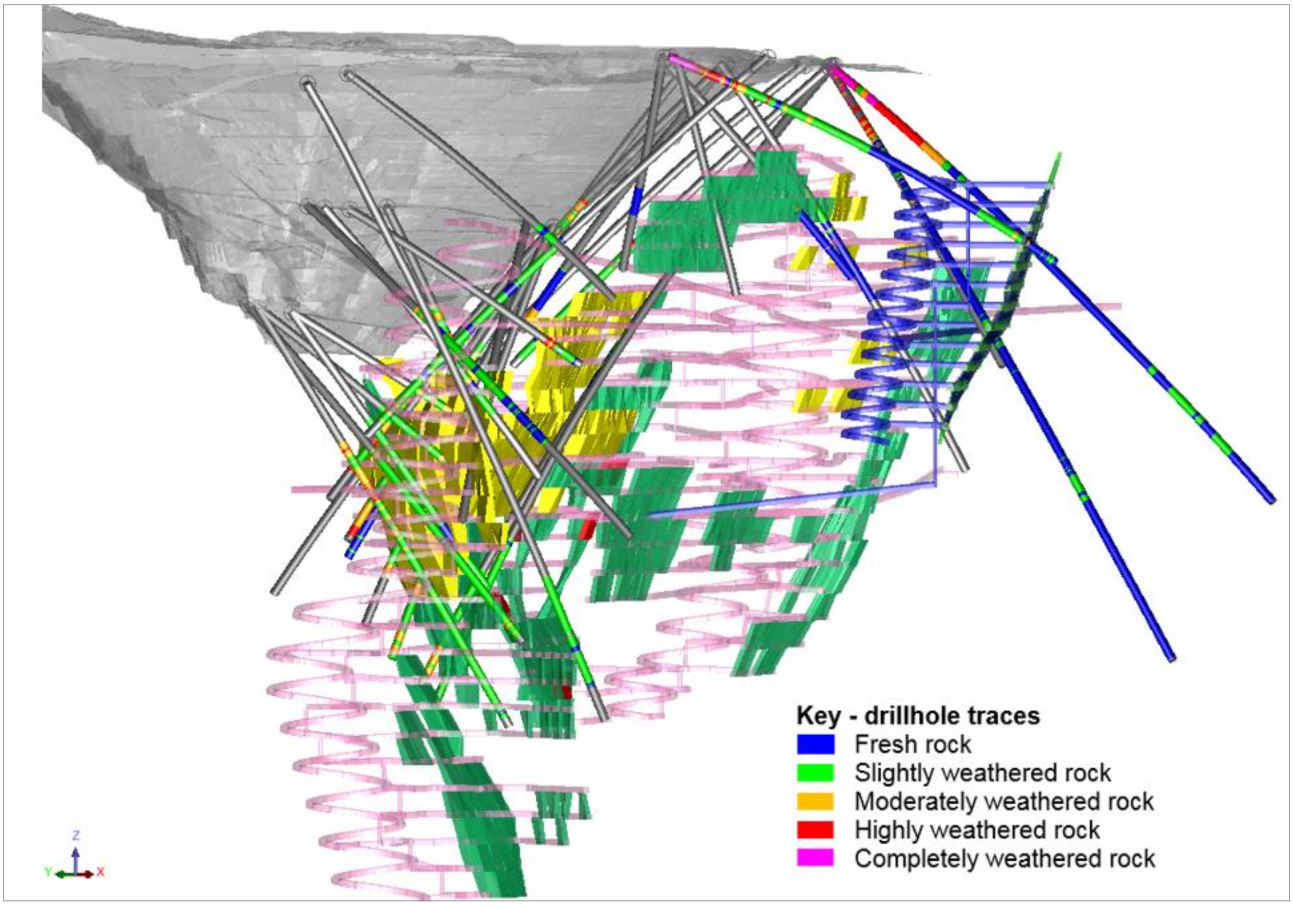
Figure 4.4 Example of fresh rock

4.3 Geotechnical domains

Based on the geotechnical data, the geotechnical domains were selected to represent the degree of weathering. The distribution of weathering is presented in Figure 4.5.

Locally, deeper weathering is encountered in several drillholes. This is probably associated with persistent structures including vein contacts. There is also evidence of the effects of historic mining, which has allowed oxidation and weathering along structures that have been dilated through relaxation of the rock mass.

Figure 4.5 Isometric view showing degree of weathering plotted along drillhole traces (note that colours used for the lodes and development are arbitrary and do not reflect degree of weathering)



In addition to AMC's review of geotechnically-logged drillholes, PSM has conducted a comprehensive review of ground conditions using a scheme based on the degree of disturbance, as indicated by diamond drill core.

This assessment indicates that much of the planned underground mining at Martha will be affected by stress redistribution effects, predominantly relaxation adjacent to previously mined lodes. There are also zones that were affected by historical 'caving', most notably the 'Milking Cow' zone. AMC notes that this is contained completely within the existing Martha Pit and has no effect on stability outside of the pit.

Other than the relaxation associated with previous stoping, the overall rock mass is still considered to be relatively undisturbed as a result of the previous mining. The main concern is likely to be zones of locally more intense disturbance/degradation associated with continuous structures such as faults and shears. As geotechnical investigations continue as part of the current mine development plan, it is reasonable to expect that structures will be identified and the structural model will be further developed in response to this. This data will in turn be taken into consideration in ongoing detailed mine planning and design.

4.4 Major structures

As discussed above, there are many major structures in the Martha mining area, including the various lodes. These could affect ground conditions locally (as discussed in the previous section) but were not expected to have an adverse effect on a larger scale according to Entech (2017).

The numerical modelling being undertaken by PSM to investigate the interaction between the Martha open pit, surface and underground voids (both pre-existing and planned) will provide a better understanding of the likely effects of such structures on local and larger scale stability.

4.5 Minor structures

The minor structures were assessed by SRK (2012). They found that there are three to four joint sets for each of the orebodies assessed. At least one of the structures is orientated sub-parallel to the orebody with several cross-cutting structures.

In AMC's assessment, it is likely that the dominant structures near the lodes will be fabric or jointing that is parallel to the lode. This can be expected to be generally favourable to stope stability as stope walls will break cleanly to the structure. In pillars and stope abutments, the structures will tend to be 'clamped' by stresses acting normal to them, limiting the potential for shear.

5 Geotechnical considerations for mining

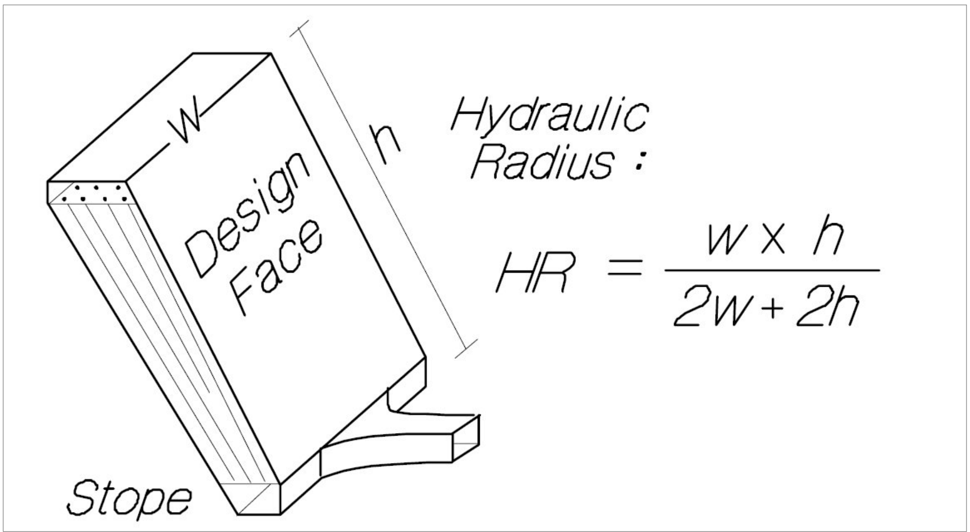
5.1 Stope stability

For this study, the proposed SRK stope designs provided by OGNZL were reviewed using the Stability Graph Method. This was originally developed in Canada (Mathews et al, 1981 and Potvin, 1988) and is widely used in the mining industry to develop preliminary stope design parameters from rock mass classification data.

The method is described in detail in Hutchinson and Diederichs (1996). Stope spans are described using a 'Hydraulic Radius' (HR). This is simply the area of the span under consideration, divided by the perimeter.

This concept is illustrated in Figure 5.1.

Figure 5.1 Calculation of Hydraulic Radius (after Hutchinson and Diederichs, 1996).



For example, a vertical stope that is 20 m high and extends 25 m along strike would have a HR of:

$$20\ x\ 25 / 2(20 + 25) = 5.55\ m$$

The stability graph is used to relate stope spans (expressed as HR) to ground conditions (represented by 'stability number' values). The stability number is based on ground conditions, adjusted by three factors to account for stress versus rock strength (Factor A), the effect of structures (Factor B) and the inclination of the stope wall under consideration (Factor C).

The stability graph is divided into 'stable', 'transitional' and 'caving' (unstable) zones. It is conventional at the preliminary design stage to consider designs that plot in the stable zone, or on the stable/transitional boundary. For such designs there is a reasonable expectation that the stopes will be stable.

The inputs for the stability graph analysis as assessed by AMC are presented in Table 5.1. The values of Q' proposed for design by AMC are the median values presented in Section 4. Values used by Newmont for the Correnso study were used to derive Factor A. Factor B was derived with the assumption that the ore-parallel structures will be parallel to the hangingwall.

The SRK stope design dimensions range from HR = 3.3 m (for transverse stoping near voids or against backfill) to HR = 5.6 m in 'virgin' conditions.

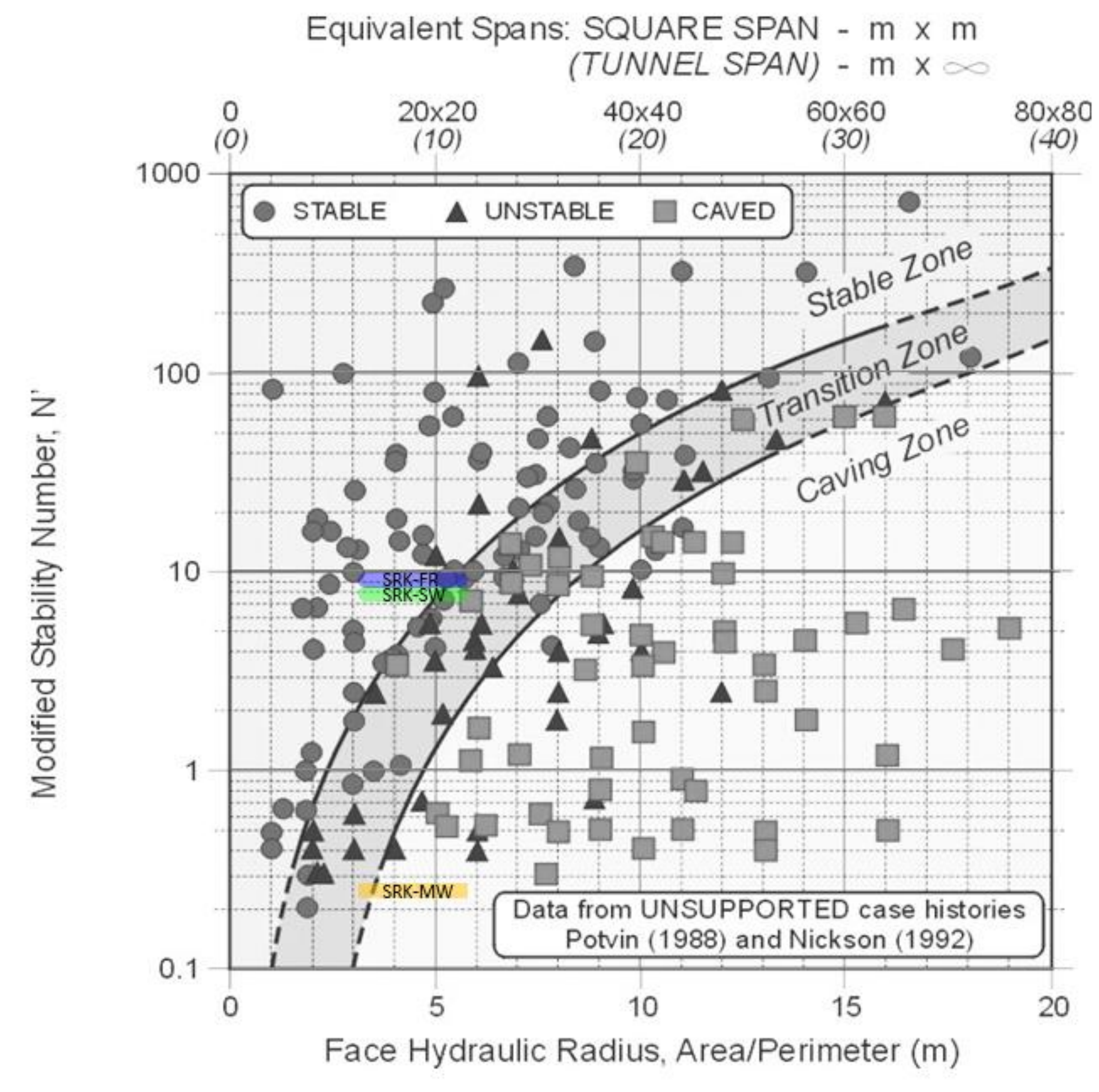
Long-hole open stoping is not considered to be a suitable mining method for highly to moderately weathered rock and cut-and-fill methods should be considered in these areas. A stability graph assessment was not conducted for the highly weathered domain. At the stope dimensions proposed by SRK, designs in moderately weathered rock plot in the caving zone.

Table 5.1 Inputs for the stability graph method (AMC)

Input	Value
Q' moderately weathered rock	1.5
Q' slightly weathered rock	5.8
Q' fresh rock	6.9
Factor A – moderately weathered rock	0.1
Factor A – slightly weathered and fresh rock	0.8
Factor B	0.3
Factor C	5.4
N' Moderately weathered rock	0.24
N' Slightly weathered rock	7.52
N' Fresh rock	8.94

The results of the stability graph analysis based on the unsupported case histories from Potvin (1988) and Nickson (1992) are presented in Figure 5.2. The results indicate that stope spans proposed by SRK are generally appropriate for slightly weathered and fresh rock (that is, they plot in the stable zone, or close to the 'stable/transitional' boundary), but are aggressive for moderately weathered rock. Where such conditions are identified, it may be necessary to employ mining methods which involve smaller spans, such as overhand cut-and-fill or using a modified AVOCA method whereby fill is placed progressively to ensure the stope span remains relatively small.

Figure 5.2 Stability graph showing stope design parameters as provided by SRK



5.2 Surface subsidence and open pit interaction

The proposed mining methods involve stope excavations that have a high level of assurance of stability, as discussed in Section 5.1. Stopes will be filled immediately on completion (Modified Avoca and open stoping), or in the case of Avoca stoping, on a continuous basis with the fill being progressively advanced to follow the stope face and to maintain a minimal hangingwall/footwall exposed span.

Most of the planned stopes lie below the existing Martha pit. Although the tight backfilling proposed should prevent any large-scale disturbance, should any unforeseen settlement occur, it would not have an impact on surface outside the pit. AMC notes that PSM has been retained by OGNZL to assess the interaction between the historical and proposed underground workings, including the use of three-dimensional numerical modelling.

Where remnant mining methods are employed, existing voids within 10 m of any proposed stopes will be backfilled with cemented aggregate fill (CAF) or rockfill, prior to mining the adjacent backfilled stopes.

CAF comprises screened or crushed rock combined with cement slurry. It has some capacity to 'flow', which can be used to fill voids with limited access. Rockfill is backfill comprised only of broken rock without the addition of a cement slurry.

The added cement allows the CAF to develop some cohesion and strength when it cures, similar to concrete. This strength allows CAF exposures to be self-supporting which is useful where the filling of an existing void is undertaken to allow recovery of a pillar.

Where re-exposure is not planned, and the backfilling is primarily to fill a stope void to provide confinement to the walls, in turn to stabilize them for the long term, there is no requirement for the fill to develop cohesive strength. Uncemented rockfill may be suitable for this situation.

Where development through backfill is required, the techniques described in Section 5.4.4 could be required to ensure excavation stability is maintained.

Some of the stopes proposed by SRK will involve mining of remnant stopes and pillars within the down dip extension of the Royal Lode. This will require careful assessment through probe drilling, to investigate the condition of the lode. The historical stopes were apparently largely unfilled (Richards et al, 2002), although some of the material from the 1961, 1999 and 2001 sinkholes may have locally filled old stope voids. Such materials could be potentially capable of flowing if they have a sufficiently high water content. However, it would be expected that dewatering will occur well ahead of any mining, including development near old stopes.

Where stoping is proposed below old stoping voids, it will be necessary to backfill the lower part of the void to create a pillar comprised of fill (CAF or other cemented fill). The vertical extent of such fill pillars will depend on local conditions and void geometry, but it would be expected that the minimum requirement will be at least twice the stope 'thickness' or footwall to hangingwall span.

Placement of such pillars may be technically and practically very challenging, as access may be restricted. In some cases, the fill may need to be introduced through boreholes, which will require that it can flow. Such fill materials will be difficult to contain in the desired location. In some instances, should access to form a pillar prove unworkable, it may be necessary to abandon parts of the current mine plan. The total tonnage at risk is assessed as very small.

A critical aspect of the proposed stoping operations will be the requirement to observe the existing stand-off distances from any identified open stopes, until probe drilling has been undertaken to define the extent of the void, confirm its location and to establish the extent of zone of loosening around it. Where it is feasible to do so, some stopes will be tight filled using cemented aggregate fill (CAF) or other suitable materials.

5.3 Underground mining implementation

When adopting and implementing the underground design parameters that have been developed in this study, it is assumed that several standard conditions will be met throughout the excavation of the mine. These include, but are not limited to:

- Probe drilling, as discussed above, will be undertaken to establish the location and condition of existing voids.
- When assessing stoping in 'virgin' areas (where no historical mining is nearby), sufficient information will be available from infill drilling to design stable stopes.
- Appropriate blasting measures are to be applied to minimize damage to development and stope walls.

To ensure that these conditions are met, specific measures need to be incorporated into the design and evaluation process as part of mining operations. These measures refer specifically to a long-hole open-stoping mining method and are discussed in more detail below.

5.3.1 Data collection

The persistence and orientation of the structures requires verification once mining commences to ensure local structural conditions are accounted for in design. Large scale structures should be recorded and modelled in 3D, particularly in stoping areas. The mapping information should be analysed and where appropriate be used to update stope design, pillar design, and development reinforcement and support design.

At least one stress measurement should be allowed for in the operating budget, if mining is planned below about 700 mRL. Experience to date in recent stoping at Correnso indicates that stresses are not sufficient to cause stress related issues, including seismicity. This may not be the case at greater depth. The data obtained should be used to update any mine design studies including numerical models.

5.3.2 Blasting

Smooth-wall blasting is recommended for all underground development. The zone of loosening caused by blasting is typically 0.3 m to 0.5 m into the rock with good blasting practices. This can increase up to 0.8 m with poor blasting practices which in turn increases the ground support requirements.

A robust QA/QC system is recommended for stope drillholes as part of a broader quality control programme.

AMC understands that other consultants have been engaged by OGNZL to look specifically at blasting practices to ensure appropriate management of blast vibration.

5.3.3 Monitoring and void management

Routine cavity monitoring system (CMS) surveys are recommended to analyse stoping performance. If necessary, stope designs or blast designs may need to be modified in order to reduce overbreak. Alternatively, there may be opportunities to increase stope dimensions to take advantage of better-than-expected stope stability performance.

Routine visual monitoring is recommended for all operating stopes and development to confirm acceptable performance of the rock mass and ground support.

Some instrumentation may be required to optimize support systems, particularly hangingwall reinforcement.

Microseismic monitoring has been implemented at Correnso. This can assist with understanding the large-scale rock mass response to mining, and in the management of seismic hazards. The latter is unlikely, based on the experience at Correnso. Nonetheless, installation of a modest seismic system should be considered as part of the overall geotechnical monitoring programme.

As discussed in Section 5.2, it is not expected that stoping will cause any surface disturbance, but in any case, nearly all the stoping will occur below the Martha pit. The main exception to this is the proposed Rex Lode. The uppermost planned level is about 80 m below surface. A programme of extensometer monitoring should be considered, either with uphole installations from the top level, or surface down holes, or a combination of both. Surface down holes have the advantage of allowing ongoing monitoring, after underground activities at Rex have been completed.

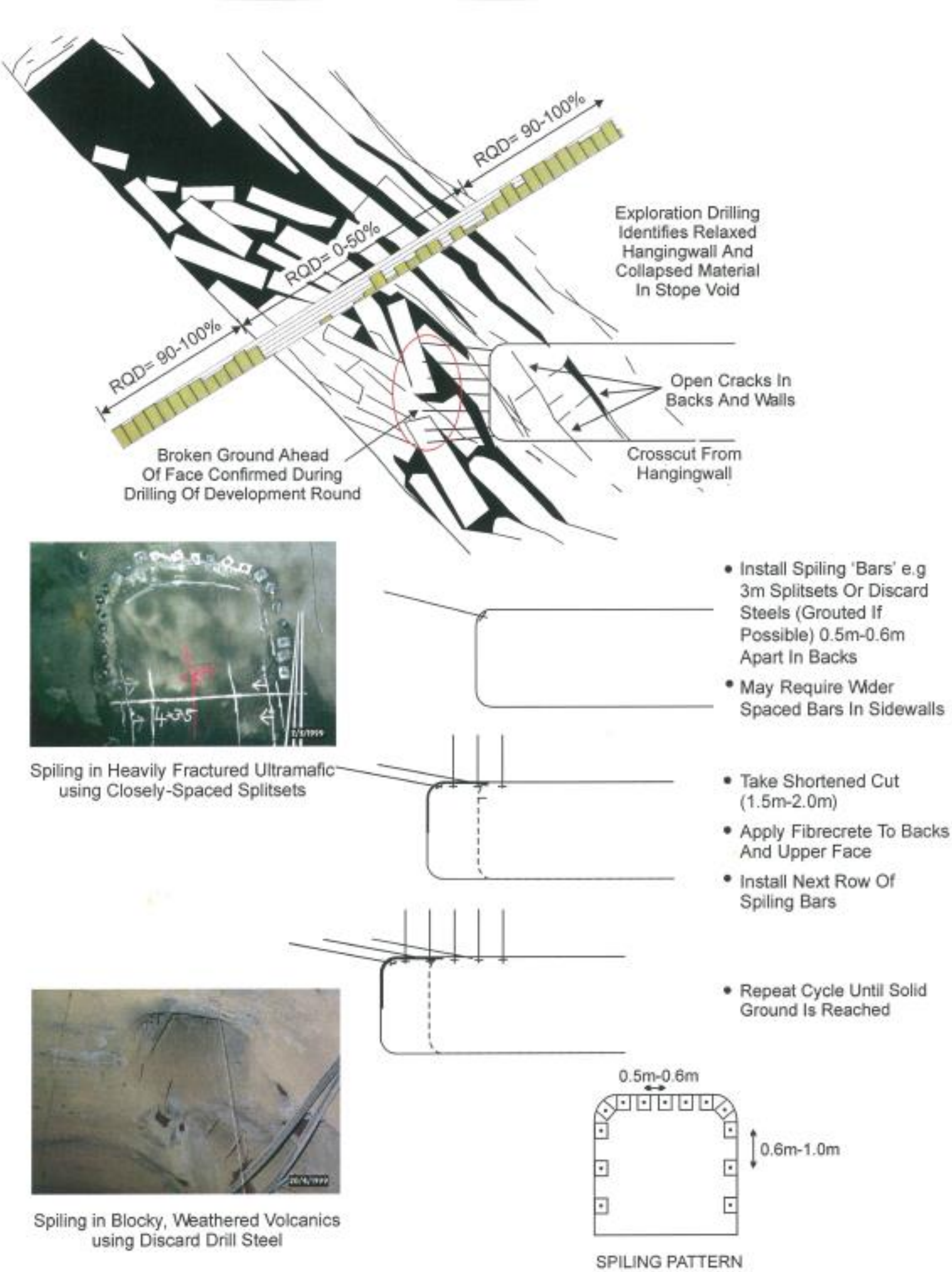
OGNZL has developed a void management plan (WAI-400-PLN-011) which includes procedures for probe drilling, managing blast vibrations, prism monitoring and cavity scanning. The risk management process is outlined in this document and is considered by AMC to be fit-for-purpose for this project.

5.3.4 Development in poor ground

OGNZL has considerable experience in managing poor ground in underground development at its Waihi and Frasers (Otago) underground operations. The techniques commonly used to avoid overbreak and to maintain drive profile in ground that is prone to unravelling include:

- Use of short development rounds (typically 1.5 m to 2.0 m instead of the 3.0 m used in 'full' rounds).
- Use of fibrecrete, including application to the face if required to maintain control of the ground.
- Use of spiling bars across the backs and walls as required. This technique has been successfully used in developing through very weak or highly fractured materials (Devereux, 1977) as well as unconsolidated fill (Carroll, 2014). An example is shown in Figure 5.3.
- Resin or cementitious grout injection has also been successfully employed in broken or loosened zones to consolidate the ground ahead of development (Samosir and Snyman 2014, Sainsbury et al, 2014).

Figure 5.3 Example of spiling using 'nested' spiles in loosened ground



5.3.5 Scaling

Scaling is recommended in underground development as routine practice, particularly for areas of the walls where surface support will not be installed. These areas would require check-scaling at appropriate intervals.

5.3.6 Geotechnical hazard management

AMC recommends a system be implemented for formally managing the geotechnical hazards associated with underground mining at Martha. This would involve defining how the measures above are implemented. Geotechnical hazard management would consist of three main elements:

- A Ground Control Management Plan (GCMP), which includes but is not limited to the following:
  - Description of the mine design basis.
  - Description of specific geotechnical hazards and how they are managed.
  - Monitoring and data collection requirements.
  - Processes for integrating new data into the mine design.
  - Processes for reporting geotechnical hazards/incidents.
  - Responsibilities of key mine personnel, such as the mine manager, shift supervisors, geologists, geotechnical engineers, surveyors and workforce in general.
- A geotechnical hazard register, which includes all current geotechnical hazards including development and stope hazards, the status of each hazard, and the strategy for risk management of each hazard.
- A trigger-action-response plan (TARP) for managing geotechnical hazards. The TARP identifies the required actions and responsible personnel for geotechnical hazards of varying degrees of potential risk.

AMC notes that the Waihi Underground Void Management Plan (VMP, OGNZL, 2016) addresses all of these elements, in the context of the SUPA and MDDP projects. A Principal Hazard Management Plan (PHMP) for ground control has been developed for Correnso as part of the GCMP. This has been regularly updated as required under occupational health and safety legislation in New Zealand.

The VMP provides a detailed discussion of the methods proposed for hazard identification and management associated with historical voids, and planned new development in the MDDP and SUPA projects. The SUPA project also includes stoping using mining methods that will achieve close control of the ground, eliminating the potential for widespread disturbance including surface effects.

AMC recommends that the existing VMP and GCMP documents are adapted and updated to reflect the currently proposed activities in Martha.

6 Ground support

Previous recommendations for ground support at Martha Underground include an assessment by Ground Control Engineering (2012).

The Ground Control Engineering (2012) assessment indicated that a range of ground support standards would be required in the decline (Table 6.1). Intersections or wide spans greater than 6.5 m are recommended to be reinforced with cable bolts installed in two passes. Twin-strand cable bolts of 6.0 m length are specified with a spacing of 2 m.

Table 6.1 Decline ground support recommendations (Ground Control Engineering, 2012)

Ground Conditions	Q	Support Pressure (t/m^3)	Surface Support	Reinforcement
Very poor to poor	0.1 – 4.0	6.0	100 mm fibrecrete, floor to floor	Resin-grouted solid bar bolts, 1.5 m spacing, nine per row
Fair	4.0 – 10.0	2.5	50 mm fibrecrete, to grade line	Resin-grouted solid bar bolts, 1.5 m spacing, eight per row
Good	>10.0	1.9	50 mm fibrecrete, to shoulder	Resin-grouted solid bar bolts, 1.5 m spacing, eight per row

AMC considers that these ground support recommendations or equivalent are appropriate for the decline and other 'life of mine' development. A tighter bolt spacing could be required in the 'very poor' and 'poor' ground conditions.

Short term development such as ore drives could possibly be supported with friction bolts and mesh instead of solid bar bolts and fibrecrete in 'fair' and 'good' ground conditions. Indicative ground support recommendations for short term development are presented in Table 6.2.

Table 6.2 Short term development ground support recommendations

Ground Conditions	Q	Support Pressure (t/m^3)	Surface Support	Reinforcement
Very poor to poor	0.1 – 4.0	6.0	100 mm fibrecrete, floor to floor	Resin-grouted solid bar bolts, 1.2 m spacing, 10 per row
Fair	4.0 – 10.0	2.5	Mesh, to grade line	Friction bolts, 1.2 m spacing, nine per row
Good	>10.0	1.9	Mesh, to shoulder	Friction bolts, 1.2 m spacing, nine per row

Whilst these recommendations are considered appropriate for a range of timeframes up to the full life of mine, it is recognized that some of the support will eventually deteriorate and may fail after several decades or longer. Any ground that was stabilized by the support could then unravel or fail. The mine plan will manage this long-term issue by ensuring that any remaining voids at the end of mining operations, including backfilling, will be of such limited extent that propagation of the void is arrested through the effects of bulking.

All voids including development will be assessed on completion of their service life and where necessary, additional backfilling will be undertaken.

7 Conclusions and recommendations

Based on the current understanding of ground conditions, the planned ongoing investigation of conditions as suitable drilling positions become available, and the proposed cautious approach to development using close ground control techniques where required, AMC is confident that the proposed Martha underground mine can be developed and brought into production without any compromise to underground or surface stability. This is on the basis that:

- The proposed designs are appropriate and conservative.
- The planned development, drilling and interpretation as outlined in Section 5.4 of this report will provide additional information at a detailed level and hence provide sufficient opportunity to adjust the design in response to encountered ground conditions.
- The proposed mining methods involve stope excavations that have a high level of assurance of stability, as discussed in Section 5.1 of this report. Stopes will be filled without delay on completion (Modified Avoca), or in the case of Avoca stoping, on a continuous basis with the fill being progressively advanced to follow the stope face and to maintain a minimal hangingwall/footwall exposed span. Where open stopes are encountered and it is intended to recover some of the adjacent resources, it is proposed that the voids will be filled with suitable materials before stoping commences.

Key recommendations include:

- Ongoing investigations are undertaken to establish the extent and location of historical workings, and the extent of any associated loosened or disturbed zones.
- The effects of any voids and disturbed zones are adequately considered in the planning of any future stoping.
- Where indicated as necessary to maintain stability, existing voids are as far as practicable, backfilled with a suitable material.
- All new voids should be backfilled to the extent necessary to prevent any possibility of eventual propagation to surface.
- Appropriate monitoring systems are designed and implemented to ensure that the response to the proposed mining is adequately understood. It is likely that this will include deformation monitoring such as strategically placed extensometers and regional monitoring such as microseismic monitoring.
- The existing VMP and GCMP developed for Correnso and SUPA are adapted and updated to reflect the currently proposed activities in Martha.

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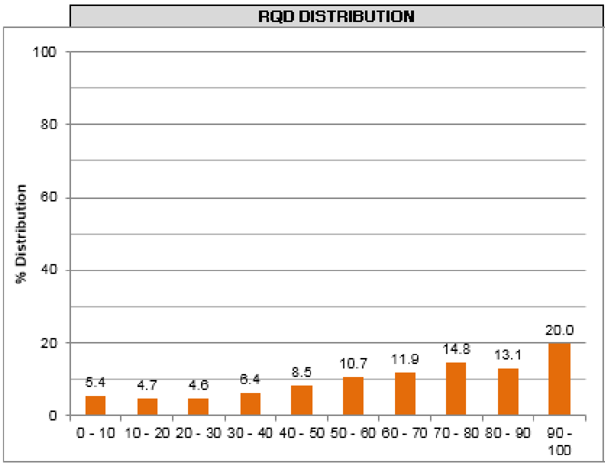
Appendix A
Rock mass classification distribution plots

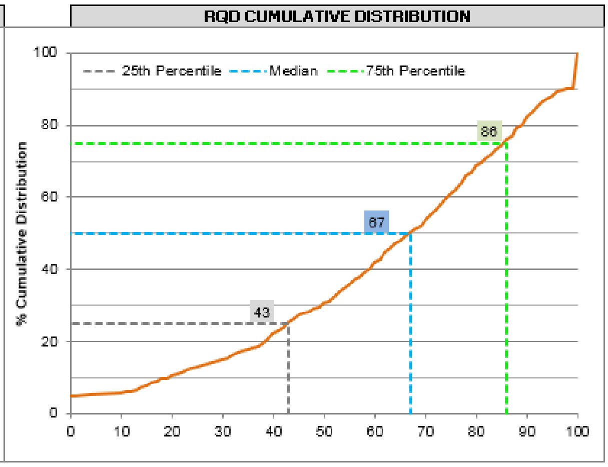
ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

Domain: Slightly weathered rock

RQD Metres Logged: 1770.9 m



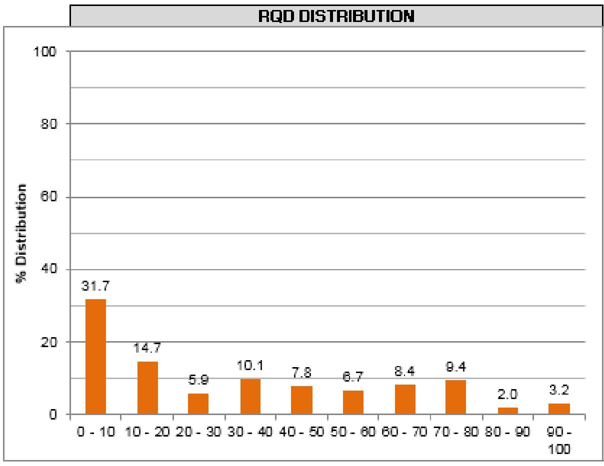


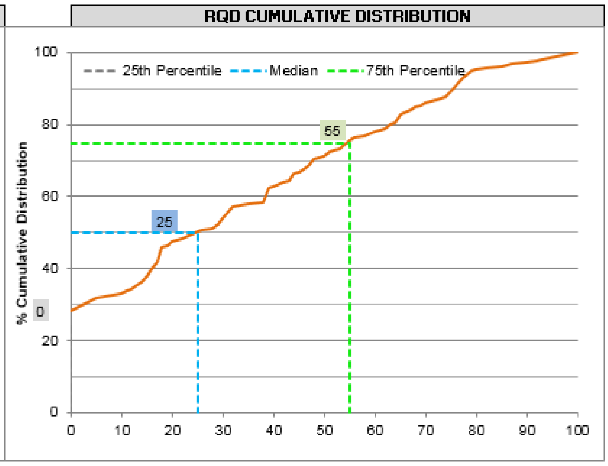
ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

Domain: Previously stoped ground

RQD Metres Logged: 201.8 m



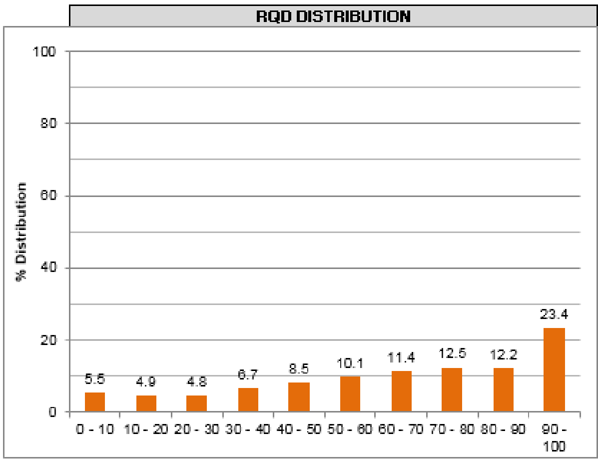


ROCK MASS DATA - Q' PARAMETERS

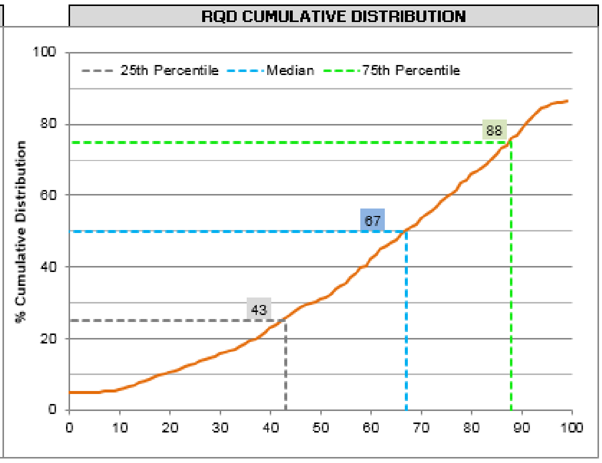
217049 - Project Martha - Phase 1

Domain: Virgin ground RQD Metres Logged: 2056.5 m

RQD DISTRIBUTION



RQD CUMULATIVE DISTRIBUTION

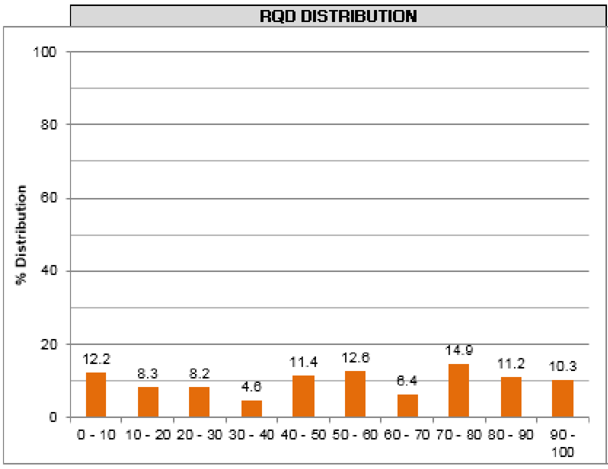


ROCK MASS DATA - Q' PARAMETERS

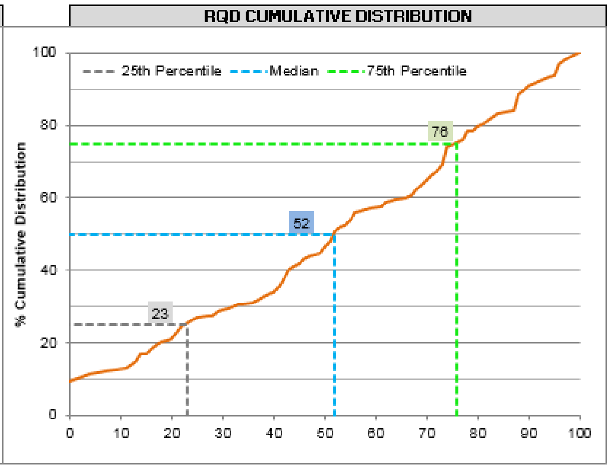
217049 - Project Martha - Phase 1

Domain: Ground within 10 m of old stopes RQD Metres Logged: 263.8 m

RQD DISTRIBUTION



RQD CUMULATIVE DISTRIBUTION

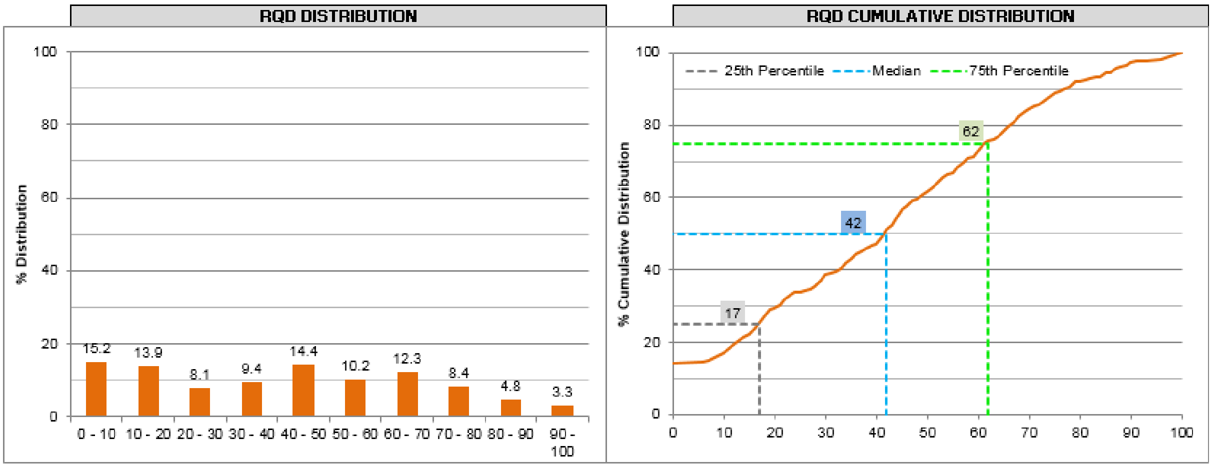


ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

Domain: Moderately weathered rock

RQD Metres Logged: 367.4 m

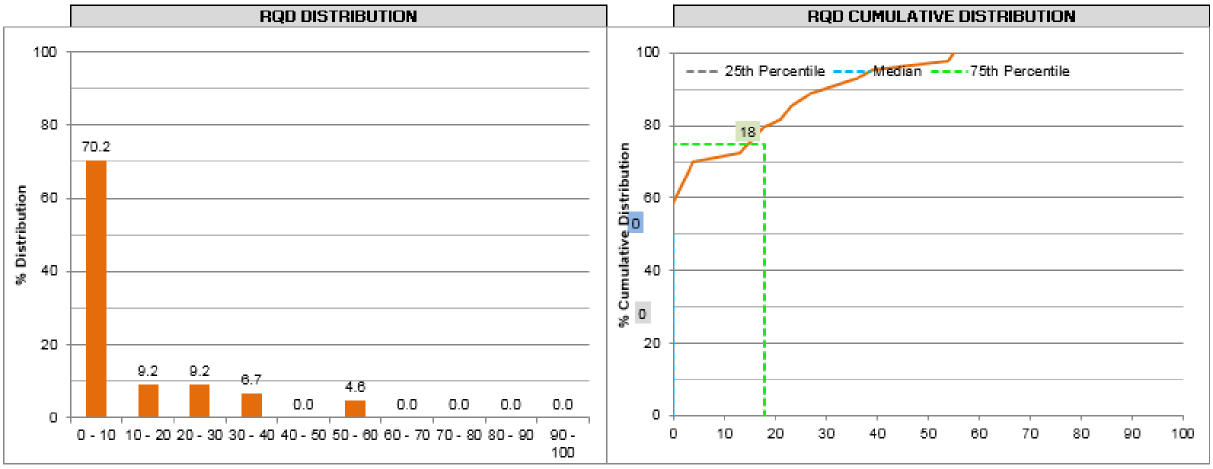


ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

Domain: Highly weathered rock

RQD Metres Logged: 43.3 m

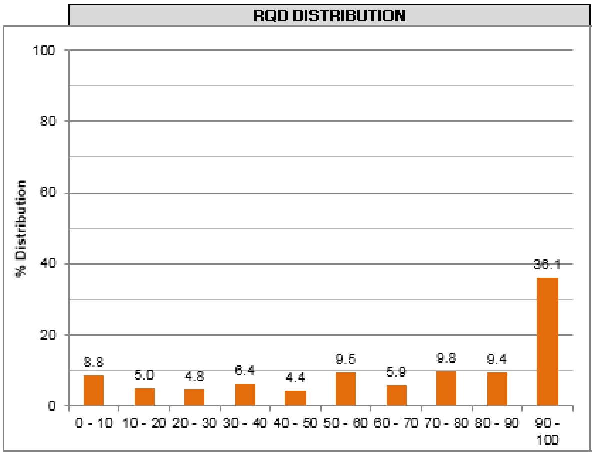


ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

Domain: Fresh rock RQD Metres Logged: 447.8 m

RQD DISTRIBUTION



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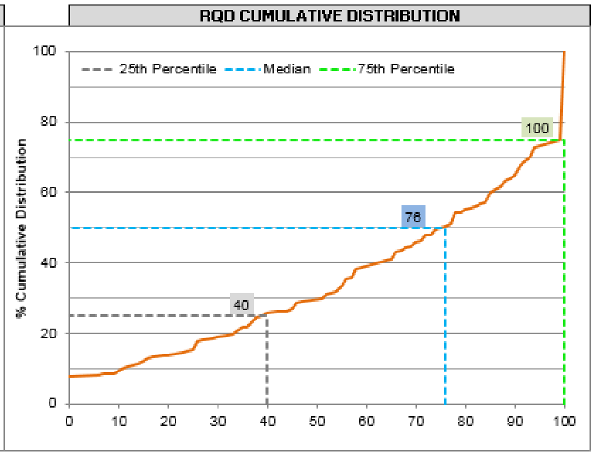
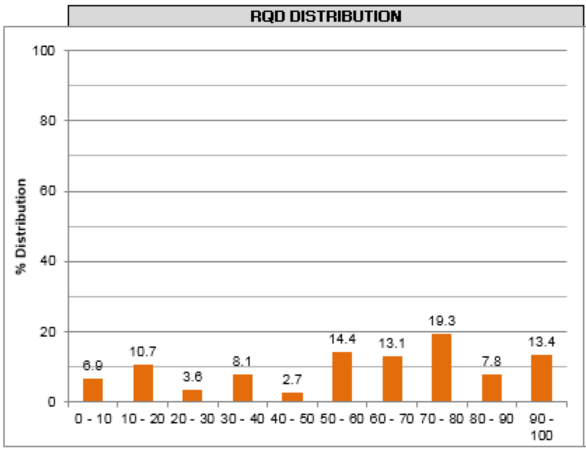


ROCK MASS DATA - Q' PARAMETERS

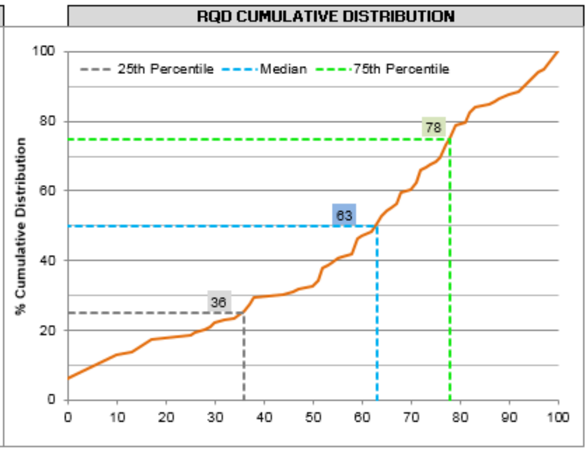
217049 - Project Martha - Phase 1

Domain: Ground near old development RQD Metres Logged: 110.1 m

RQD DISTRIBUTION



RQD CUMULATIVE DISTRIBUTION

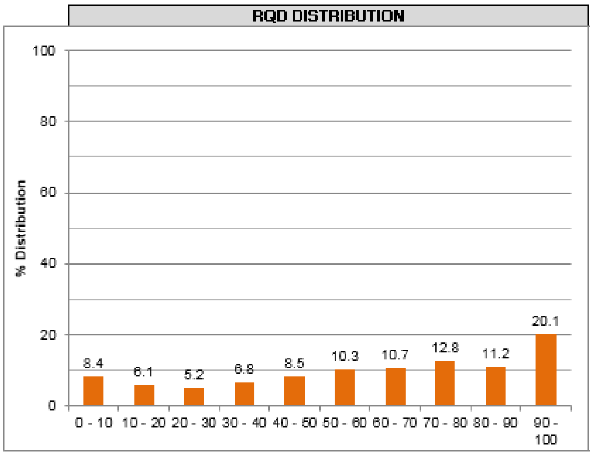


ROCK MASS DATA - Q' PARAMETERS

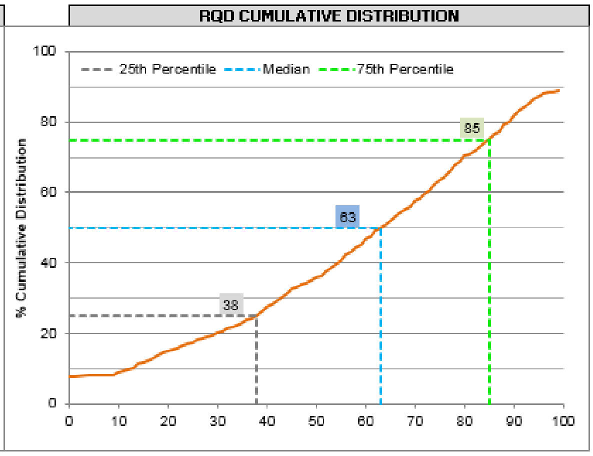
217049 - Project Martha - Phase 1

Domain: All data RQD Metres Logged: 2632.2 m

RQD DISTRIBUTION



RQD CUMULATIVE DISTRIBUTION

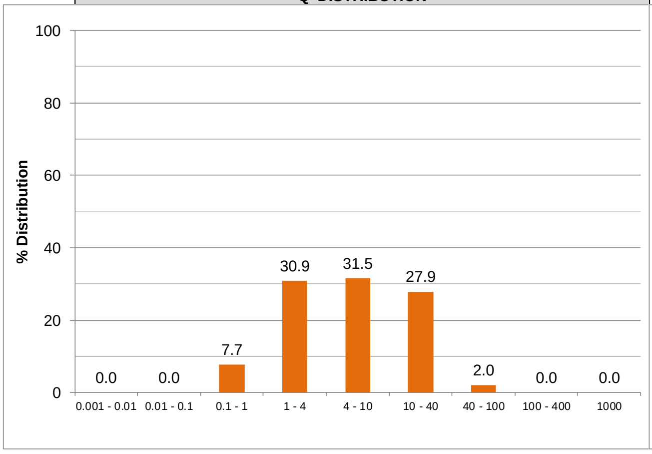


ROCK MASS DATA - Q' PARAMETERS

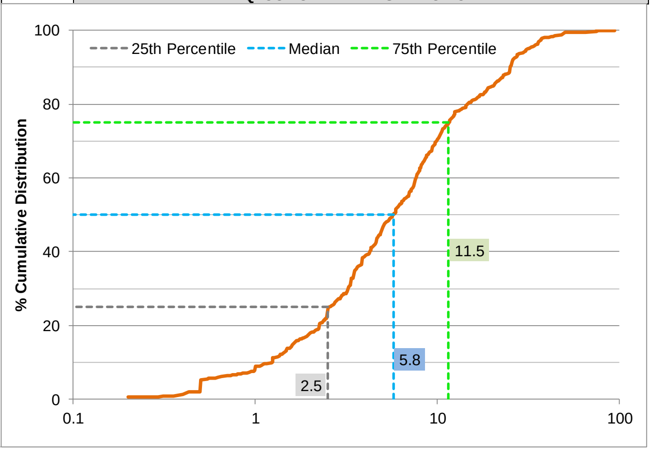
217049 - Project Martha - Phase 1

Domain: Slightly weathered rock   Q' Metres Logged: 740.3 m

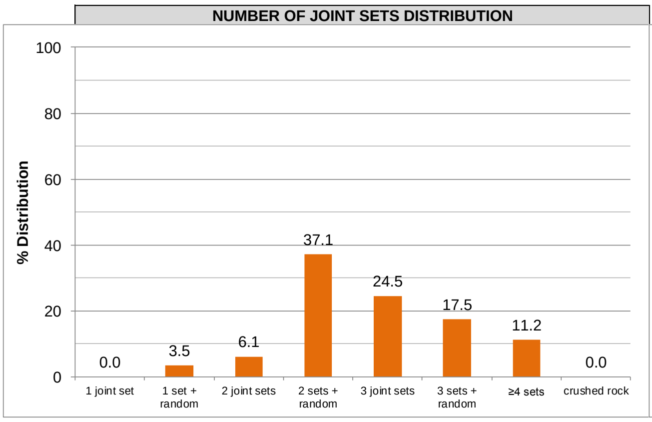
Q' DISTRIBUTION



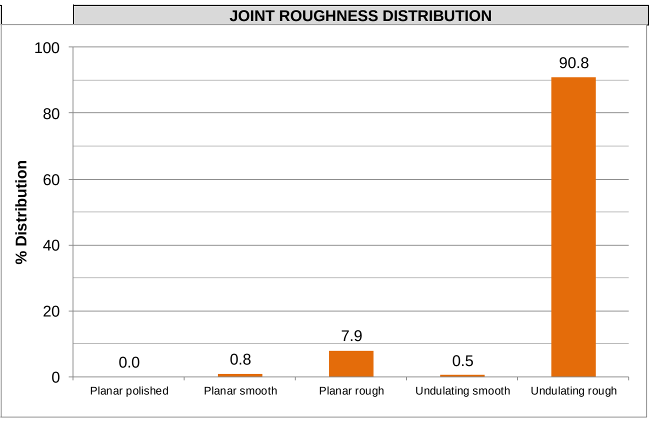
Q' CUMULATIVE DISTRIBUTION



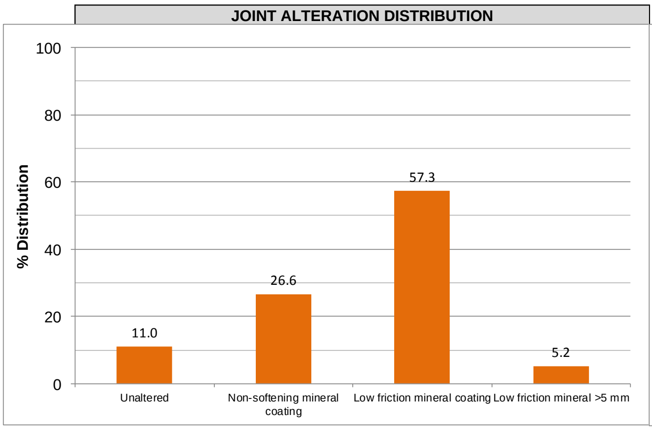
NUMBER OF JOINT SETS DISTRIBUTION



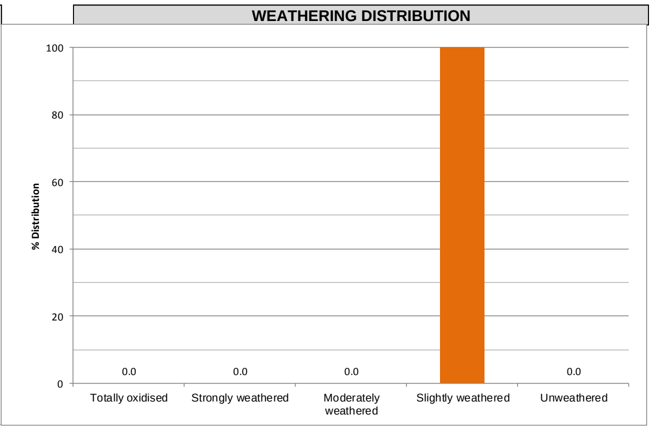
JOINT ROUGHNESS DISTRIBUTION



JOINT ALTERATION DISTRIBUTION



WEATHERING DISTRIBUTION

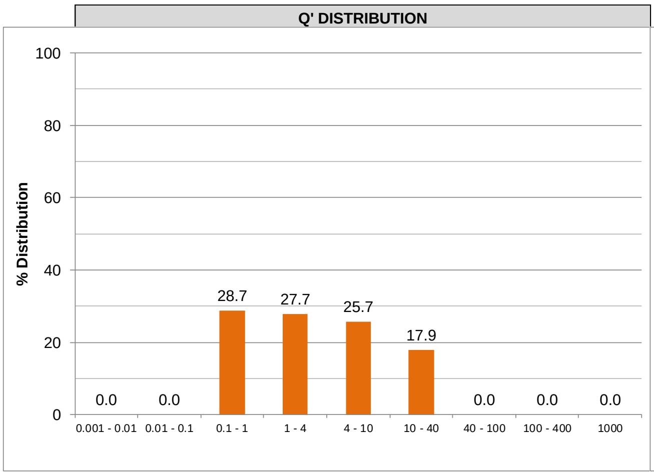


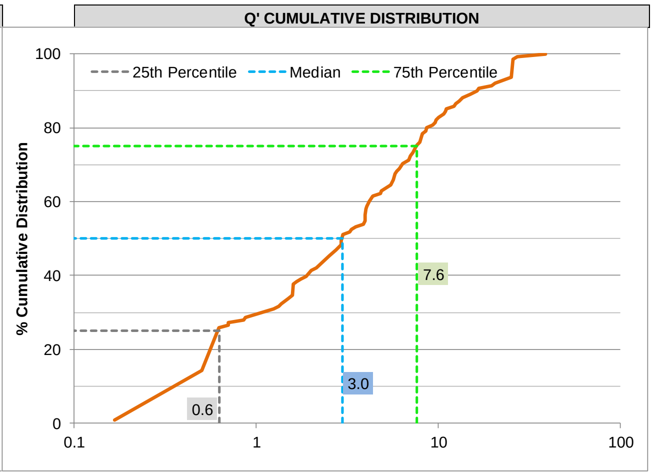
ROCK MASS DATA - Q' PARAMETERS

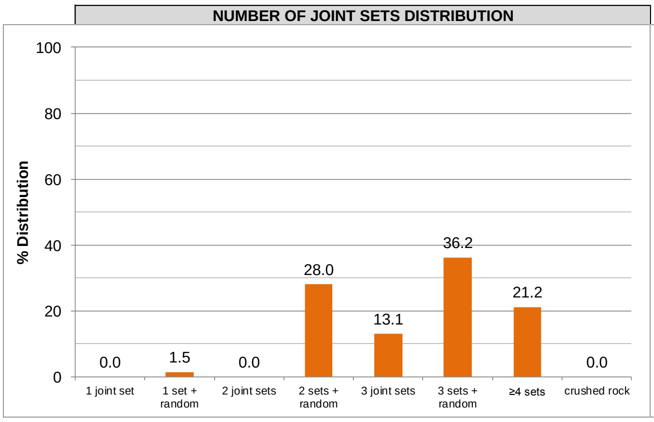
217049 - Project Martha - Phase 1

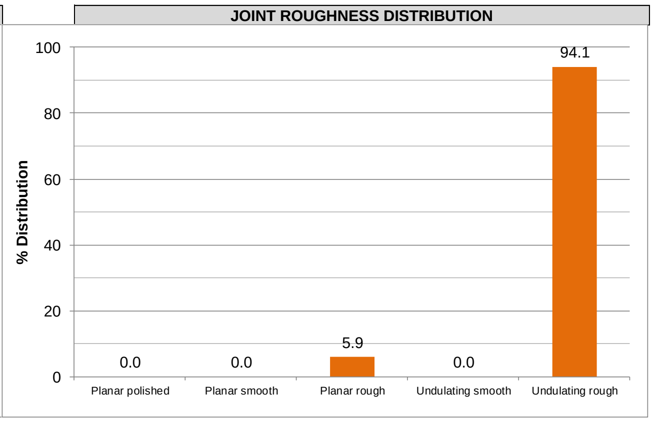
Domain: Old stopes

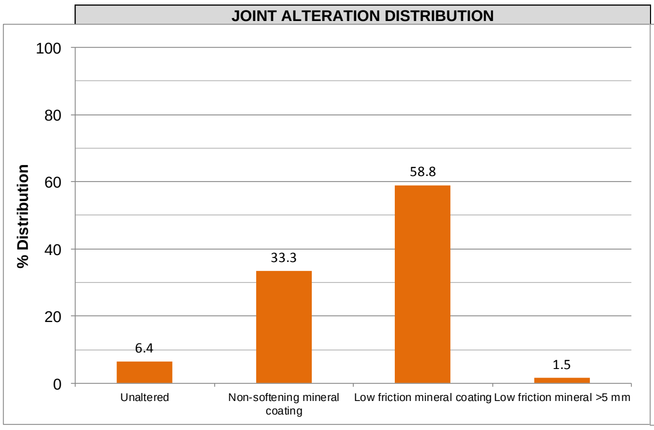
Q' Metres Logged: 134.8 m

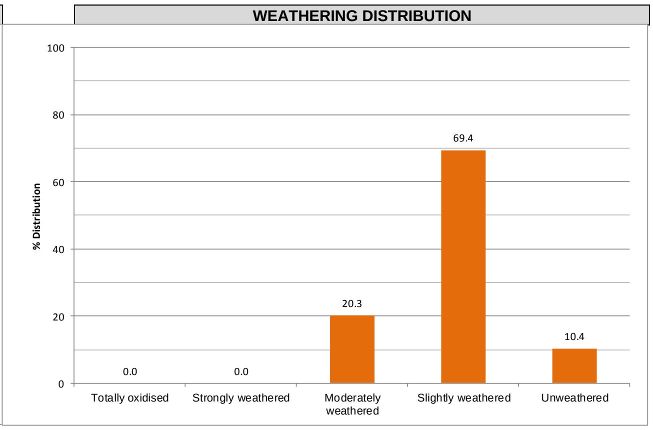












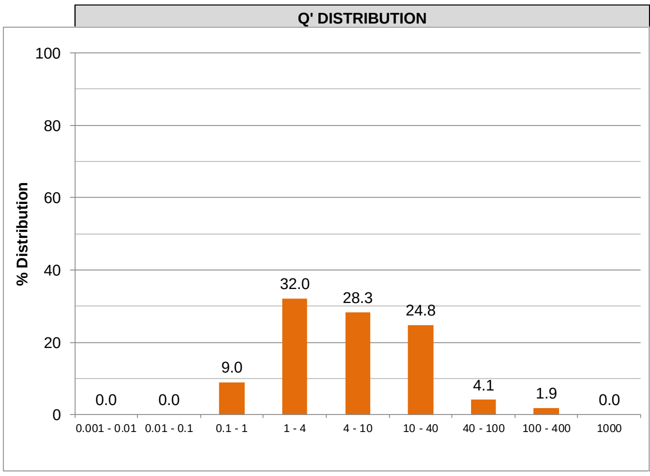
ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

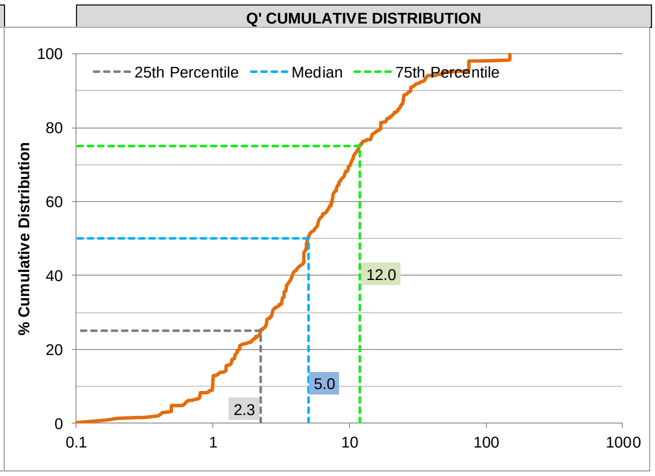
Domain: Virgin ground

Q' Metres Logged: 715.0 m

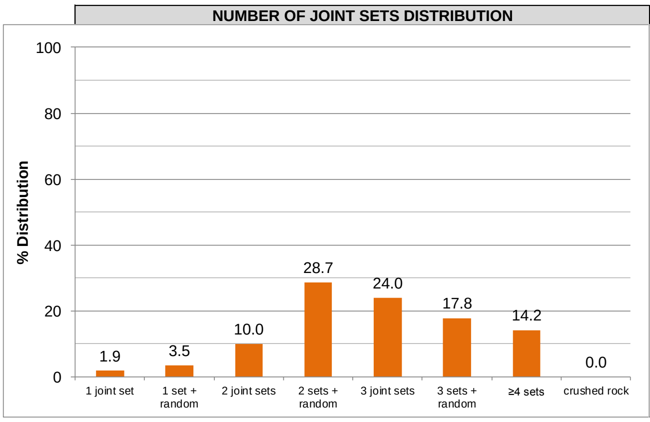
Q' DISTRIBUTION



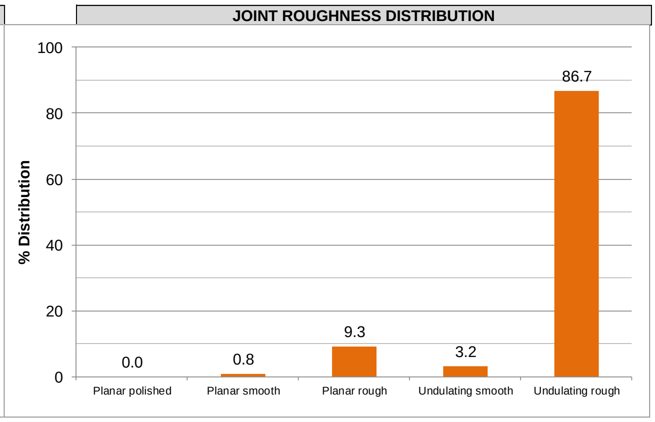
Q' CUMULATIVE DISTRIBUTION



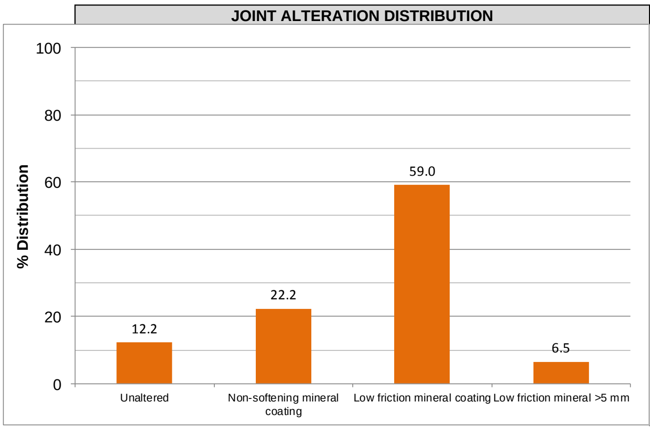
NUMBER OF JOINT SETS DISTRIBUTION



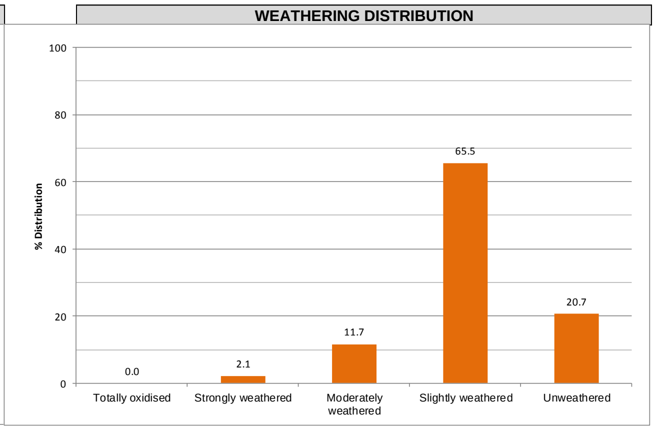
JOINT ROUGHNESS DISTRIBUTION



JOINT ALTERATION DISTRIBUTION



WEATHERING DISTRIBUTION



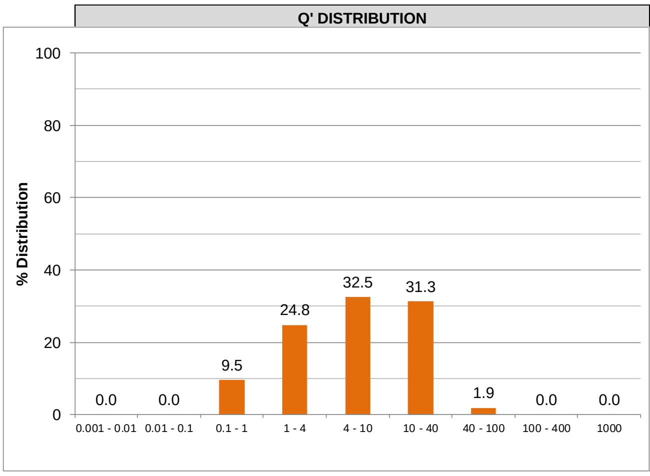
ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

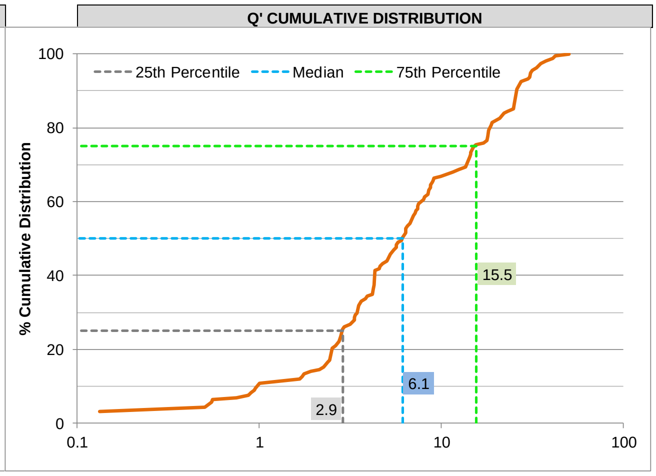
Domain: Within 10 m of old stopes

Q' Metres Logged: 157.1 m

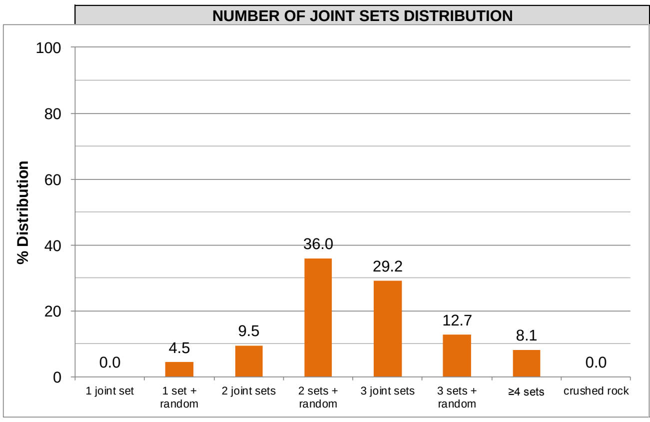
Q' DISTRIBUTION



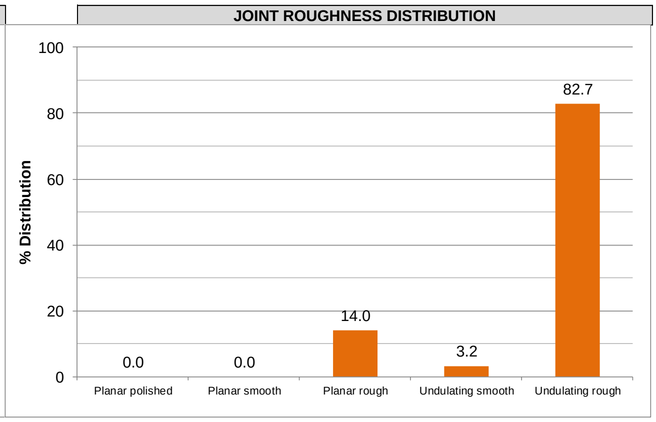
Q' CUMULATIVE DISTRIBUTION



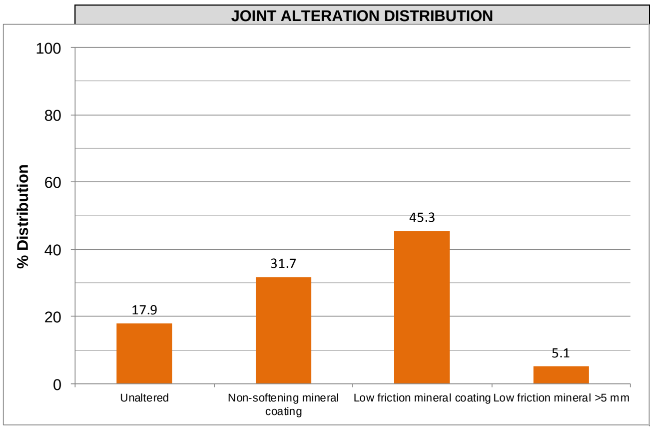
NUMBER OF JOINT SETS DISTRIBUTION



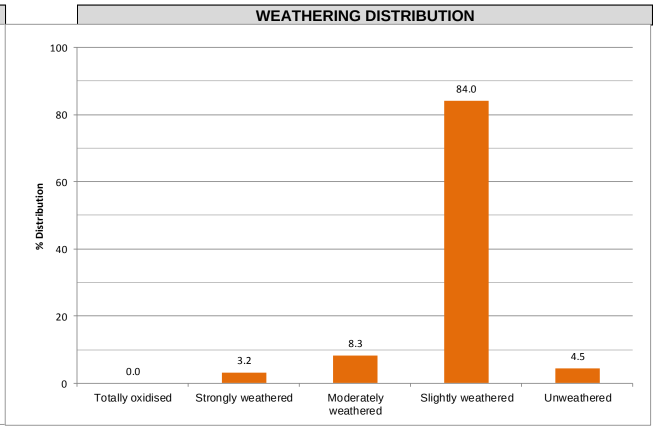
JOINT ROUGHNESS DISTRIBUTION



JOINT ALTERATION DISTRIBUTION



WEATHERING DISTRIBUTION



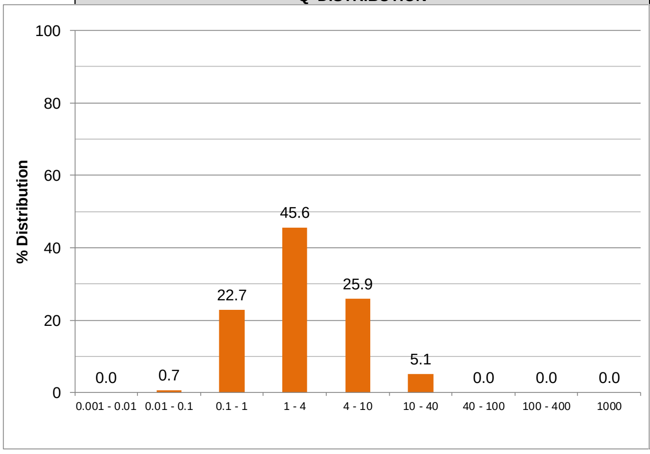
ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

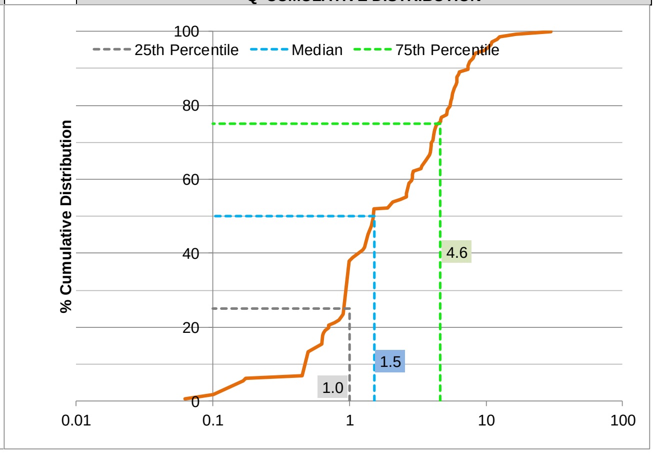
Domain: Moderately weathered rock

Q' Metres Logged: 137.7 m

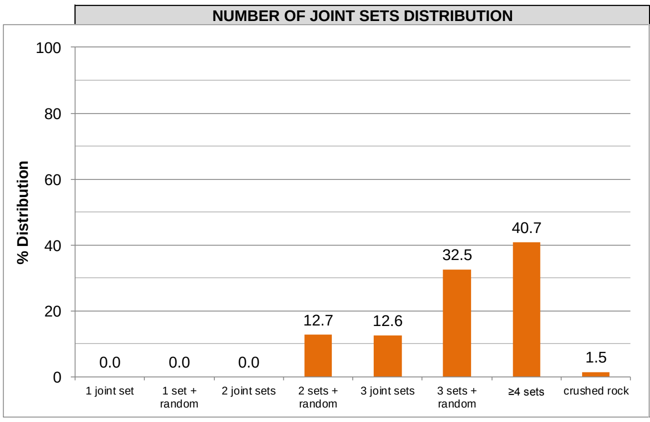
Q' DISTRIBUTION



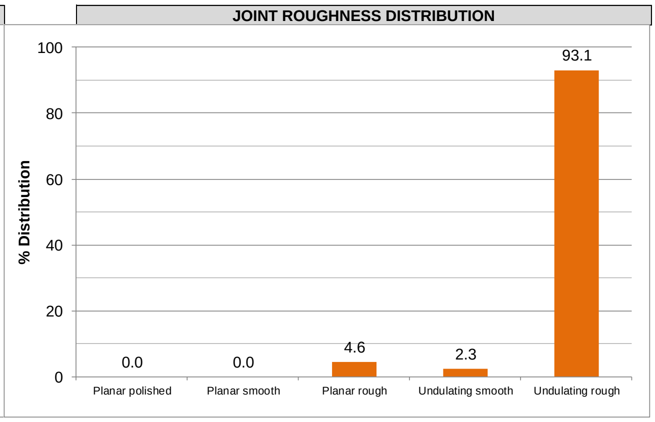
Q' CUMULATIVE DISTRIBUTION



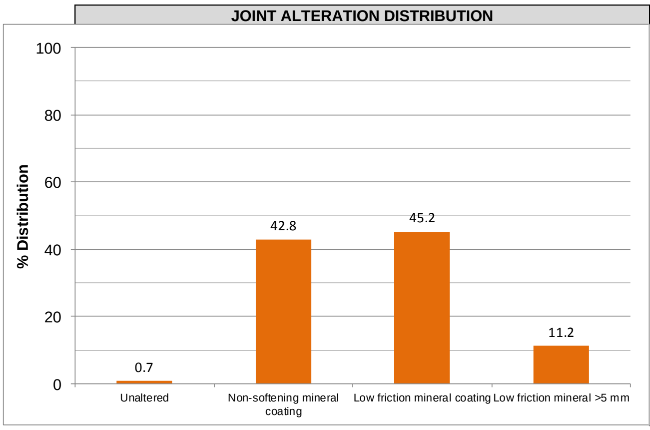
NUMBER OF JOINT SETS DISTRIBUTION



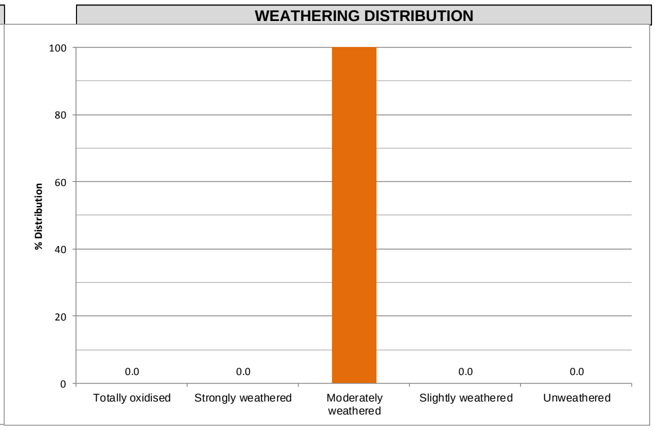
JOINT ROUGHNESS DISTRIBUTION



JOINT ALTERATION DISTRIBUTION



WEATHERING DISTRIBUTION



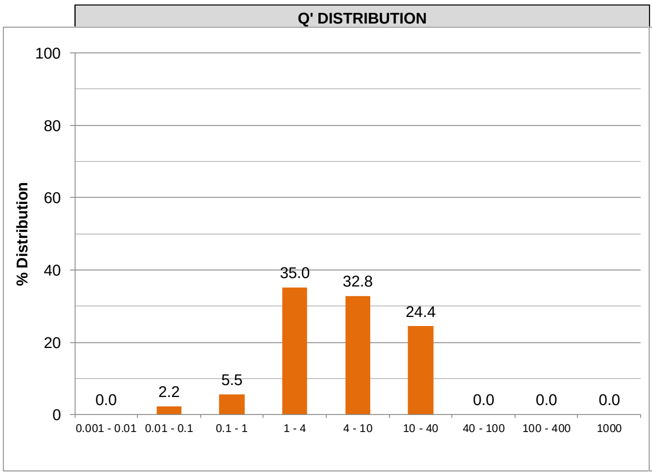
ROCK MASS DATA - Q' PARAMETERS

217049 - Project Martha - Phase 1

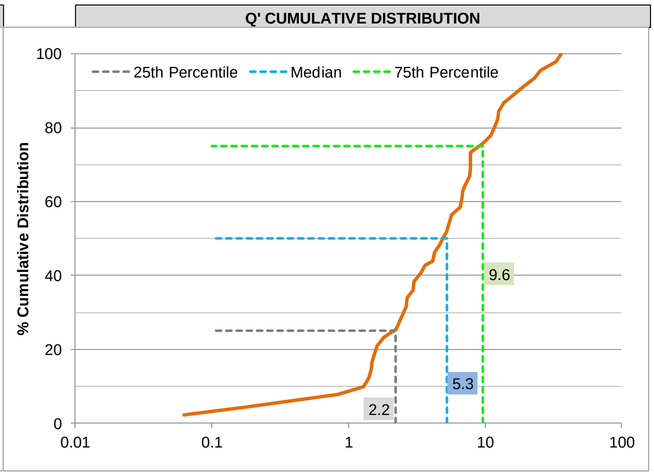
Domain: Near old development

Q' Metres Logged: 45.1 m

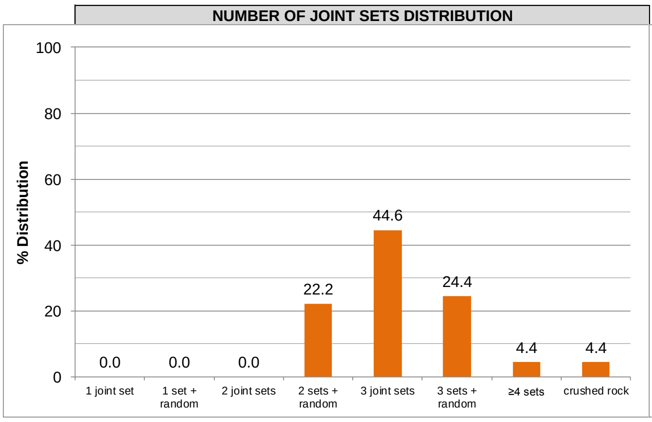
Q' DISTRIBUTION



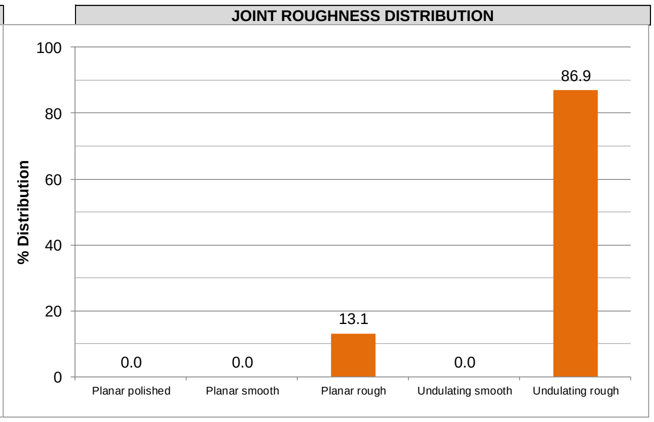
Q' CUMULATIVE DISTRIBUTION



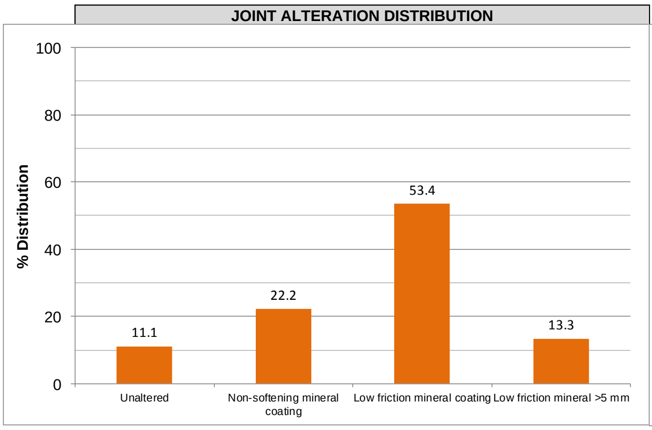
NUMBER OF JOINT SETS DISTRIBUTION



JOINT ROUGHNESS DISTRIBUTION



JOINT ALTERATION DISTRIBUTION



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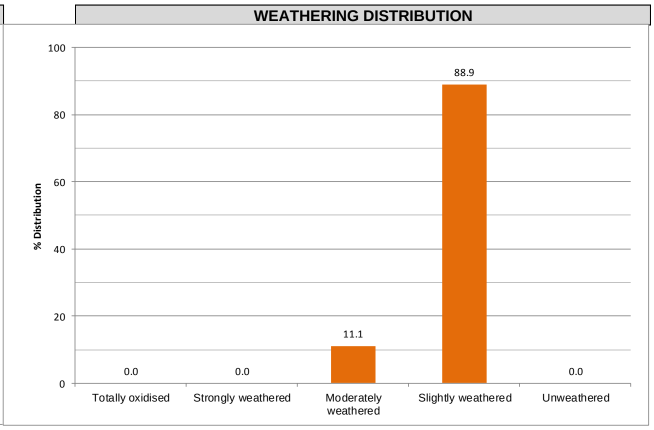
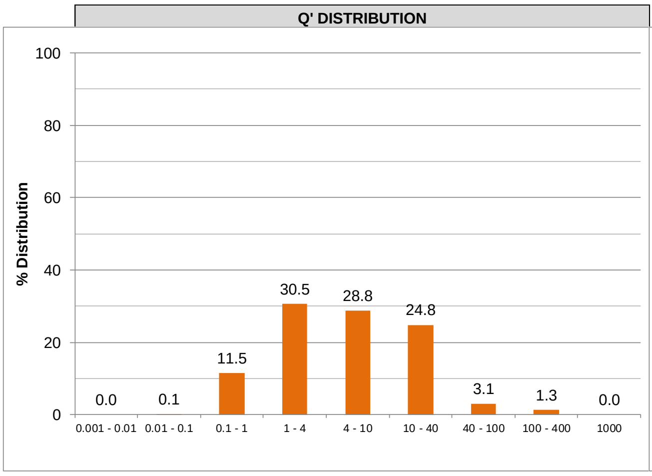


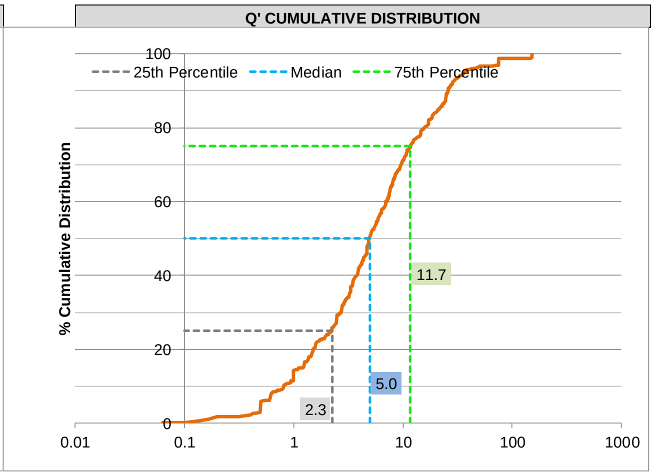
ROCK MASS DATA - Q' PARAMETERS

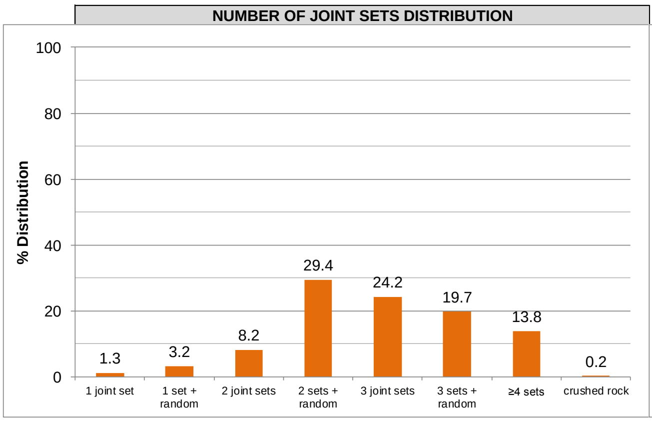
217049 - Project Martha - Phase 1

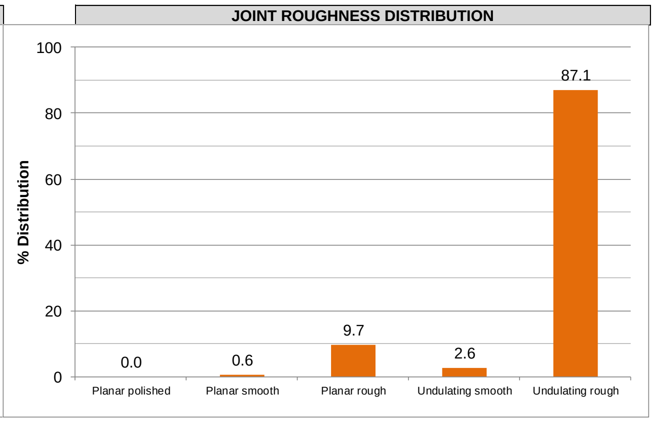
Domain: All data

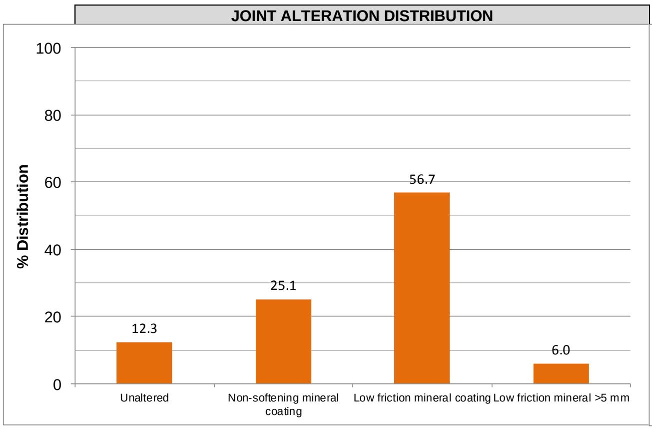
Q' Metres Logged: 1052.0 m

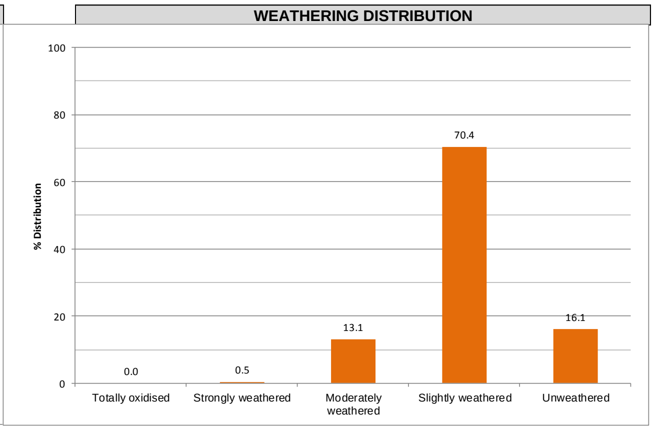












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