Appendix C5_Vibration, Blast and Stability Assessment

Kroondal West – Vibration, Blast and Stability Assessment

Prepared for:	The General Manager Sibanye Stillwater Kroondal West Operations Rustenburg

Prepared by:	Quintin Grix Senior Consulting Geotechnical Engineer Open House Management Solutions Potchefstroom 

Reviewed by:	Koos Bosman Principal Consulting Geotechnical Engineer Open House Management Solutions Potchefstroom 

Date & Versions:	05 August 2024
Reference Number:	QLG_SP_KW2_rev5.0
Distribution:	Sibanye Stillwater – PDF Copy Open House Management Solutions – PDF Copy

OHMS

Table of Contents

List of Figures

List of Tables

1. Introduction

Open House Management Solutions (OHMS) was contracted by Sibanye Stillwater (The Client) to conduct a vibration, blast and stability study of the Kroondal West shallow mining deposit. Originally, a desktop study was conducted to assess whether three blocks could safely be extracted (Grix, 2021). In the desktop study, three blocks namely, Block A, Block B and Block C Figure 1-1 was considered. For this study however, only Block A and Block B are under consideration.

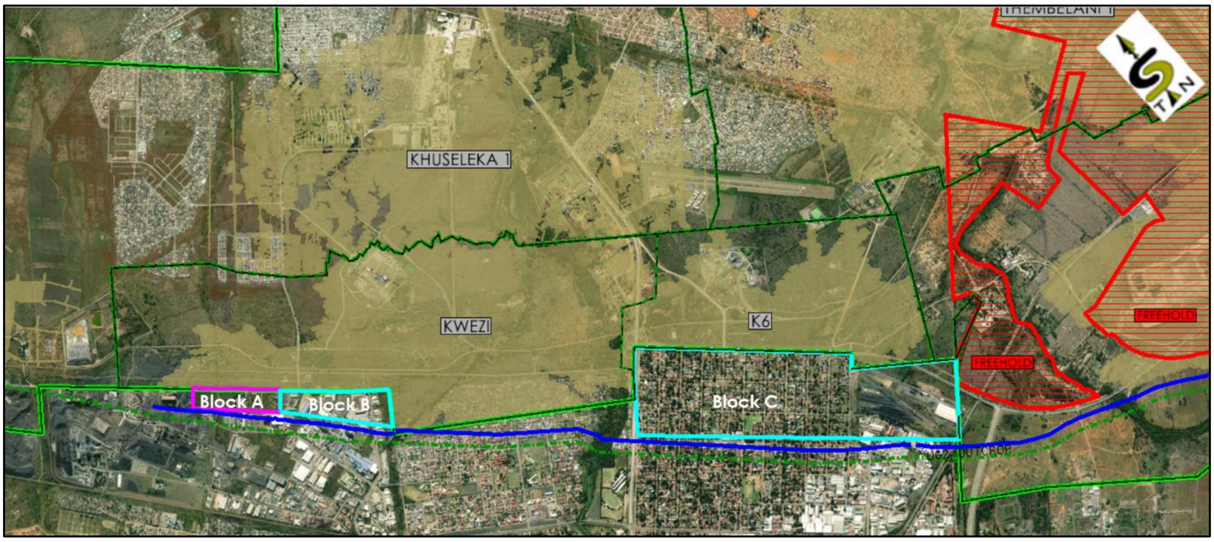


Figure 1-1: Three blocks under scrutiny during initial study (Sibanye-Stillwater, 2021)

Block A

Block A has an area of 130 473 square meters. The UG2 mineral deposit target depth ranges from 40m to 80m. There are no building structures directly below Block A, however the block is within the 100m horizontal mining limit to the Glencore Chrome Smelter, several warehouses, some electrical and water service infrastructure. There is evidence of renewed building activity in this block, for example new fencing and landscaping clearing the empty stands.

Block B

This mineral deposit block has area of 219 663 square meters. Like Block A, the UG2 mineral deposit target depth ranges from 40m to 80m. This area is highly developed and has several warehouses and office blocks directly above the target UG2 mineral deposit.

This supplement study aims to update any assumptions made during the initial study owing to a site visit to the shallow area that was previously inaccessible.

2. Scope of Work

The scope of work agreed to between The Client and OHMS is as follows:

- Site visit and data collection for the purpose of updating the original Kwezi design,
- Geotechnical desktop verification study:
  - Verification of rock mass classification in the shallow area;
  - Verification of the discontinuity database used in the initial assessment;
  - Update of historic observations with observations made in the shallow area;
  - Assessing GPR results from scans conducted in the shallow area;
  - Assess available vibration data to update initial assumptions in regard to vibration limits.
- Write a formal report with the outcomes of the vibration, blast and stability assessment.

Since discussions with the client revealed that the study is aimed at a level above that of a desktop-level study, OHMS opted to include comprehensive numerical modelling, even though it did not form part of the initial scope of work.

3. Methodology

The methodology agreed between The Client and OHMS considered the following key activities:

- Site visit, data collection and data familiarization:
  - Data collection, site familiarization and review,
  - Visit to all underground and surface project areas.

- Geotechnical desktop assessment:
  - Assessment of collected data, and knowledge gathered from underground visit for Site a and B, in order to verify historical geotechnical models' assumptions:
    - Update statistical models for rock mass classification,
    - Update statistical discontinuity database,
    - Update general historic observations,
    - Assess the GPR results in order to verify assumptions made in regard to likely hanging wall stability.
    - Reporting.

4. Numerical Modelling

4.1 Pillar Stability Assessment

Numerical modelling, for the purpose of pillar stability, was conducted using the Map3D software suite.

Pre-mining Stress State

No previous stress measurements have been conducted at the Kwezi operation. The client provided assumptions on the underground pre-mining stress regime (as per e-mail correspondence). The in-situ stress regime was thus assumed as follows:

Table 4-1: Stress tensor used in the numerical model (e-mail correspondence)

Parameter	Value
Datum (m):	1132.0m
Sxx (MPa/m):	-0.0275
Syy (MPa/m):	-0.0275
Szz (MPa/m):	-0.0275
Sxy (MPa/m):	0.0
Sxz (MPa/m):	0.0
Syz (MPa/m):	0.0

Numerical Modeling Input Parameters

As with the stress state, the additional required modelling input parameters were sourced from the mine's geotechnical engineering department. Table 4-2 depicts all the numerical modeling input parameters used in the Map3D model.

Table 4-2: Map3D - Numerical modeling input parameters

Parameter	Value
Young's Modulus (MPa)	75,000
Poisson's Ratio	0.25
Density (kg/m³)	2,850
K-ratio	
Qxx/Qzz	1.00
Qyy/Qzz	1.00
Qxx/Qyy	1.00
Stress variation	
Sigma ZZ (MPa/m)	0.0275
Sigma XX (MPa/m)	0.0275
Sigma YY (MPa/m)	0.0275

Model Geometry

A portion of the historic as-mined geometry, along with the future mining layouts were constructed as Displacement Discontinuity (DD) elements in Map3D. The model battery limits are depicted in Figure 4-1.

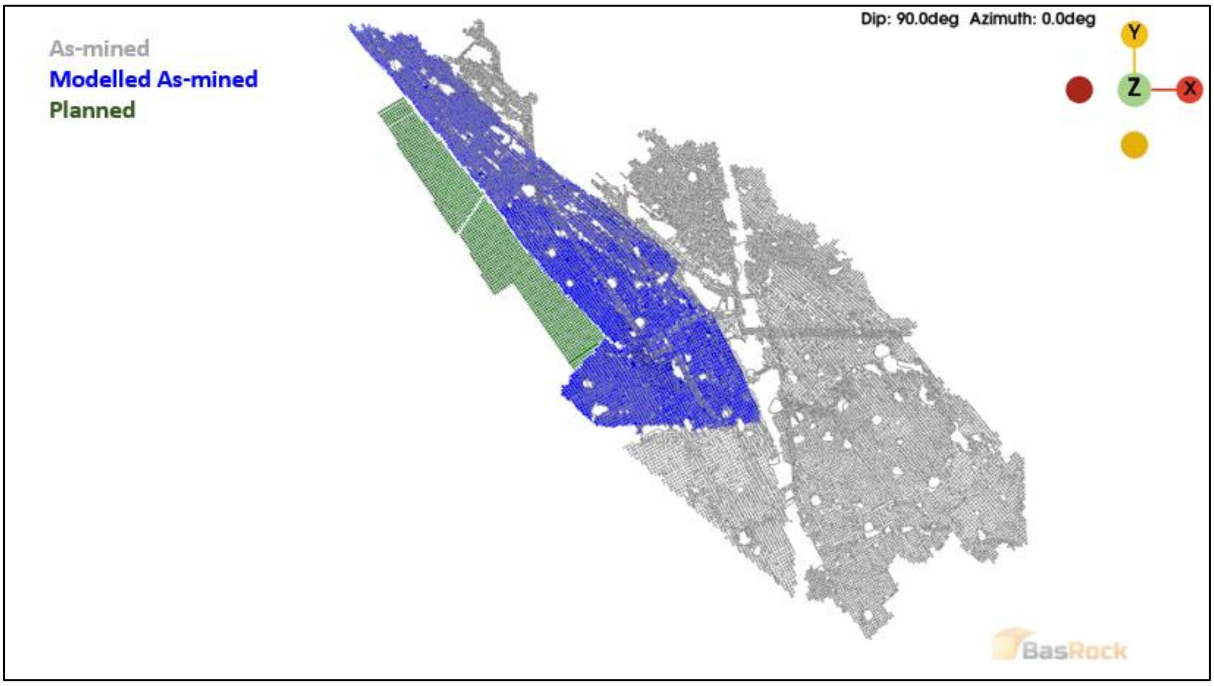


Figure 4-1: Numerical model battery limits for the purpose of pillar stability calculations

Figure 4-2 depicts the range of depth below surface (dbs) for future mining of the Kwezi operation. The average pillar depth for the planned area is between 21.0m and 100.0m below surface (mbs) with the maximum pillar depth being at 85.0mbs and the minimum pillar depth being 21.0mbs. The numerical model is solved in order to attain average pillar stresses that are to be used in the subsequent assessments. Figure 4-3 depicts the resulting average pillars stresses for each of the individual pillars for the as mined, as well as the proposed layouts.

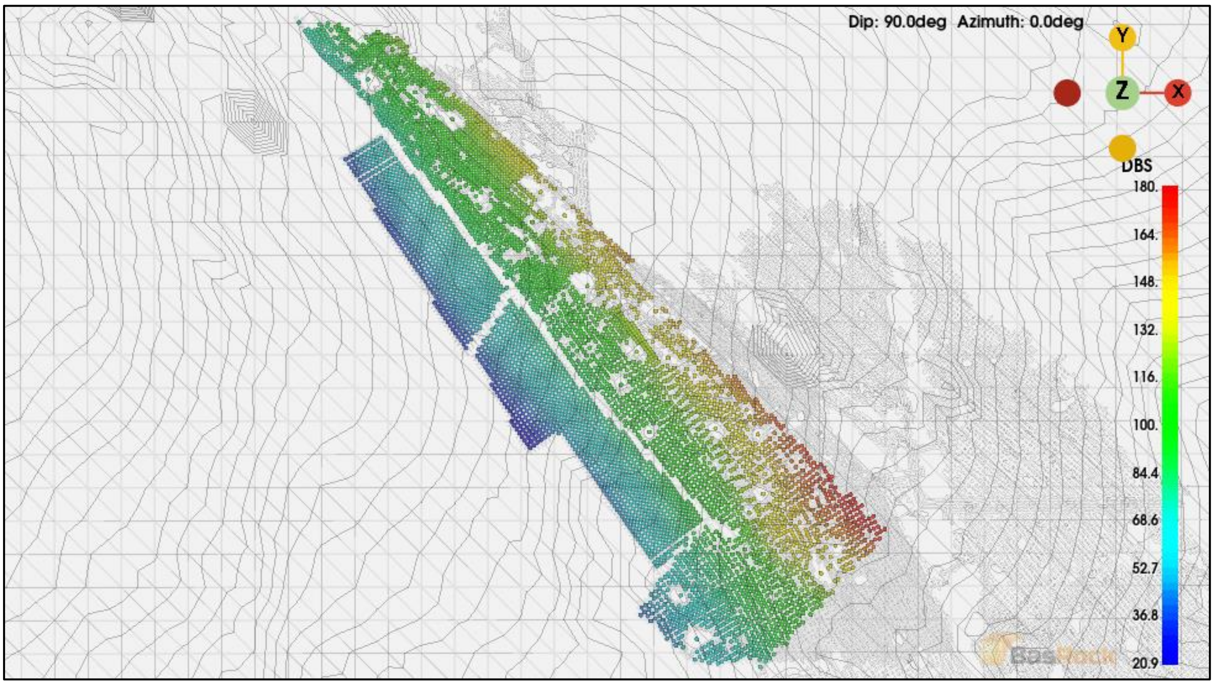


Figure 4-2: Kwezi's future mining's depth below surface.

Figure 4-3: Average pillar stresses calculated for each individual pillar in the as mined and planned areas.

Limitations of the numerical modeling assessments

It is important to understand that numerical simulations have specific limitations. The first important factor to understand is that numerical modelling is used as a tool to assist with the understanding of the behavior of the rock mass, subjected to stress and stress changes.

The following limitations of the numerical modelling should be kept in mind:

- The rock mass is assumed to behave elastically and is continuous. (The effect of changes in mechanical properties associated with lithology changes and localized structural changes is ignored).
- Rock mass failure is not simulated in the numerical model.
- Input parameters governing the behavior of the model are generalized and based on the statistical interpretation of the data collected or supplied.
- Models are constructed based on surveyed information and do not reflect minor irregularities caused by over- or under-breaking of pillar dimensions.
- The sequence or date when excavations were mined is ignored.
- The effect of the mining rate or rate of extraction is not accounted for.

Pillar Stability Assessment

Assessment Methodology

For the pillar stability assessment, the pillar strength is estimated using the latest industry standard for the UG2 Reef. The Average Pillar Stress (APS) is obtained from the detailed numerical model. For due diligence, Tributary Area Theory (TAT) was also calculated in Excel spreadsheets for benchmarking and comparison. Having both the pillar strength and pillar stress, the ratio can be calculated to assess the Factor of Safety (FoS) and benchmarked against the required criteria.

Pillar Strength Estimation

At Kwezi, the Hedley and Grant power law formula is the proposed and standard method to determine pillar strength for pillars with a width-to-height ratio of less than 4.5 (Haasbroek, 2023). The formula is shown below:

$$PS = k \times \frac{w^{0.50}}{h^{0.75}}$$

where:

k = Design Rock Mass Strength

w = effective width of the pillar in meters

h = height of the pillar in meters

Since the depth of the various pillars on Kwezi shaft varies dramatically, ranges of DRMS were proposed. Typically, a DRMS of 76MPa is used for Kwezi. For depth ranges between 75.0mbs and 150.0mbs, a DRMS of 54MPa is used, and in the shallow areas where weathering of the material is more likely, a conservative estimate of 34.0MPa is used for DRMS.

An accurate effective pillar width was calculated for each pillar, from the CAD mine plans (both planned and as mined), by using the areas and perimeters of pillar polygons in the effective width (W_{eff}) calculation.

$$Weff = 4\frac{Area}{Permimeter}$$

where:

Area = area of the pillar

Perimeter = perimeter of the pillar

Pillar Width-to-Height Ratio

The pillar width-to-height ratio informs the pillar confinement. Confinement in a pillar has a significant influence on the overall strength of the pillar. Table 4-3 depicts the design criteria limits for the different pillar systems. Included in the table is the typical factors of safety and pillar systems associated with specific width to height ranges.

Table 4-3: Pillar System width-to-height ratios and factor of safety

Pillar System	Width-to-Height (W:H)	Factor of Safety (FoS)
Stable non-yield	2.5 < W:H < 5.0	FoS > 1.6
Yield	3.0 < W:H < 4.0	1.0 < FoS < 1.6
Crush	1.7 < W:H < 2.5	FoS < 1.0

The pillars under consideration are meant to be stable, non-yield pillars and thus requires width to height ratios > 2.5 and factors of safety > 1.6

Pillar Risk Potential

The pillar risk can be assessed by utilizing the theoretical Extraction Ratio (e) and the Stress Concentration Factor (SCF). Figure 4-4 illustrates the relationship between pillar stress level (SCF) and extraction ratio (e). When operating at a high extraction ratios, a high incremental change in pillar stress level is observed, for a small change in extraction ratio (Brady & Brown, 2005). Based on the extraction ratio and resultant stress levels, the pillars can be classified as low (e < 0.75), medium (0.75 < e < 0.85), or high-risk pillars (e > 0.85).

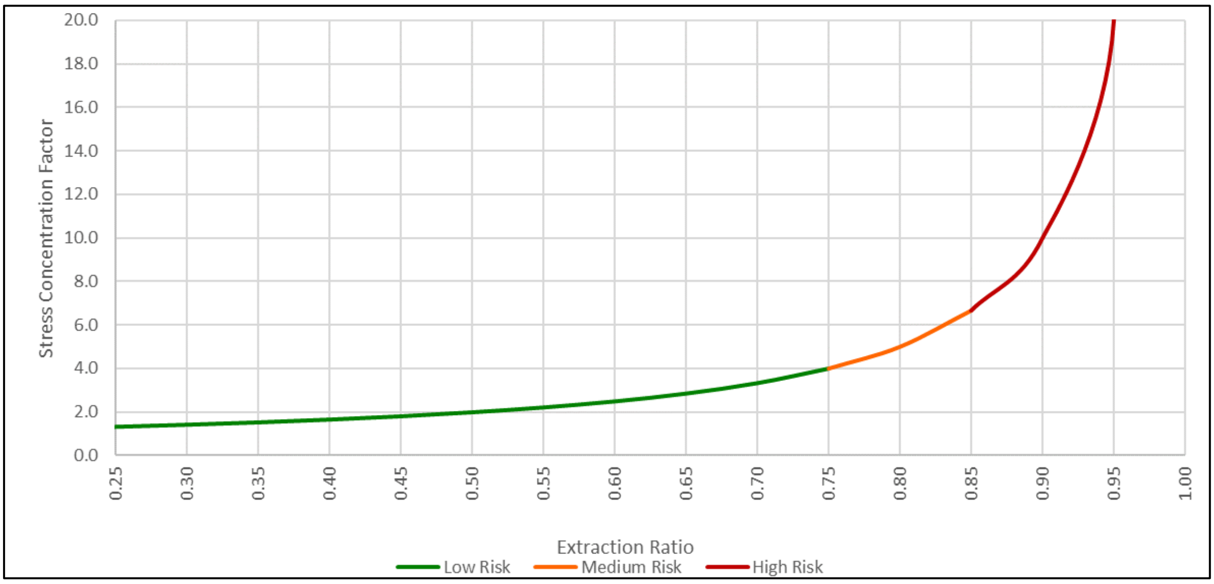


Figure 4-4: Relation between pillar stress level and extraction ratio

To estimate a stress concentration factor, the following equation is used:

$$SCF = \frac{APS}{pgH}$$

In addition, the theoretical extraction ratio is calculated using a re-arrangement of the well-known average pillar stress equation, by substituting the modelling average pillar stress into the equation, and solving "e":

$$e = 1 - \frac{pgH}{APS}$$

In-Stope Pillar Stability Assessment Outcome

The pillar stability assessment for the future design layout was conducted using the mining layout provided by the mine. Figure 4-5 depicts the design layout with the pillar FoS values for the bord and pillar sections of the layout. From the figure, it is evident that the planned mining area has factors of safety well above 1.6. In the as-mined area however, factors of safety range from 1.0 to > 5.0.

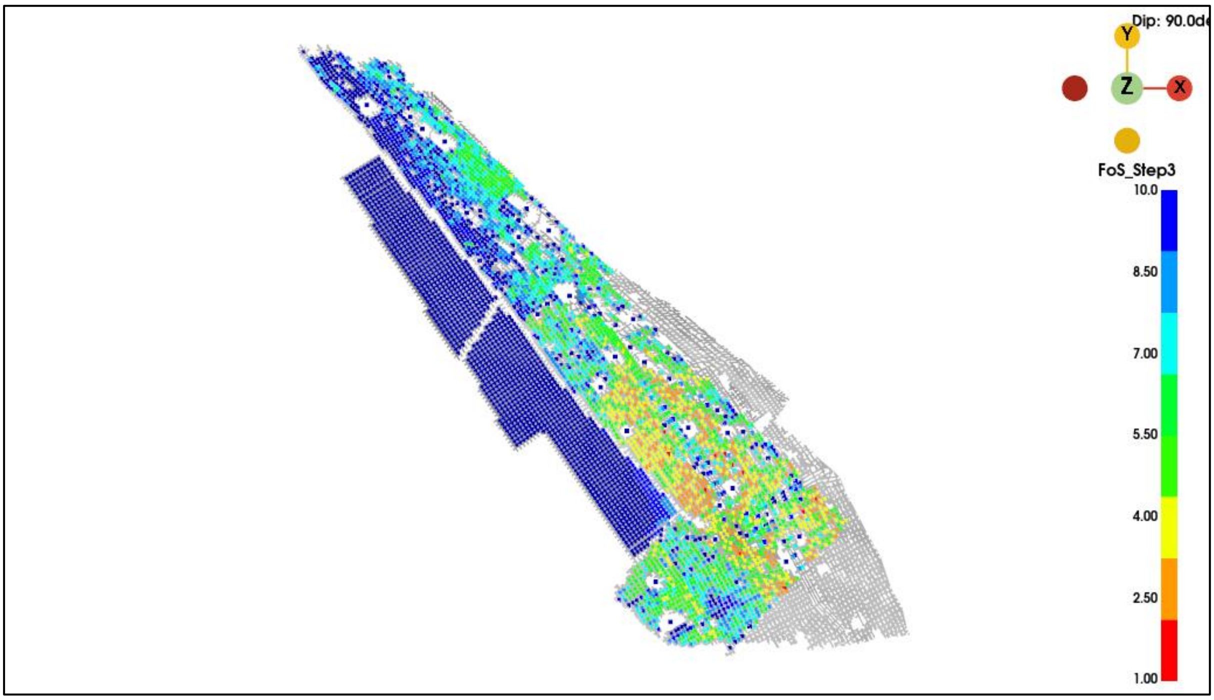


Figure 4-5: Design layout pillar factor of safety

Figure 4-6 depicts the same assessment and data, classified into two categories namely FoS > 1.5 and FoS < 1.5. From the figure, it is evident that no pillars in the proposed layout will have factors of safety < 1.5.

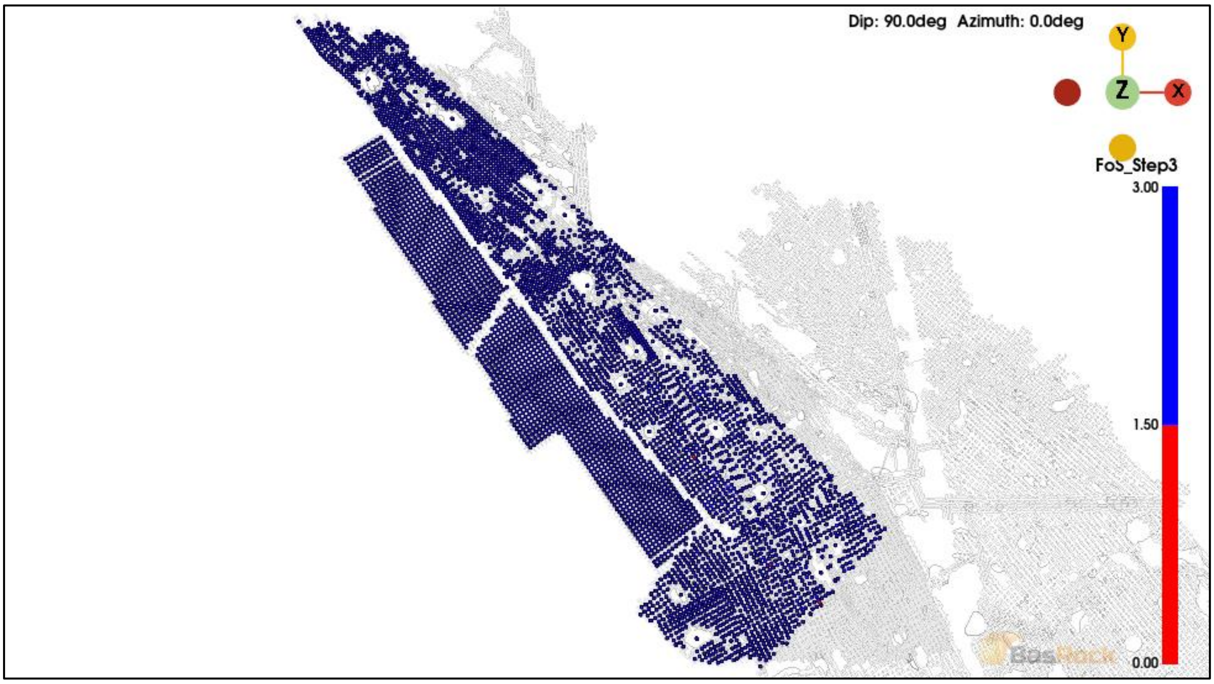


Figure 4-6: Classified factors of safety for the areas under consideration

Figure 4-7 depicts the outcome of the quantitative stress concentration factor calculation on each individual pillar. Figure 4-8 classifies each individual pillar according to its perceived risk as per the risk graph in Figure 4-4.

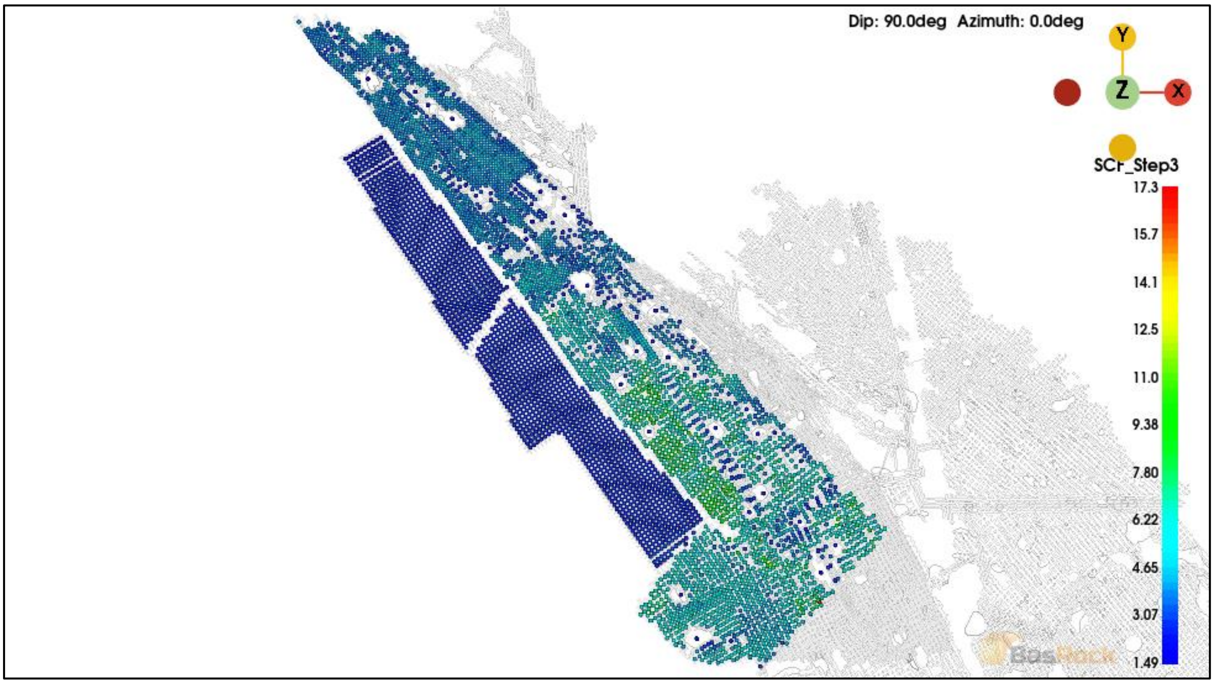


Figure 4-7: Calculated stress concentration factor for each pillar

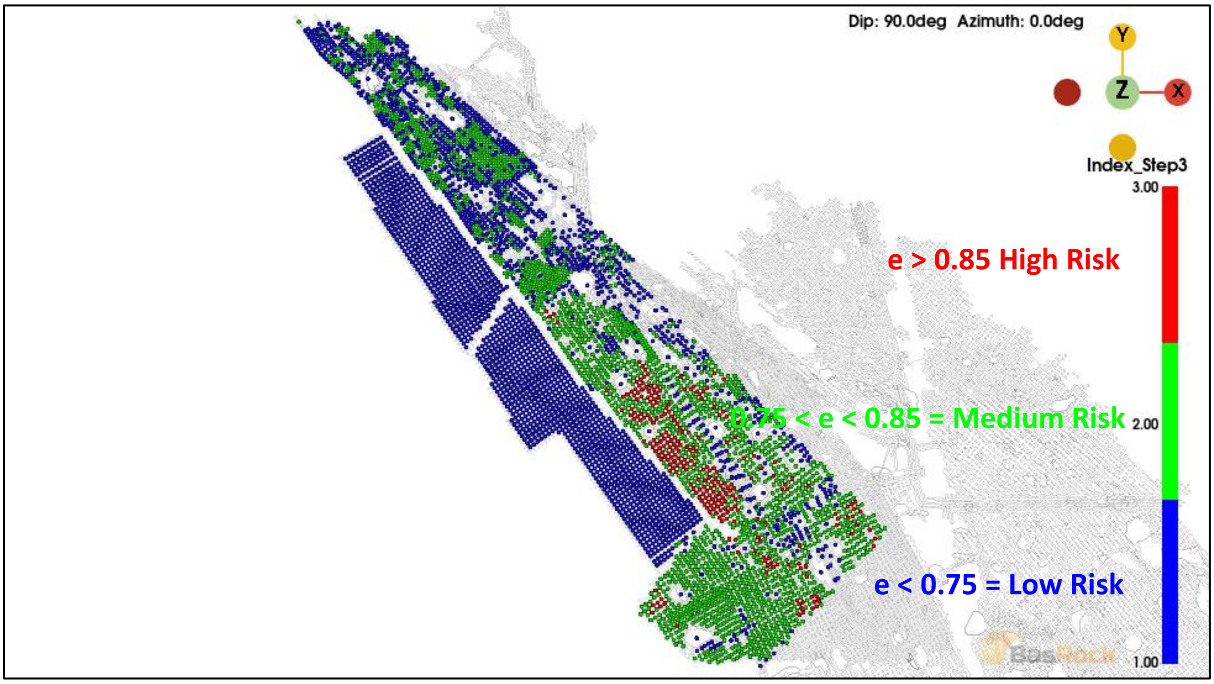


Figure 4-8: Categorized risk classification for each individual pillar

From the risk classification assessment, it should be noted that the risk rating for the proposed pillars is all classified as "Low".

4.2 Subsidence Assessment

Subsidence Methodology

Two methodologies were deployed in order to assess subsidence for the Kwezi shallow mining area. The first methodology is regarded as the absolute worst-case scenario, where complete collapse of the pillar system is simulated. It must be noted, given the results of Section 0, that his is highly unlikely to occur. The methodology followed to estimate this worst-case-scenario subsidence is that proposed by van der Merwe (van der Merwe, 2018), where the expected subsidence is related to the mining height, mining depth and the extraction ratio. The methodology takes the form of:

$$Sm = a \times h \times e$$

where:

Sm = maximum expected subsidence

a = 0.8 if depth ≤ 80 m or a = 0.5 if depth > 80 m

h is the mining height

e is the extraction ratio

Depending on the ratio of the maximum subsidence to the mining depth, the subsidence profile can be smooth and continuous to stepped with almost vertical sides. The classification (van der Merwe and Madden, 2002) presented in Table 4-4 can be used to gain some insight into what to expect.

Table 4-4: Classification of subsidence profiles (van der Merwe and Madden, 2002)

Class	Sm/H ratio	Description
A	Sm /H < 0.001	Barely noticeable, smooth, continuous profile, hair-line cracks
B	0.001 < Sm /H < 0.005	Difficult to notice, smooth profile, cracks 1–2 cm wide
C	0.005 < Sm /H < 0.02	Noticeable in flat terrain, smooth, cracks 2–10 cm wide, compression ridges 1 to 5 cm high
D	0.02 < Sm /H < 0.05	Noticeable in most terrains, visible vertical displacements across cracks, cracks 10 to 50 cm wide, compression ridges 5 to 50 cm high
E	Sm /H > 0.05	Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm

The second methodology employed to assess the likely subsidence, is 3D numerical modelling. A 3D finite element numerical model was constructed using the geometry initially constructed in Map3D. Pillars in the model was simulated as rigid, since failure of these pillars is not expected. Modelling input parameters were kept the same as previously recorded for the Map3D modelling. The RS3 model geometry is depicted in Figure 4-9.

The model, simulating only the surface topography, was allowed to converge in mining step 1, thereafter an additional mining step was simulated where the proposed stopes were extracted. Induced vertical displacements were assessed owing to the actual mining, and conclusions drawn in regard to the effect on the surface.

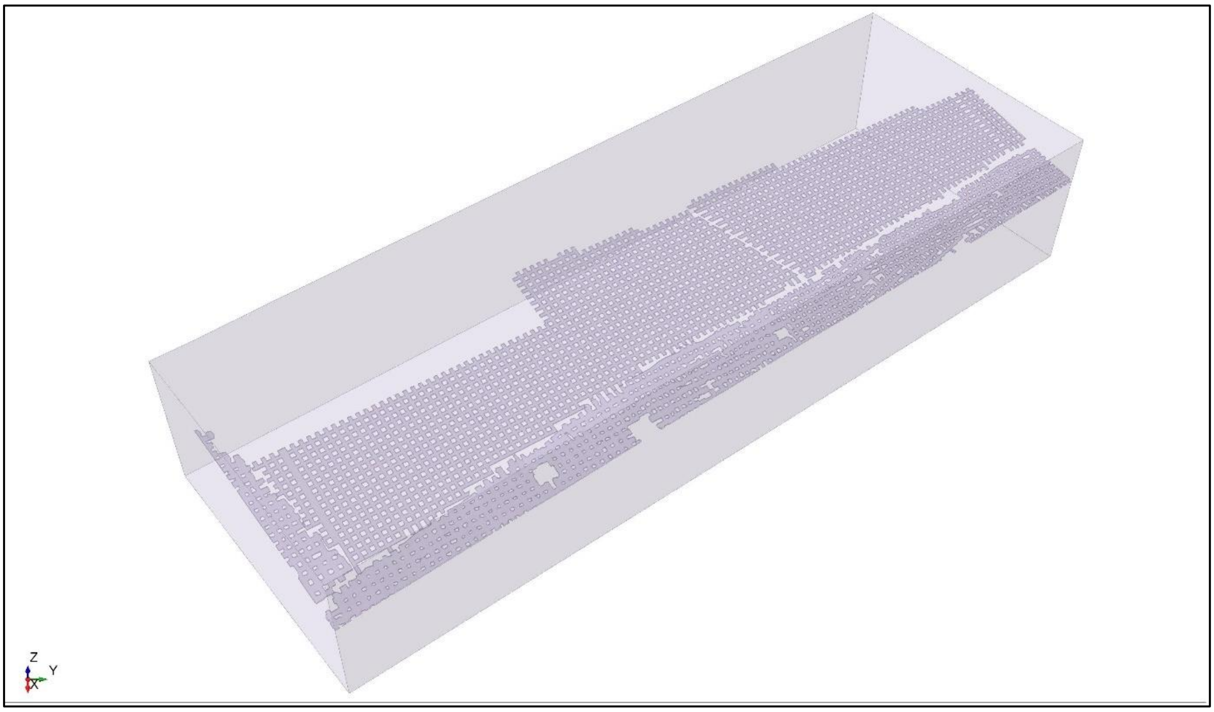


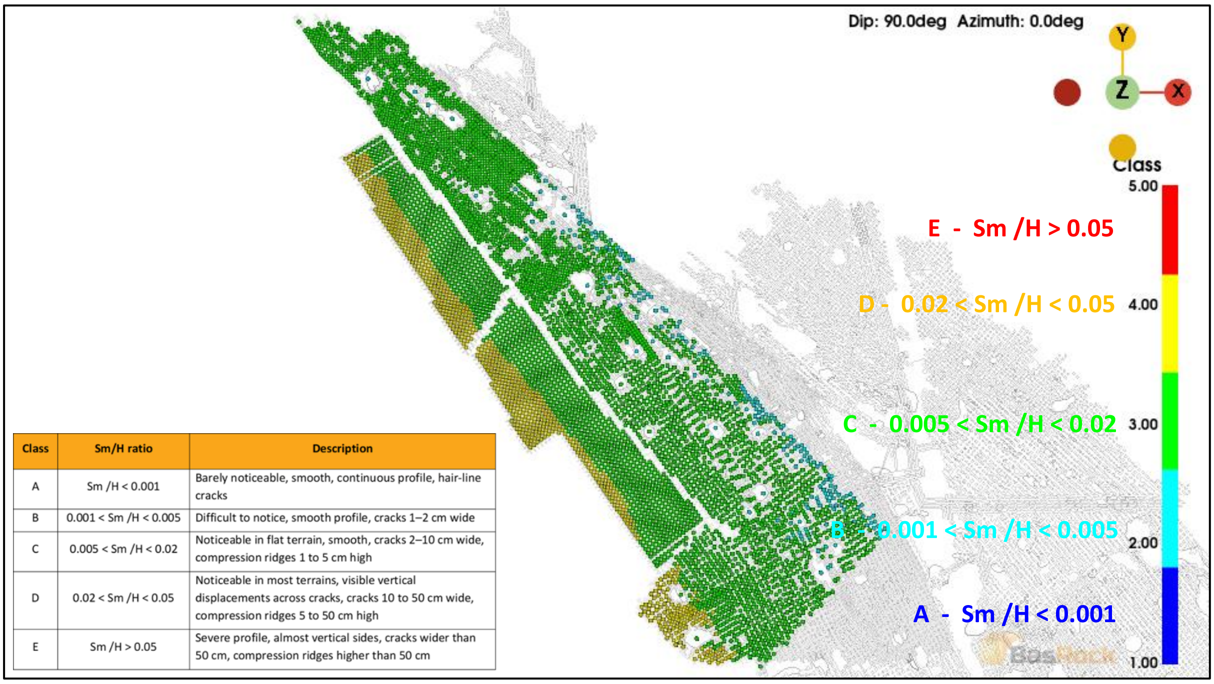
Figure 4-9: RS3 numerical model geometry

Subsidence Assessment Outcome – Worst-Case-Scenario Methodology

The maximum expected subsidence in the event of a catastrophic failure was calculated and plotted for each pillar in Figure 4-10. The plot shows the actual quantitative values of Sm as previously reported on. Note that the planned area shows Sm values in the region of 1.0m.

Figure 4-10: Maximum worst-case-scenario expected subsidence (van der Merwe, 2018)

Considering the different classes proposed by van der Merwe (van der Merwe, 2018), the actual Sm values were classified according to the various classes and plotted on the mine plan. Note from the classification, that the proposed mining area, especially the areas < 50.0m below surface will result in Class D subsidence (should complete pillar collapse occur), and thus cracks might occur with visible vertical displacements across the cracks. Cracks can be expected 0.1m to 0.5m wide in the event of catastrophic failure.



Class	Sm/H ratio	Description
A	Sm /H < 0.001	Barely noticeable, smooth, continuous profile, hair-line cracks
B	0.001 < Sm /H < 0.005	Difficult to notice, smooth profile, cracks 1–2 cm wide
C	0.005 < Sm /H < 0.02	Noticeable in flat terrain, smooth, cracks 2–10 cm wide, compression ridges 1 to 5 cm high
D	0.02 < Sm /H < 0.05	Noticeable in most terrains, visible vertical displacements across cracks, cracks 10 to 50 cm wide, compression ridges 5 to 50 cm high
E	Sm /H > 0.05	Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm

Figure 4-11: Classified maximum subsidence values

Subsidence Assessment Outcome – Anticipated Scenario Methodology

The most likely expected surface influence was derived from a 3D finite element numerical model. The expected maximum vertical displacement at the underground stopes is depicted in Figure 4-12. Note that some 4mm of displacement is expected to have occurred in the historic mined stopes (as mined). Maximum expected vertical displacement of around 1mm is expected towards the center of the proposed mining area and reduces as the stoping progresses to the shallower extends.

A similar plot is depicted in Figure 4-13 however, for this plot, the vertical displacement that is expected on the surface above the stoping area is plotted. Note that vertical displacement < 0.5mm is expected in the shallow areas of the proposed mining area. The vertical displacement resulting from the as-mined stopes is expected to be in the region of 2.5mm. Referring to *Table 4-4*, both these cases are orders of magnitudes below the criteria for Class A and could thus be regarded as insignificant.

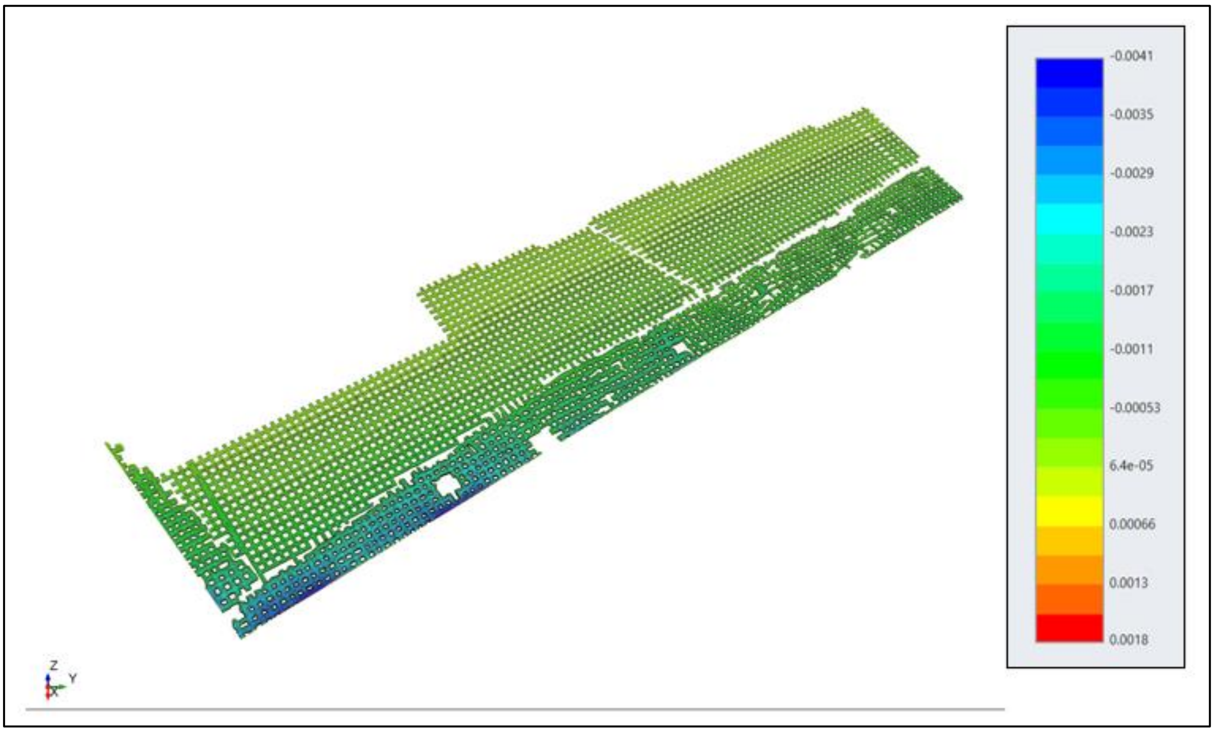


Figure 4-12: Maximum vertical displacement at the underground stopes

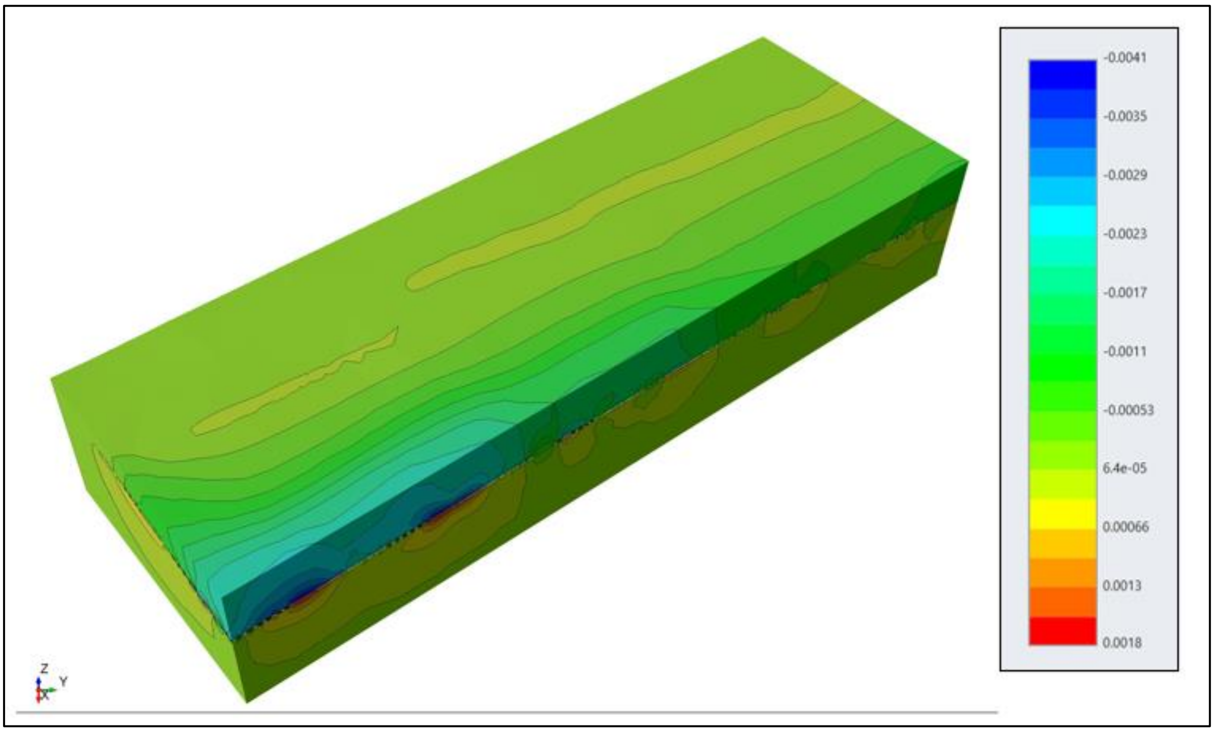


Figure 4-13: Maximum vertical displacement at the surface above the stoping area

The expected elastic deformation data was superimposed onto a surface plan, and a satellite image of the surface area in question. The image is depicted in Figure 4-14.

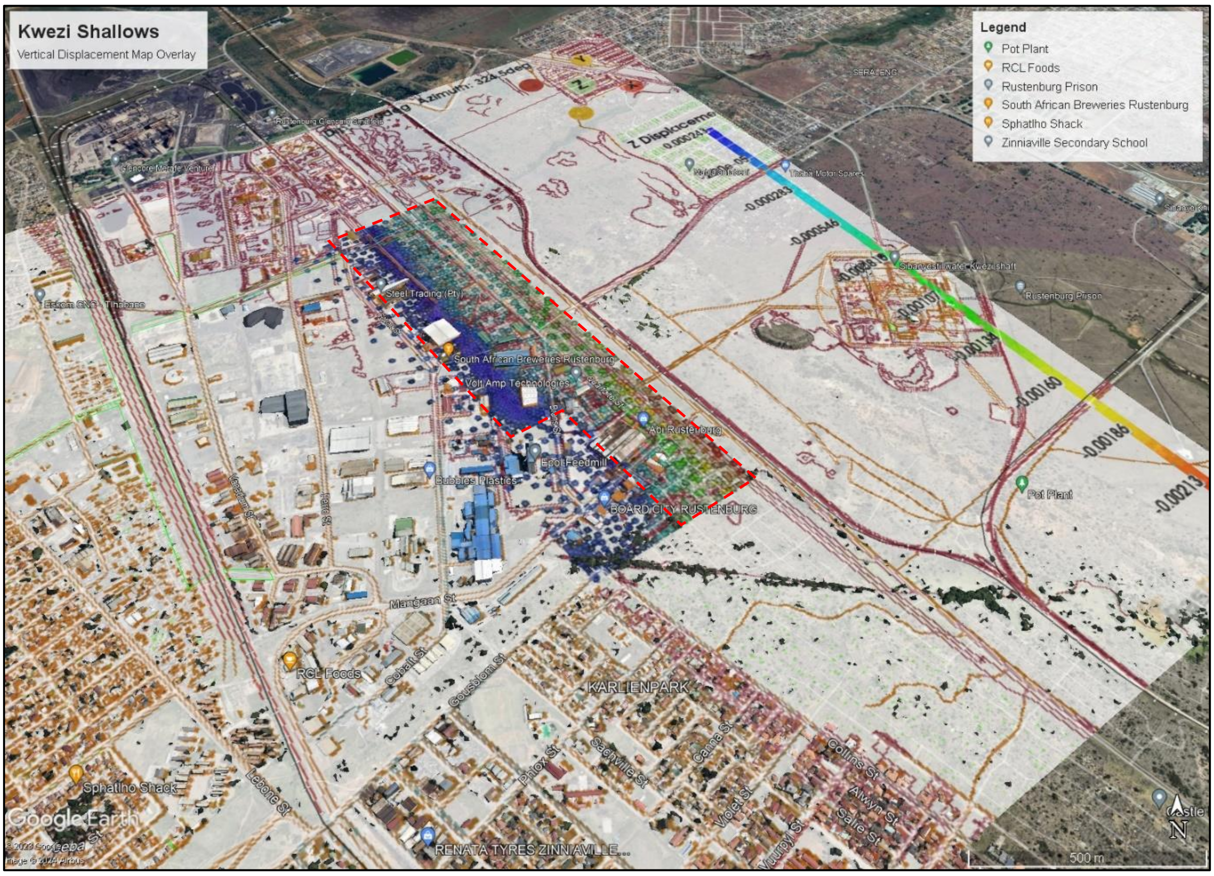


Figure 4-14: Vertical displacement overlayed onto Google Earth image of surface area

The mining outline is depicted as a red, dashed outline in the figure. Note that mining underneath the feed mill, owned by Epol, has previously been excluded from the mine plan. The maximum expected vertical displacement is expected to be along the eastern boundary of the project area and will be limited to a mere ~1mm.

5. Blasting and Vibration

5.1 Vibration Assessment

Undermining surface structures by means of drilling and blasting will result in the said surface structures experiencing some form of vibration. These vibrations are typically measured as peak particle velocities, and reported in mm/sec. In South Africa, guidelines in terms of maximum allowable PPV's is not readily available and thus, the guidelines set out by the United States Bureau of Mines (USBM) are typically used. The guidelines prescribed by the USBM is tabulated in Table 5-1.

Table 5-1: Ground vibration limits as per USBM

Structure Description	Ground Vibration Limit (mm/sec)
National Roads/Tar Roads	150
Electrical Line (Pylons)	75
Railways	150
Transformers	25
Gas/Fuel Lines	25
Water Wells	50
Telecoms Tower	50
General Houses of Proper Construction	25
Houses of Less Proper Construction	12.5
Rural Buildings – Mud Houses	6

Empirical and theoretical calculations exist that can be used to assess the likely PPV caused by a blast hole. It is generally accepted, that blast holes initiated > 8 milliseconds apart can be assessed individually. However, once the delay becomes shorter i.e., < 8 milliseconds, vibrations will be a function of the sum of the two explosive charges.

PPV's were calculated for a 2.0m and 3.0m face advance using a single 38mm diameter blast hole and repeated for two holes being set off with delays less than 8 milliseconds. The outcome of the analysis is depicted in graphical form in Figure 5-1.

Given the fact that mining is not planned closer than 40.0m from surface, the 40.0m below surface point on the graph can be regarded as the worst-case scenario.

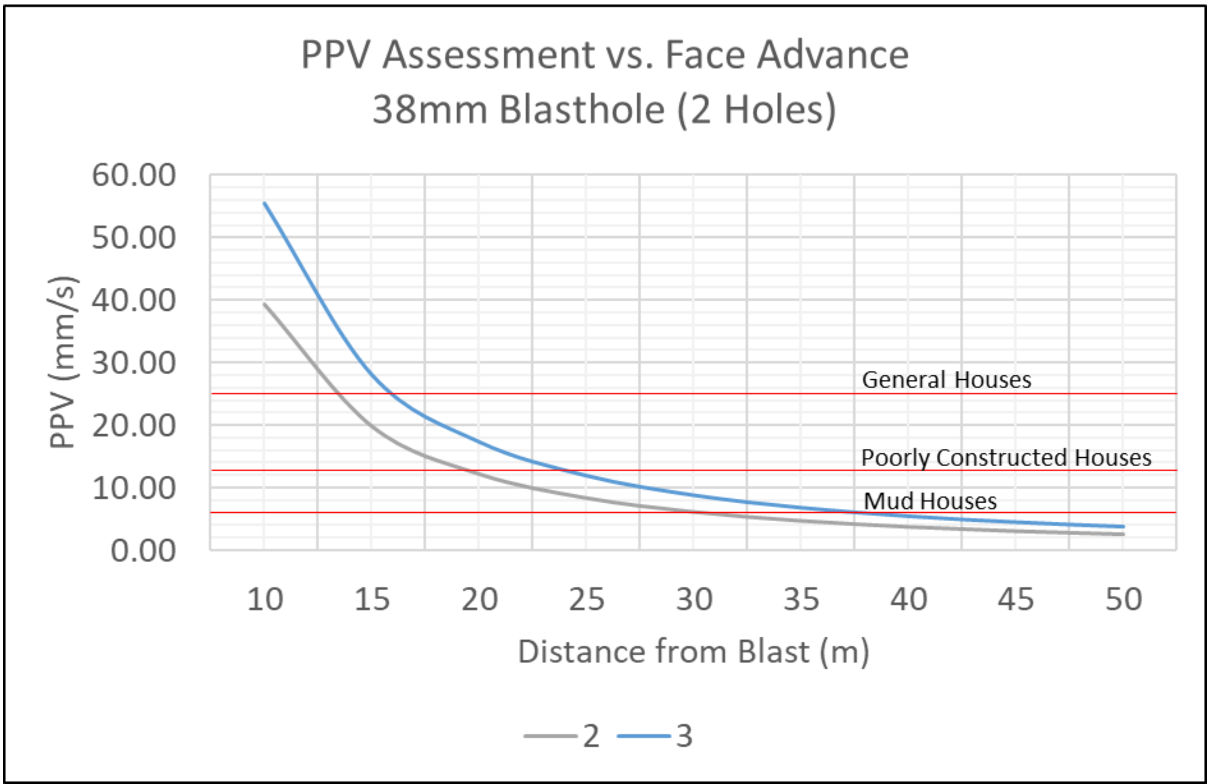


Figure 5-1: PPV for a single 38mm blasthole as a function of distance and face advance.

The assessment indicates that for a 3.0m face advance, the 6mm/sec criteria is exceeded at a distance of approximately 37.0m (below surface). For a 2.0m face advance, the same criteria are exceeded at a distance of just below 30.0m below surface.

In order to visualize the likely permitted face advance in the planned mining area, the planned mining was divided into four depth classes namely 0-25mbs, 25-50mbs, 50-75mbs and 75-100mbs. Considering a factor of safety of some 1.4, the minimum depth at which 3.0m advance rates should be employed is 50.0m and is depicted in light blue in Figure 5-2. Since the minimum criteria is exceeded, even when using 2.0m advances at depth just below 30.0mbs, mining below this depth is not envisaged. Figure 5-3 depicts the areas where mining is currently planned below 30.0mbs, and that should be excluded from the mining plan.

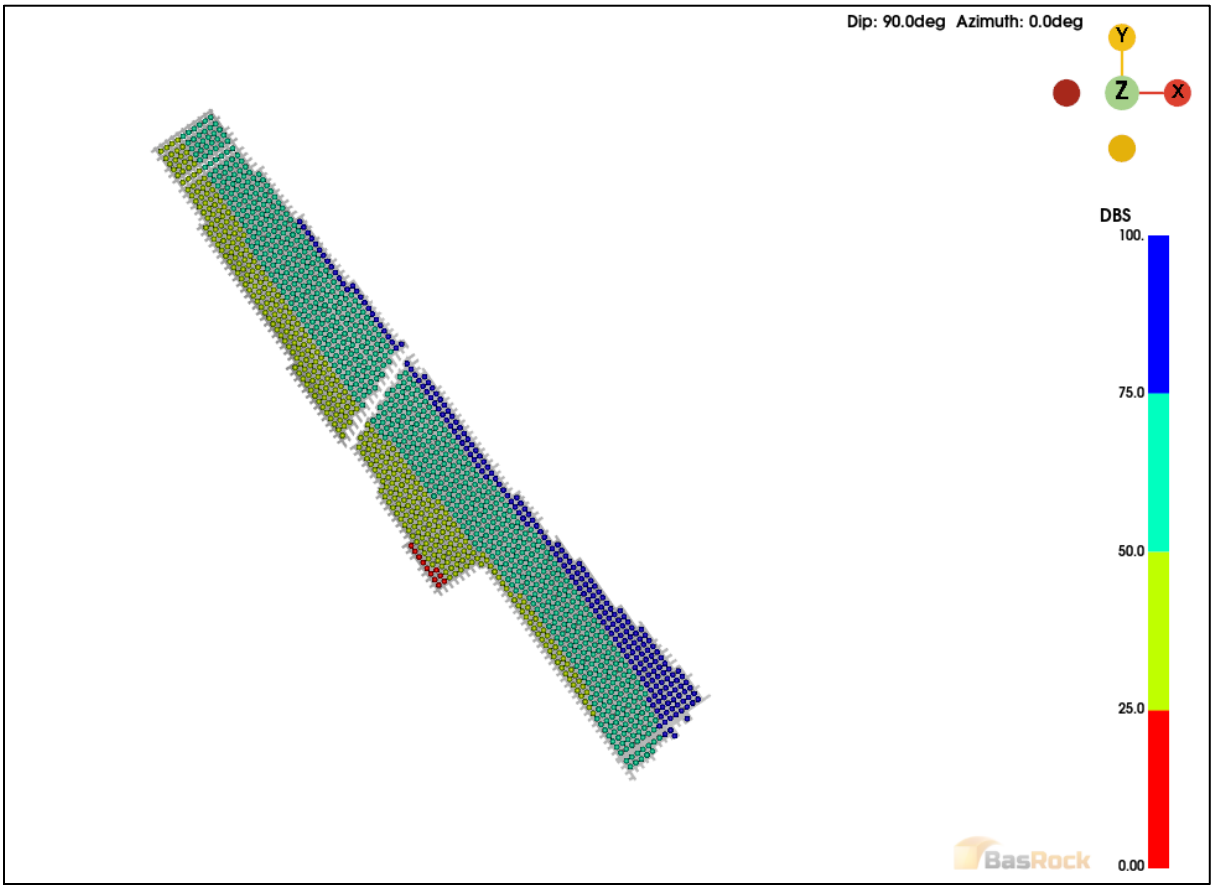


Figure 5-2: Depth classes for the planned mining area

It should be noted that air-blast in not considered in this assessment since blasting will only take place underground. However, physical measurements of the aforementioned should be undertaken once mining commences in order to confirm this assumption owing to ventilation shafts and other openings to the underground.

In addition, it must be noted that ground vibration is typically a function of ground velocity, as well as frequency. Low frequency vibrations are typically more damaging than high frequency vibrations (Figure 5-4). Thus, when mining commences in the area, dedicated blast vibration measurement stations should be envisaged to calibrate the analytical ground vibration assessment, as well as to benchmark the actual acceleration and frequency to the limits proposed by the USBM.

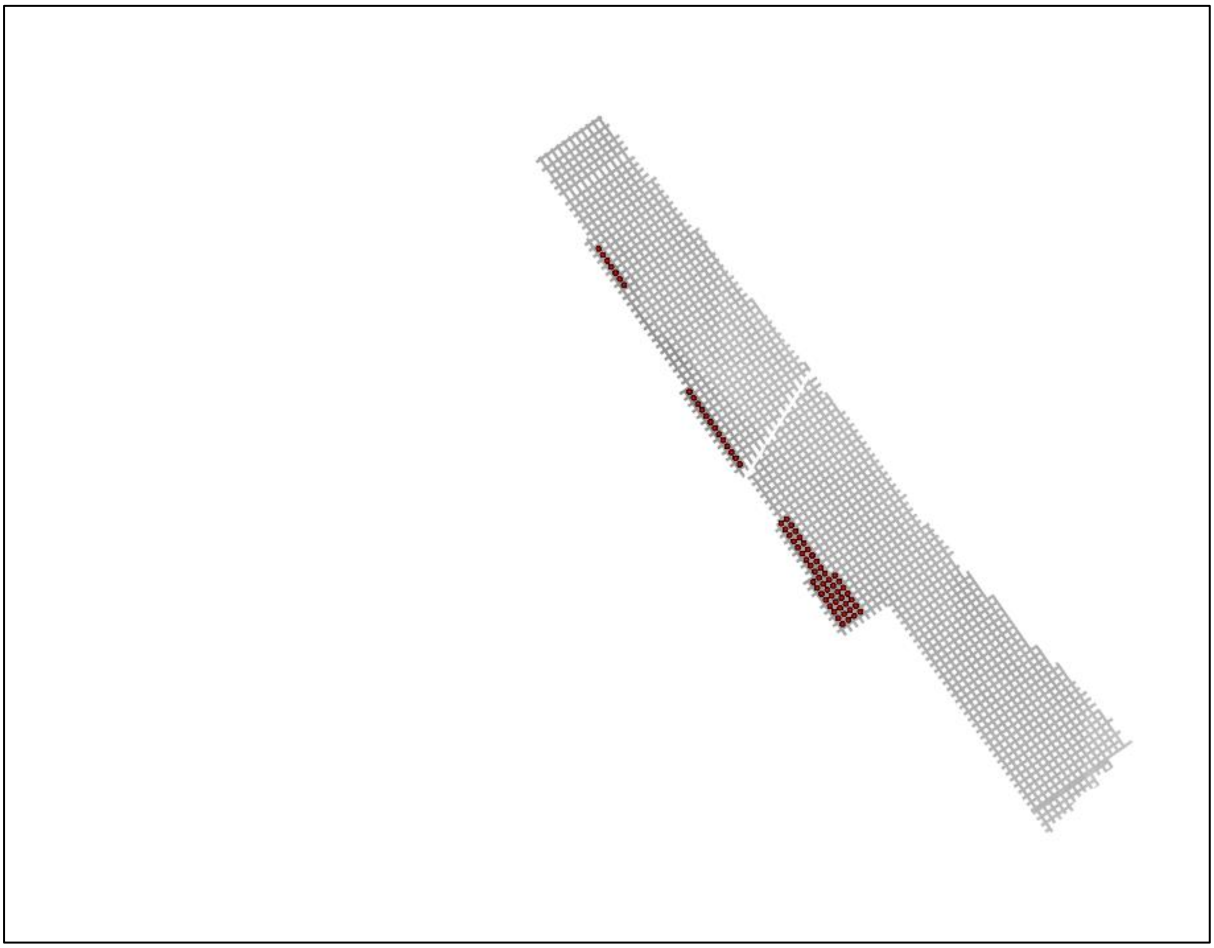


Figure 5-3: Areas < 30.0mbs in the proposed mining area

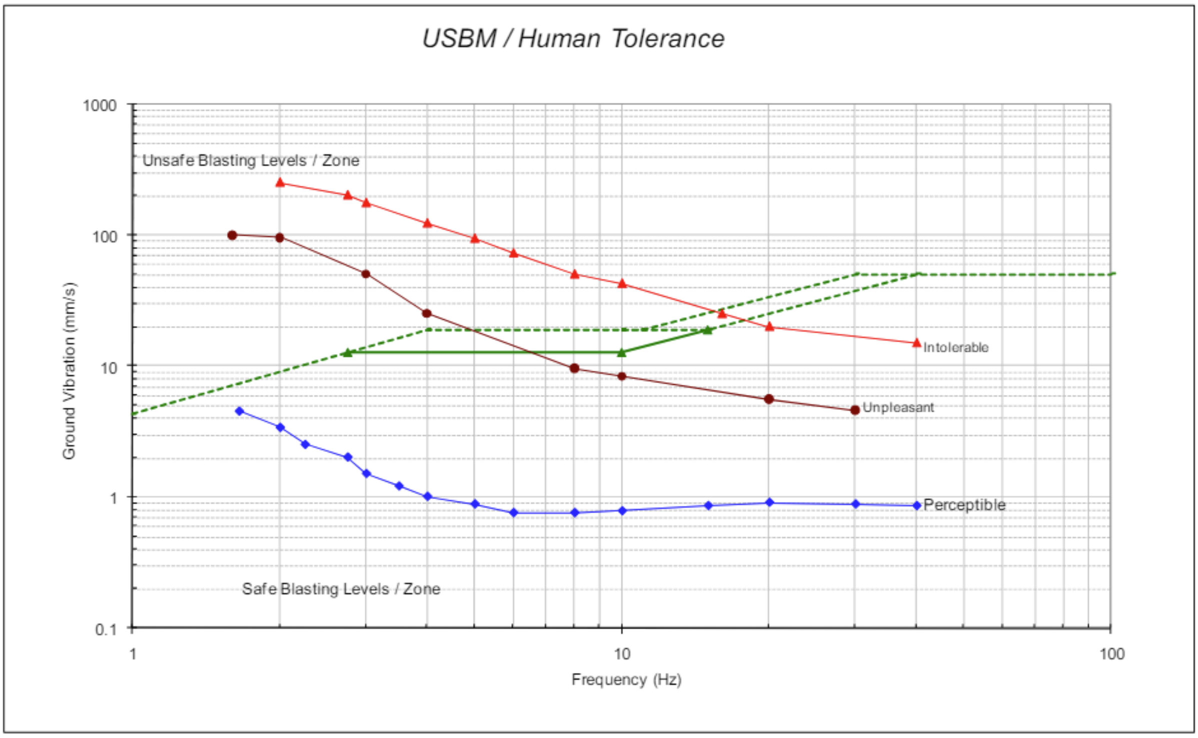


Figure 5-4: USBM criteria for safe blasting considering frequency and ground vibration

5.2 Blast Vibration Monitoring

It is prudent that blast vibration monitoring takes place throughout the project for the following main reasons:

- To calibrate blast vibration data with the empirical and theoretical calculations, and update the design and recommendations where and when required, and
- To assist with any public queries and/or claims that damage to housing or infrastructure is caused by mining activity.

The number of sensors required for the project will rely heavily on the number of isolated sections that are mining. At least one sensor per half level mined (over an area of some 8 panels), located as close as possible, vertically above the mining. Additional sensors will be required at the position of key buildings and infrastructure. These includes:

- The Smelter in Block B,
- The Silo just South of Block B,
- And any sensitive points of interest.

With the knowledge available at the time of this report, it is envisaged that at least 5 sensors will be required, of which at least two will be permanent fixtures, and three mobile units. The specifications of sensors that are to be used should be specified by a blasting engineer, similar to the blast vibration monitoring systems that are installed at other parts of the operations.

6. Support Update

6.1 Methodology

The assumptions made during the desktop study for the Kwezi shaft have been confirmed by recent underground inspections. Inspections revealed excellent hanging wall conditions, with moderate water seepage from support and camera holes in the very shallow areas of the proposed mining area.

In addition to the physical inspections, ground penetrating radar scans were conducted in order to identify any anomalies in the hanging wall of the UG2 stopes that have been exposed close to the study area, to date. During the initial desktop study, the Mine's general support standard and methodology ought to be adequate for the Kwezi shallow area. However, this was updated following the recent study conducted.

6.2 Ground Penetrating Radar Scanning

During the recent underground visit, ground penetrating radar (GPR) scanning was conducted. Ground penetrating radar is a geophysical technique that transmits electromagnetic signals as it is moved along the rock surface. This is done to quantitatively detect, locate and image changes in the electrical properties of the subsurface. Electromagnetic waves are reflected due to factors such as discontinuities in the subsurface. The GPR's sensor is moved along the surface of interest and electromagnetic signals is transmitted into the ground. On condition that the signal strikes an object, part of its energy is reflected back to the sensor while the remaining energy continues to propagate through the subsurface material. The reflected energy is detected by a receiving sensor at the surface. For each transmitted signal, the resultant reflected signal is detected, digitized, and displayed or plotted as a trace.

Scanning was conducted at arbitrary locations close to the area where the shallow mining is planned. Care was taken to include scan areas that were geologically complex, and areas where potholes were prevalent. Figure 6-1 and Figure 6-2 are typical scan results obtained from the Kwezi shallow mining area. Note that the scans start position is located to the bottom-left of the image. The scans can thus be regarded as a vertical section through the bord hanging wall. Red (or warmer) colors in the images represent signal reflections where "warmer" areas represent better, more prominent reflectors. Typical reflectors include contrasting rock types, voids, cracks, joints, fractures or anything that results in a break in the rock. Vertical striations observed in the images are typically caused by noise from losing contact with the hanging wall where the hanging wall is relatively rough, or where pipes or bolts were captured in the scan. Note that where vertical green lines are indicated on the image, markers were made using the SSP to indicate where bolts were in close proximity to the scan.

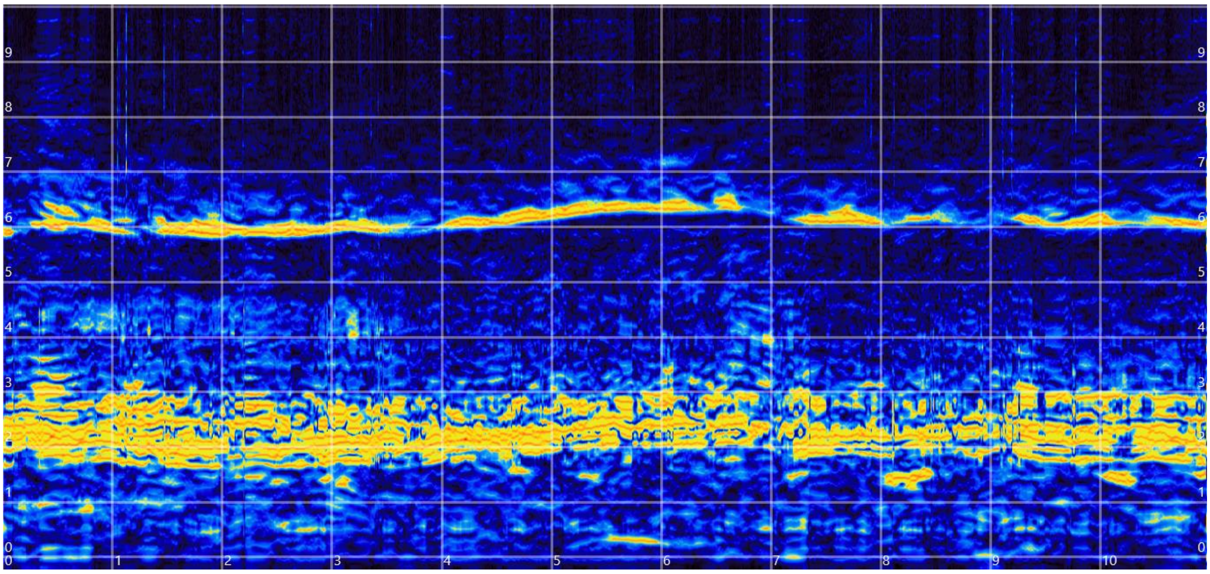


Figure 6-1: Typical scan of the hanging wall of the Kwezi shallows area

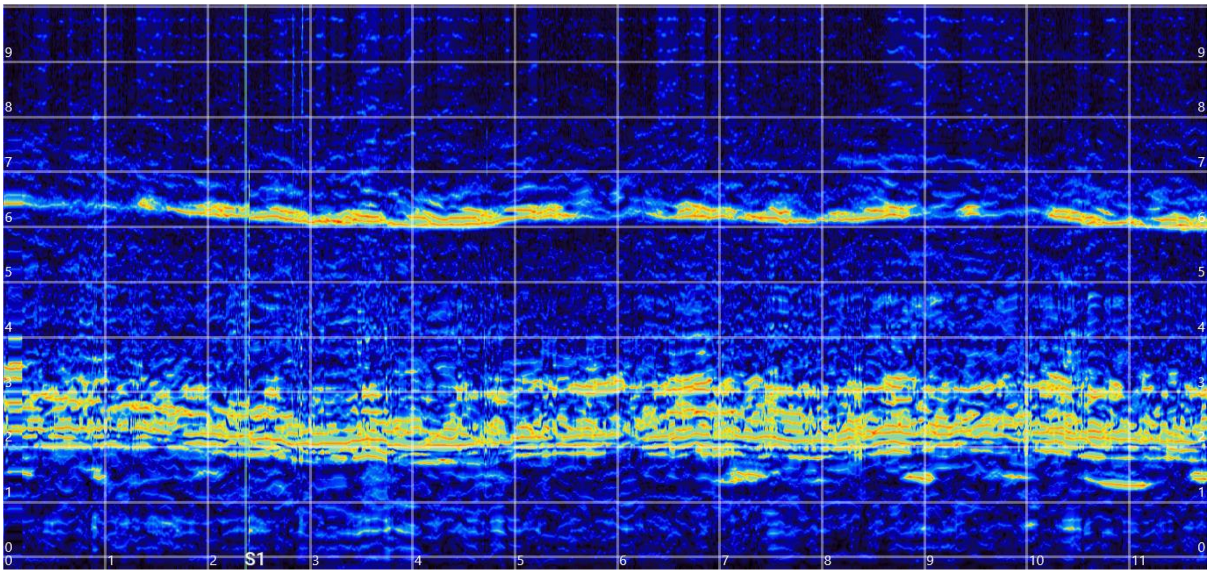


Figure 6-2: Typical scan of the hanging wall of the Kwezi shallows area

From the scans, it is evident that the triplets are observed at a distance of approximately 2.0m. These are characterized by more than one contact observed in the scan, brought about by reflections of the electromagnetic waves between the prominent chrome stringers. A second contact is observed at approximately 6.0m into the hanging wall of the excavation. This contact is thought to be the contact between the Pyroxenite and the Anorthosite. As noted, this contact constitutes a single, sharp contact.

It must be noted that the parting at 2.0m cannot be interpreted as the Leader seam, as the Leader seam is being mined out in the areas under consideration and is thus visible on the sidewalls of the excavations.

6.3 Support Requirements

Although falls of ground up to the 2.0m parting observed in the GPR scans is not prevalent, falls up to the contact have occurred in the section in the past. Weathering of the contact is expected to increase as mining depth decreases and thus the cohesive properties of the contact will in all certainty decrease. In addition to the increased weathering expected on the 2.0m contact, clamping forces in the hanging wall of the excavation is expected to decrease as mining commence shallower.

Thus, in addition to the typical support layout and ground control district of Kwezi shaft (Figure 6-3 and Figure 6-4), support will need to cater for the 2.0m contact until such time that a suitable monitoring strategy has been devised to actively monitor the contact as mining progresses. Thus, a strategy similar to the GCD A strategy for the Kroondal operations is envisaged.

No.	GCD Name	GCD description
1.	**GCD A**	Poor rock mass rating (RMR < 40, low angle features, prominent vertical features, water)
2.	**GCD B**	Transition zones from GCD A
3.	**GCD C**	Good ground conditions (RMR > 61)
4.	**GCD D**	Major fault zones e.g. Townlands fault
5.	**GCD E**	Good ground conditions (RMR > 61), single seam mining, leader seam > 1.3m above main seam
6.	**GCD F**	Good ground conditions (RMR > 61), dual seam mining, leader seam < 1.3m above main seam
7.	**GCD G**	Fair ground conditions (RMR 40 - 60), water influx (aquifer on triplets horizon), dual seam mining, leader <1.3
8.	**GCD H**	Poor ground conditions (RMR < 40), prominent low angle geological features, rolling reef, dual seam mining, leader <1.3

Figure 6-3: Ground Control District for Kwezi shaft as per the mine's COP

GCD	Span	Support (Kroondal Operations)	Support (Rustenburg Central Operations)
A	6m	3.0m anchors on 1.5m x 1.5m pattern	3.0m bolts on 1.5m x 1.5m pattern
B	6m -8m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
C	8m -10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
D	6m	Special area. Site specific support instructions	Special area. Site specific support instructions
E	10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
F	10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
G	10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
H	6m	1.5m bolts on 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern

Figure 6-4: Support requirements for Kwezi shaft as per the Mine's COP

7. Impact Assessment

Based on the outcome of the vibration, blast and stability assessments, an impact assessment was conducted. The impact assessment classifies the various risks according to their perceived environmental significance and assesses each risk pre- and post- the introduction of certain controls. The environmental significance is denoted by a numerical number that ranges between < 40 for low significance, to 150 for very high significance.

The description for each of the six environmental significance classes is depicted in Figure 7-1.

Significance Score	Environmental Significance	Description / criteria
125 – 150	Very high (VH)	An impact of very high significance will mean that the project cannot proceed, and that impacts are irreversible, regardless of available mitigation options.
100 – 124	High (H)	An impact of high significance which could influence a decision about whether or not to proceed with the proposed project, regardless of available mitigation options.
75 – 99	Medium-high (MH)	If left unmanaged, an impact of medium-high significance could influence a decision about whether or not to proceed with a proposed project. Mitigation options should be relooked at.
40 – 74	Medium (M)	If left unmanaged, an impact of moderate significance could influence a decision about whether or not to proceed with a proposed project.
<40	Low (L)	An impact of low is likely to contribute to positive decisions about whether or not to proceed with the project. It will have little real effect and is unlikely to have an influence on project design or alternative motivation.
+	Positive impact (+)	A positive impact is likely to result in a positive consequence/effect and is likely to contribute to positive decisions about whether or not to proceed with the project.

Figure 7-1: Environmental significance classes and descriptions.

In order to derive an environmental significance score, a number of evaluation components are assessed. Each environmental component, along with its associated rating, scale and description, is depicted in Figure 7-2. The outcome of the impact assessment, for the major risks identified, is tabulated in Table 7-1.

Evaluation Component	Rating	Scale	Description / criteria
MAGNITUDE of negative impact (at the indicated spatial scale)	**10**	**Very high**	Bio-physical and/or social functions and/or processes might be *severely* altered.
	8	**High**	Bio-physical and/or social functions and/or processes might be *considerably* altered.
	6	**Medium**	Bio-physical and/or social functions and/or processes might be *notably* altered.
	4	**Low**	Bio-physical and/or social functions and/or processes might be *slightly* altered.
	2	**Very low**	Bio-physical and/or social functions and/or processes might be *negligibly* altered.
	0	**Zero**	Bio-physical and/or social functions and/or processes will remain *unaltered.*
MAGNITUDE of POSITIVE IMPACT (at the indicated spatial scale)	**10**	**Very high**	Positive: Bio-physical and/or social functions and/or processes might be *substantially* enhanced.
	8	**High**	**Positive**: Bio-physical and/or social functions and/or processes might be *considerably* enhanced.
	6	**Medium**	**Positive**: Bio-physical and/or social functions and/or processes might be *notably* enhanced.
	4	**Low**	**Positive**: Bio-physical and/or social functions and/or processes might be *slightly* enhanced.
	2	**Very low**	**Positive**: Bio-physical and/or social functions and/or processes might be *negligibly* enhanced.
	0	**Zero**	**Positive**: Bio-physical and/or social functions and/or processes will remain *unaltered.*
DURATION	**5**	**Permanent**	**Impact in perpetuity. –**
	4	**Long term**	Impact ceases after operational phase/life of the activity > 60 years.
	3	**Medium term**	Impact might occur during the operational phase/life of the activity – 60 years.
	2	**Short term**	Impact might occur during the construction phase - < 3 years.
	1	**Immediate**	**Instant impact.**
EXTENT (or spatial scale/influence of impact)	**5**	**International**	**Beyond the National boundaries.**
	4	**National**	Beyond provincial boundaries, but within National boundaries.
	3	**Regional**	Beyond 5 km of the mine area and within the provincial boundaries.
	2	**Local**	Within a 5 km radius of the mine area.
	1	**Site-specific**	**On site or within 100 meters of the site boundaries.**
	0	**None**	**Zero extent.**
IRREPLACEABLE loss of resources	**5**	**Definite**	**Definite** loss of irreplaceable resources.
	4	**High potential**	**High** potential for loss of irreplaceable resources.
	3	**Moderate potential**	**Moderate** potential for loss of irreplaceable resources.
	2	**Low potential**	**Low** potential for loss of irreplaceable resources.
	1	**Very low potential**	**Very low** potential for loss of irreplaceable resources.
	0	**None**	**Zero potential.**
REVERSIBILITY of impact	**5**	**Irreversible**	Impact **cannot** be reversed.
	4	**Low irreversibility**	**Low** potential that impact might be reversed.
	3	**Moderate reversibility**	**Moderate** potential that impact might be reversed.
	2	**High reversibility**	**High** potential that impact might be reversed.
	1	**Reversible**	Impact **will be** reversible.
	0	**No impact**	No impact.
PROBABILITY (of occurrence)	**5**	**Definite**	>95% chance of the potential impact occurring.
	4	**High probability**	75% - 95% chance of the potential impact occurring.
	3	**Medium probability**	25% - 75% chance of the potential impact occurring
	2	**Low probability**	5% - 25% chance of the potential impact occurring.
	1	**Improbable**	<5% chance of the potential impact occurring.
	0	**No probability**	**Zero probability.**

Evaluation Component	Rating scale and description / criteria
CUMULATIVE impacts	**High**: The activity is one of several similar past, present or future activities in the same geographical area, and might contribute to a very significant combined impact on the natural, cultural, and/or socio-economic resources of local, regional or national concern. ***Medium:*** The activity is one of a few similar past, present or future activities in the same geographical area, and might have a combined impact of moderate significance on the natural, cultural, and/or socio-economic resources of local, regional or national concern. ***Low:*** The activity is localised and might have a negligible cumulative impact. ***None:*** No cumulative impact on the environment.

Figure 7-2: Environmental significance evaluation components.

Table 7-1: Environmental significance evaluation

DEVELOPMENT PHASE	POTENTIAL ENVIRONMENTAL IMPACT	ACTIVITY	ENVIRONMENTAL SIGNIFICANCE BEFORE MITIGATION								CUMULATIVE	STATUS	RECOMMENDED MITIGATION MEASURES / REMARKS	ENVIRONMENTAL SIGNIFICANCE AFTER MITIGATION							
			M	D	S	I	R	P	TOTAL	SS				M	D	S	I	R	P	TOTAL	SS
Operational Phase	Potential ground water impacts due to surface subsidence.	Underground Mining	6	3	2	2	3	1	16		Low	Negative	Follow recommended pillar geometry and mining span guidelines Follow recommended support guidelines Continuous vibration and surface subsidence monitoring	6	3	2	2	3	1	16	
Operational Phase	Potential surface erosion impacts due to surface subsidence.	Underground Mining	6	3	2	2	3	1	16		Low	Negative	Follow recommended pillar geometry and mining span guidelines Follow recommended support guidelines Continuous vibration and surface subsidence monitoring	6	3	2	2	3	1	16	
Operational Phase	Potential disturbing and/or damaging ground vibrations.	Underground Mining	4	2	2	2	2	4	48		Medium	Negative	Follow recommended maximum face advance, and explosive volume limits Conduct vibration monitoring when blasting commence in order to verify assumptions made during blast design	4	2	2	2	2	1	12	

From the impact assessment, it should be noted that all major geotechnical aspects related to vibration, blast and stability under consideration fall within the "Low" risk category following the implementation of adequate controls.

8. Project Conclusions

In addition to the updated conclusions resulting from this report, the original conclusions pertaining to this project are also included. This section thus summarizes the conclusions of the combined assessment:

8.1 Underground Inspections

The intact rock appears less weathered than typically expected for the depth under consideration, when compared to experience in Bushveld rocks in the Eastern Bushveld. It is believed that this may be a result of the thick clay (weathered Norites) that typically overlies the Bushveld rock in the Western Bushveld (this topic will be further discussed on the core observations). Weathering associated with particular joint sets is, however, present.

Horizontal contacts are expected to be better developed as one mine closer to surface. This results in pillars being less forgiving when overmined, or when major geological structures traverse them. In addition, weathered hanging wall parallel contacts will be less stable owing to the anticipated weathering.

8.2 Stable Spans

Empirical assessments recommend stable spans of between 5m and 12m. However, considering water, and unsupported stand-up times results in a maximum panel span of 6.0m. The proposed 6.0m span as submitted for investigation is thus adequate.

8.3 Stable Pillars

Although historic industry guidelines suggest pillars with width to height ratios of > 5 be employed, these were based on stoping widths of typically 1m, and conventional stopes. More recent suggestions in the Bushveld Complex suggest that pillars with width to height ratios > 3 is deemed acceptable for bord and pillar mines.

Thus, the proposed 8m wide pillars in the project areas yield width to height ratios > 3, with sufficient margin for overmining, both in terms of pillars, and stoping width. Factors of safety attained for 8m pillars are > 6.6 at a depth of 80.0m increasing to some 14 at a depth of < 40.0m below surface as confirmed by numerical modelling.

8.4 Blast Vibration and Monitoring

Face advances of > 3.0m at depth shallower than 37.0m yields ground vibrations on surface that exceeds the 6mm/sec limit. For 2.0m advances, this limiting criteria is exceeded at a depth of ~30.0m below surface. If advances per blast are kept < 3.0m at depths deeper than 50.0m, and advances are kept < 2.0m at depths up to 30.0m, blast vibrations will not exceed the 6mm/sec limit.

With the knowledge available at the time of this report, it is envisaged that at least 5 sensors will be required, of which at least two will be permanent fixtures, and three mobile units. The specifications of sensors that are to be used should be specified by a blasting engineer, similar to the blast vibration monitoring systems that are installed at other parts of the operations.

8.5 Support

GPR scans concluded that a hangingwall parting exists at 2.0m into the hanging wall. This parting is in all likelihood, the triplets. Given the observations of moderate water inflow from support and camera holes, this contact is likely weathered, and will need to be catered for by support. Typically, this would require the installation of long support tendons replicating a typical GCD A area.

8.6 Subsidence

3D finite element modelling indicated that the expected elastic surface subsidence expected on surface as a result of mining is < 1mm in the shallowest parts (modelled at < 25m below surface) of the project area.

9. Project Recommendations

The following recommendations are made for consideration considering the available information and assessment:

- The proposed mine geometry is fit for purpose, with the following adjustments required:
    - Update the mine plan to exclude any mining < 30.0mbs as a minimum.
    - Limit advance per blast to 3.0m up to a minimum depth below surface of 50.0m (considering a factor of safety of around 1.4).
    - Limit advance per blast to a maximum of 2.0m between 30.0mbs and 50.0ms.

- Ensure that primary support caters for a fall-out thickness equal to the distance up to the triplets (established to be 2.0m in the area of interest) plus an additional length to cater for adequate anchorage into the solid rock.
- Ensure that a monitoring and instrumentation program is developed that is specific to the shallow mining area that considers at least:
  - The condition of the hanging wall parallel contacts.
  - Increase or decrease of water flow/presence.
  - Rock mass conditions, and suitability of support to cater for conditions.
  - Ground vibration (including frequencies) and air-blast.
  - High resolution monitoring of surface deformation for comparison to expected vertical displacement.

Appendix A: Kwezi Shallows Execution_Updated_rev1.pdf

Kwezi Shallows Execution_Updated_re

Appendix B: QLG SP KW1 Kroondal West Shallow Mining Rev1.0 .pdf

QLG_SP_KW1_Kroondal_West_Shallow_Minir

Appendix C: Author and Reviewer CV

CV_Koos Bosman_2023.pdf

CV_Quintin Grix_2023.pdf

Sibanye-Stillwater Shallows Project Kwezi Shaft

Revision 1.1

2024-07-29

Content

- Pillar Design Confirmation
- Worst-Case Subsidence (Theoretical Maximum Subsidence)
- Expected Elastic Subsidence
- Maximum Expected PPV’s and PPV Limitations
- Support Requirements
- Conclusions

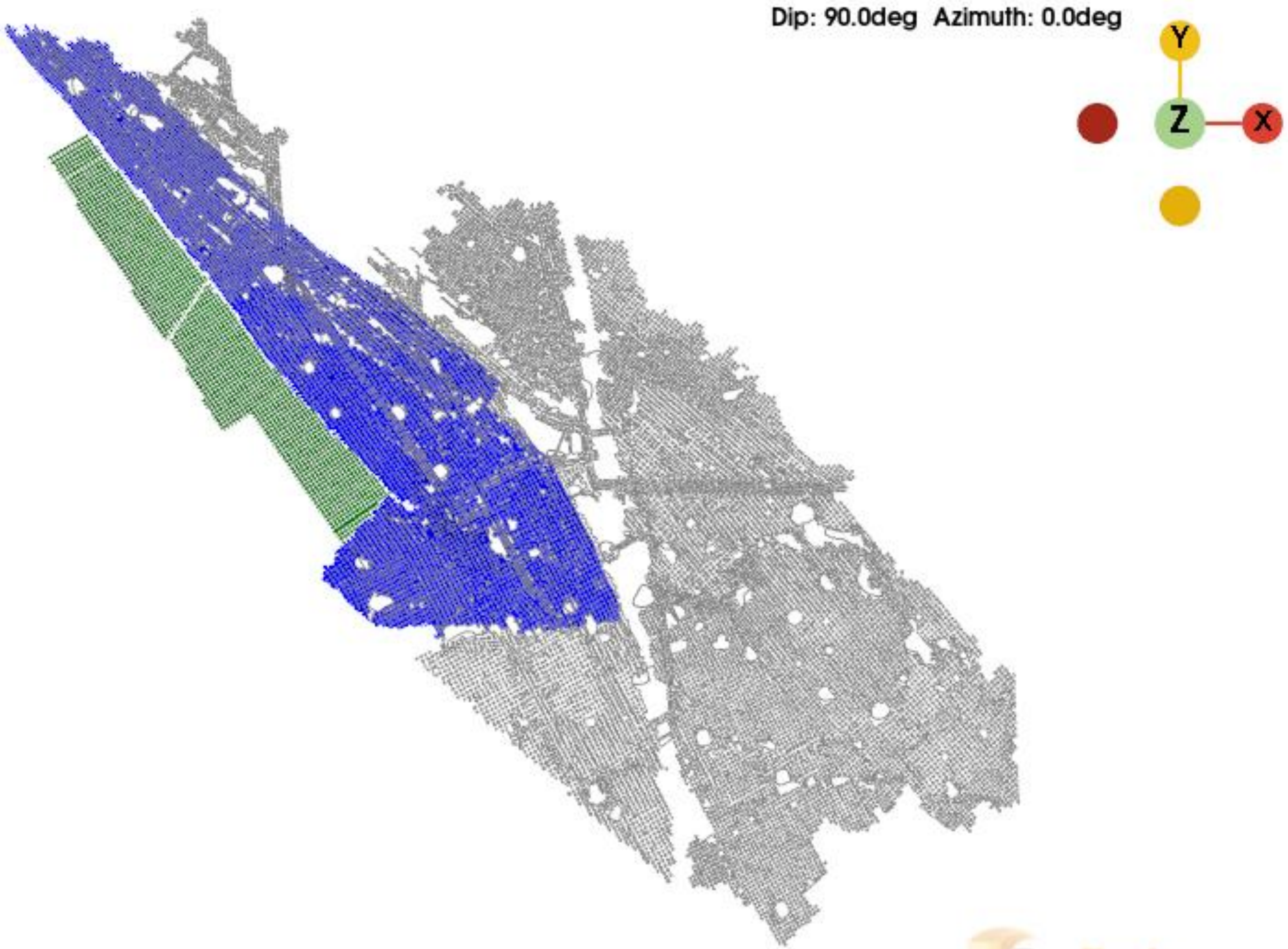
Pillar Design Confirmation

Methodology

- 3D Numerical model constructed of As-Mined & Planned mining
- Surface topography included in numerical model
- Constant mining height of 2.1m applied throughout
- Different pillar material strengths applied for different mining depths
- Pillar strengths calculated based on Hedley & Grant methodology
- Average pillar stresses obtained from 3D numerical model

Model Geometry

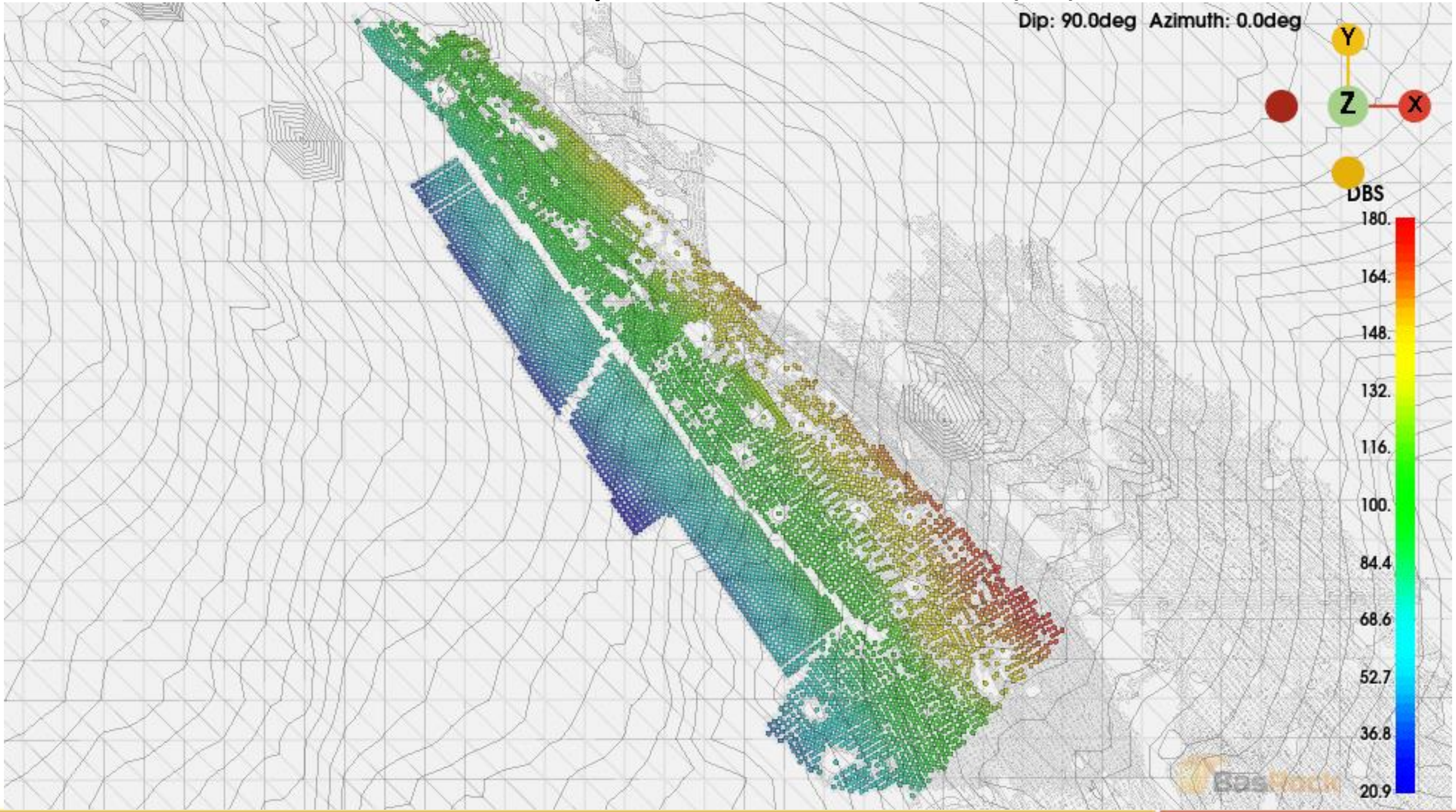
As-mined
Modelled As-mined
Planned



BasRock OHMS

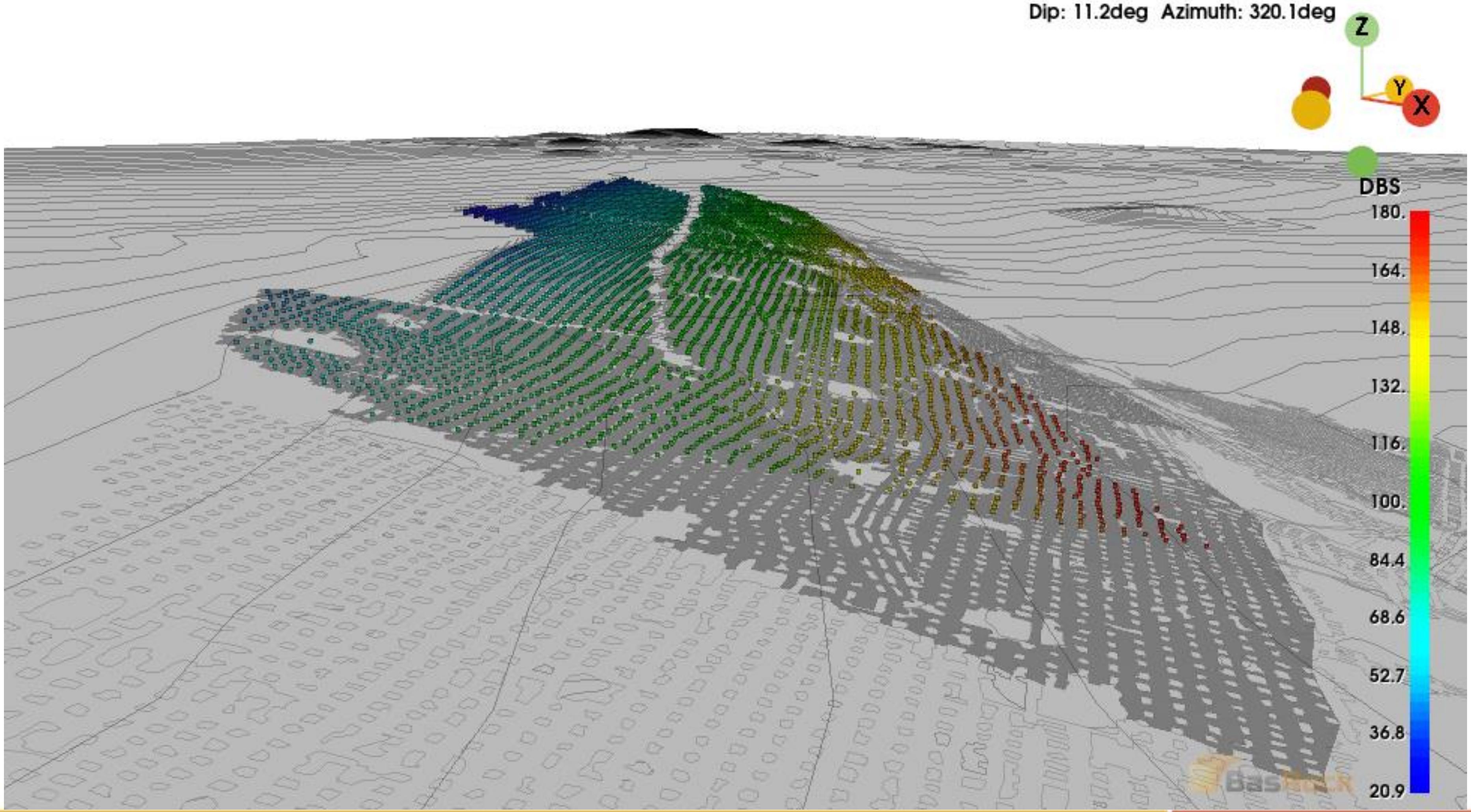
Model Geometry

Depth Below Surface (m)



Model Geometry

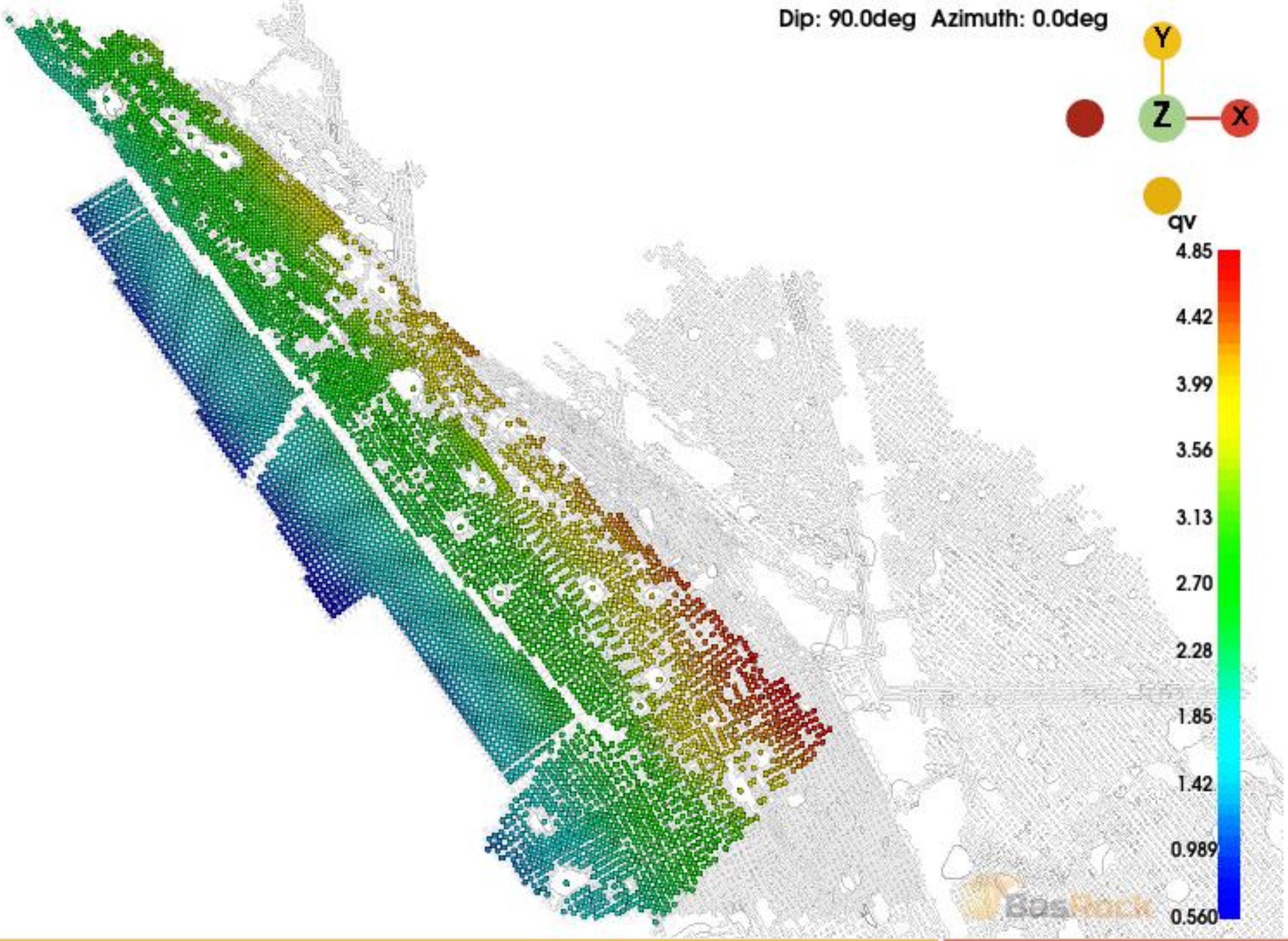
Depth Below Surface (m)



OHMS

Model Results

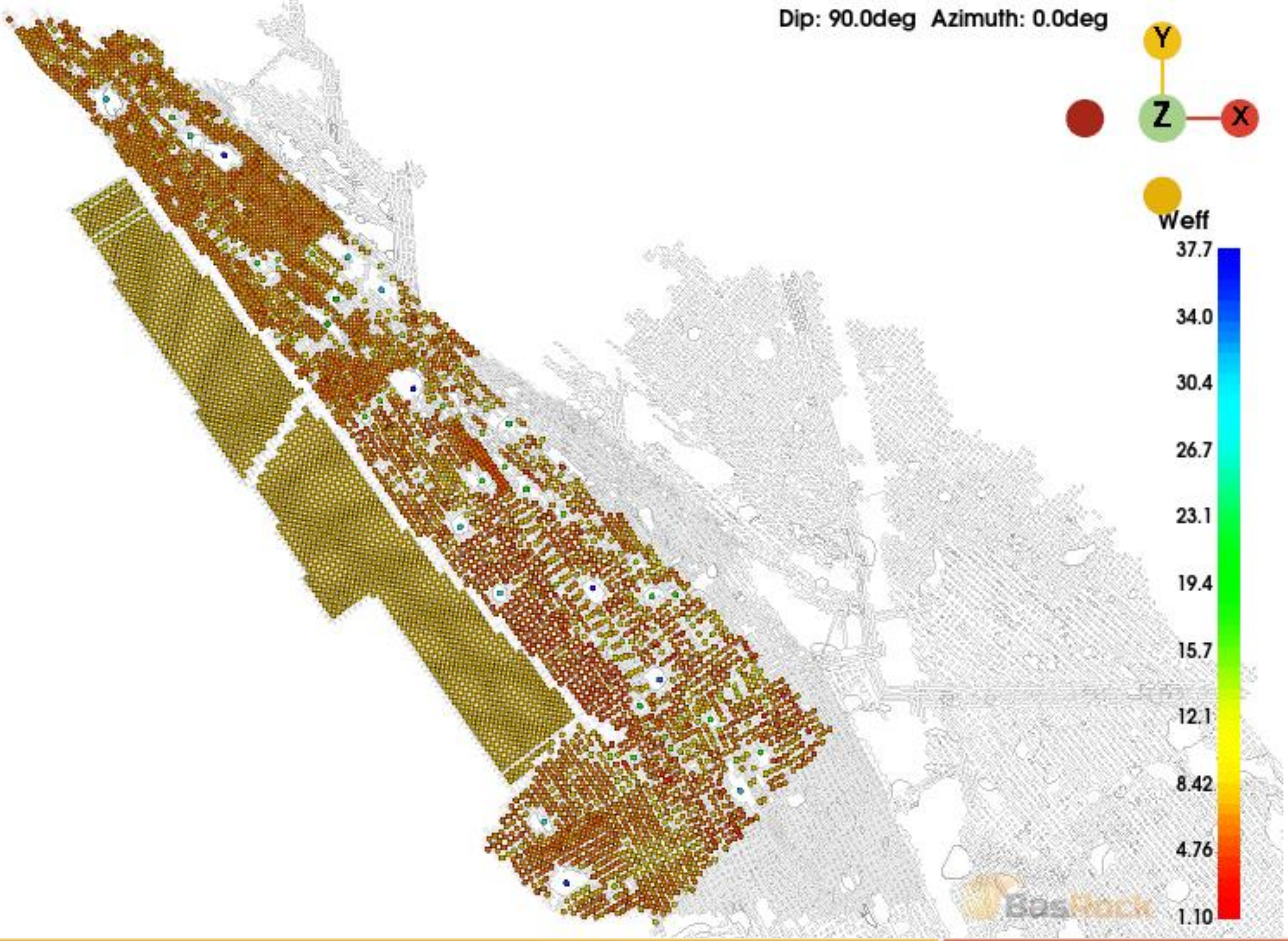
Pre-mining Stress (MPa)



OHMS
Ω β ε Δ Ø λ σ

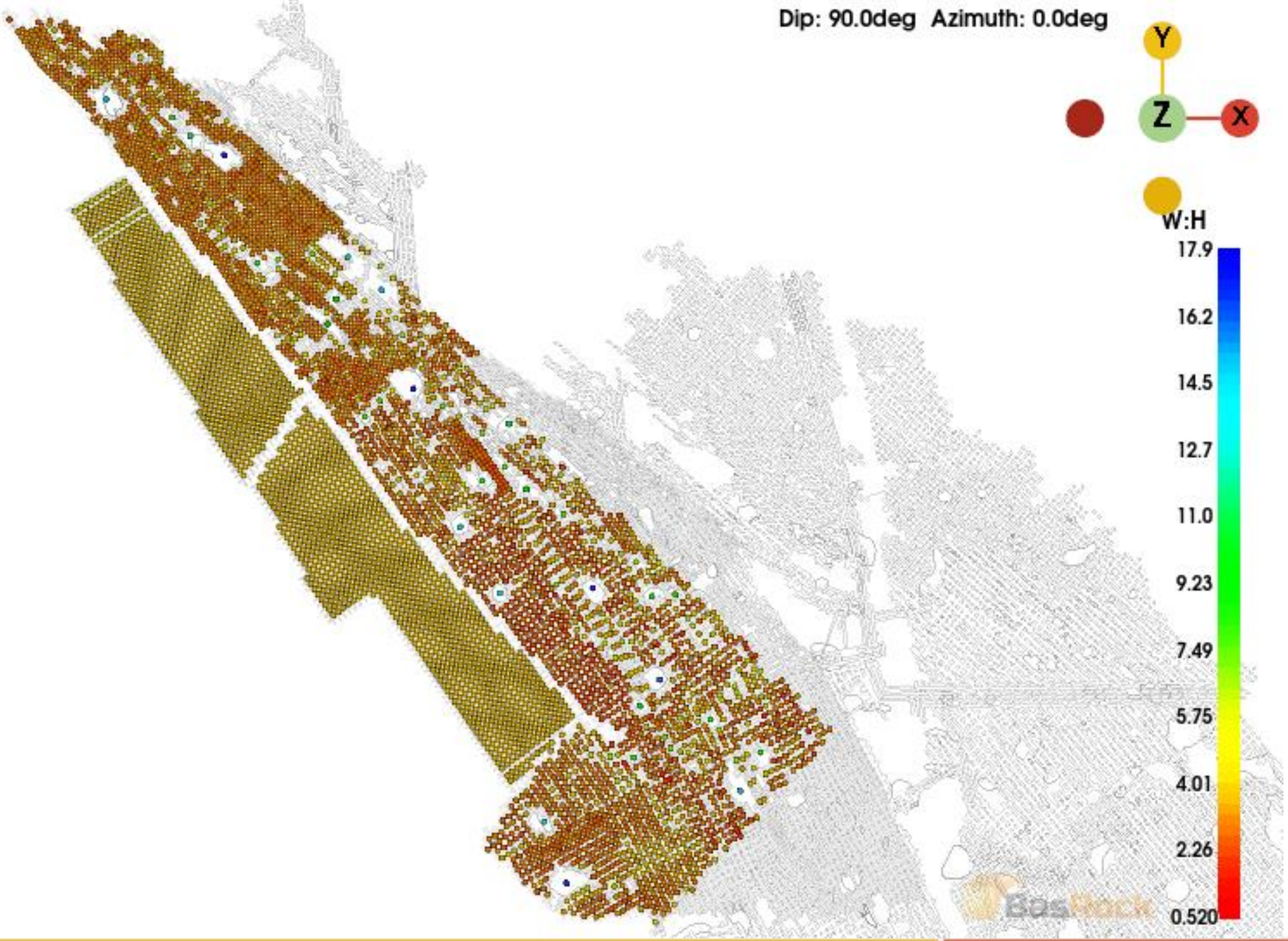
Model Results

Pillar Effective Width(m)



Model Results

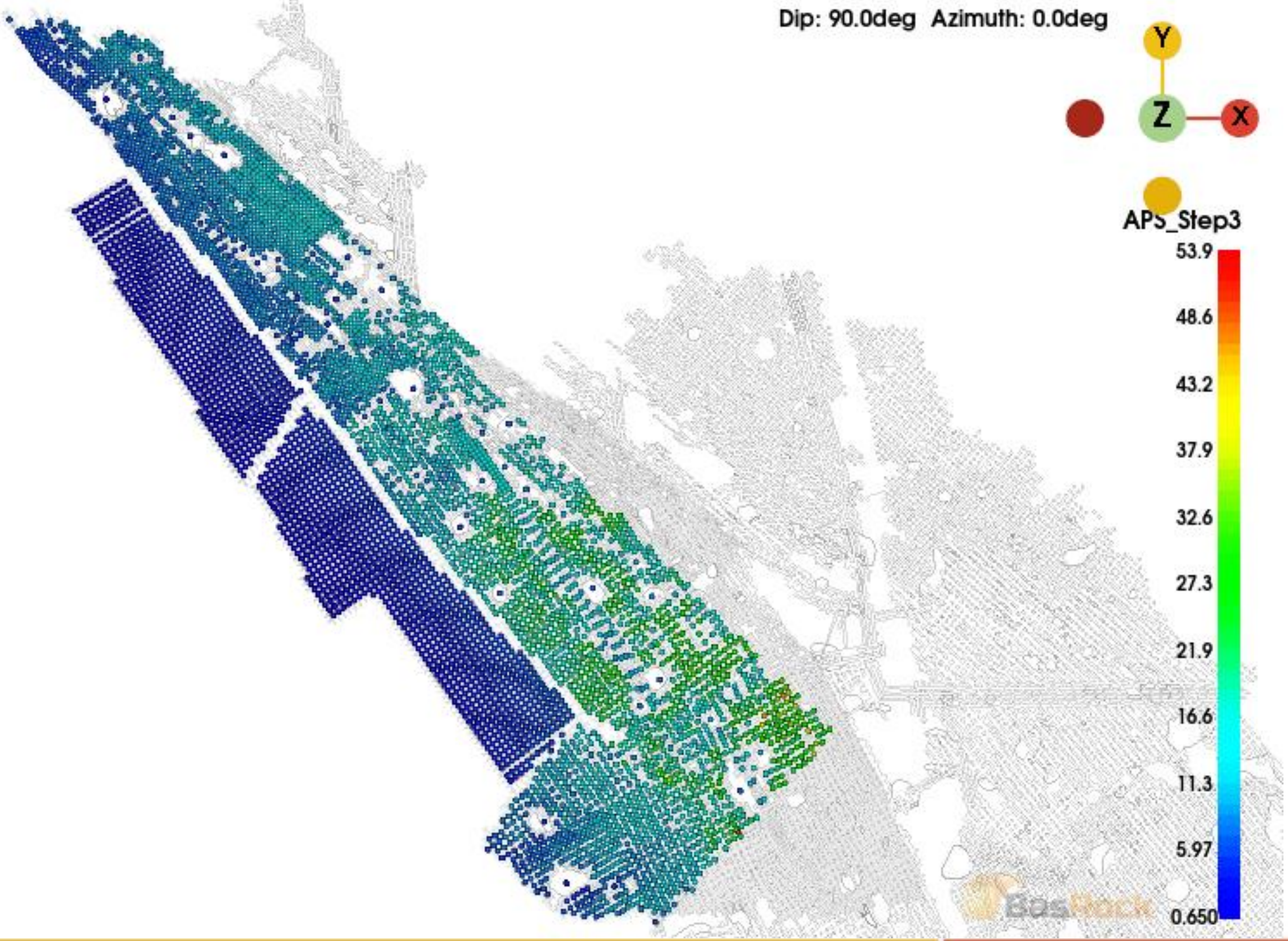
Pillar Width-to-Height Ratio



OHMS

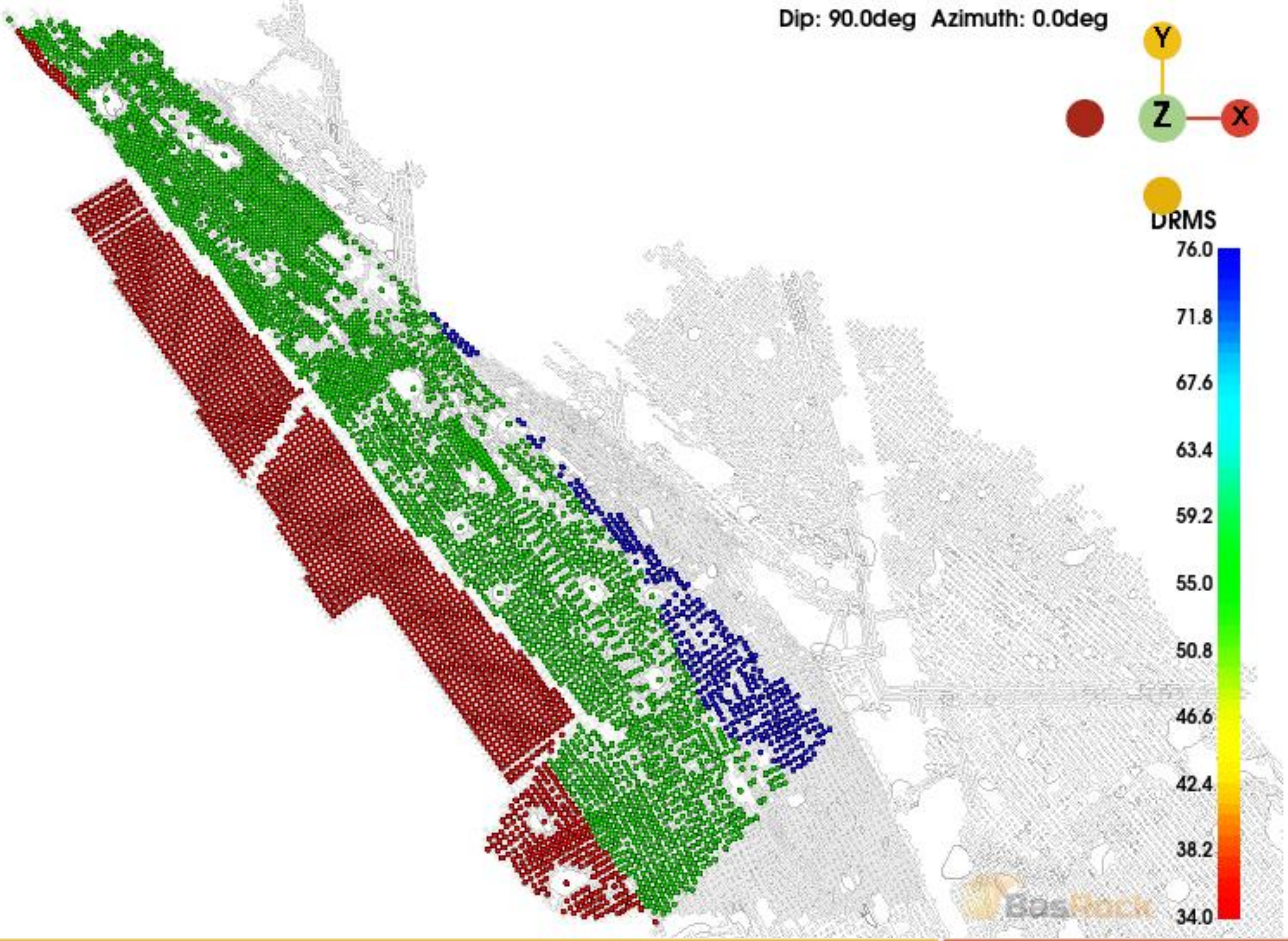
Model Results

Modelled Average Pillar Stress (MPa)



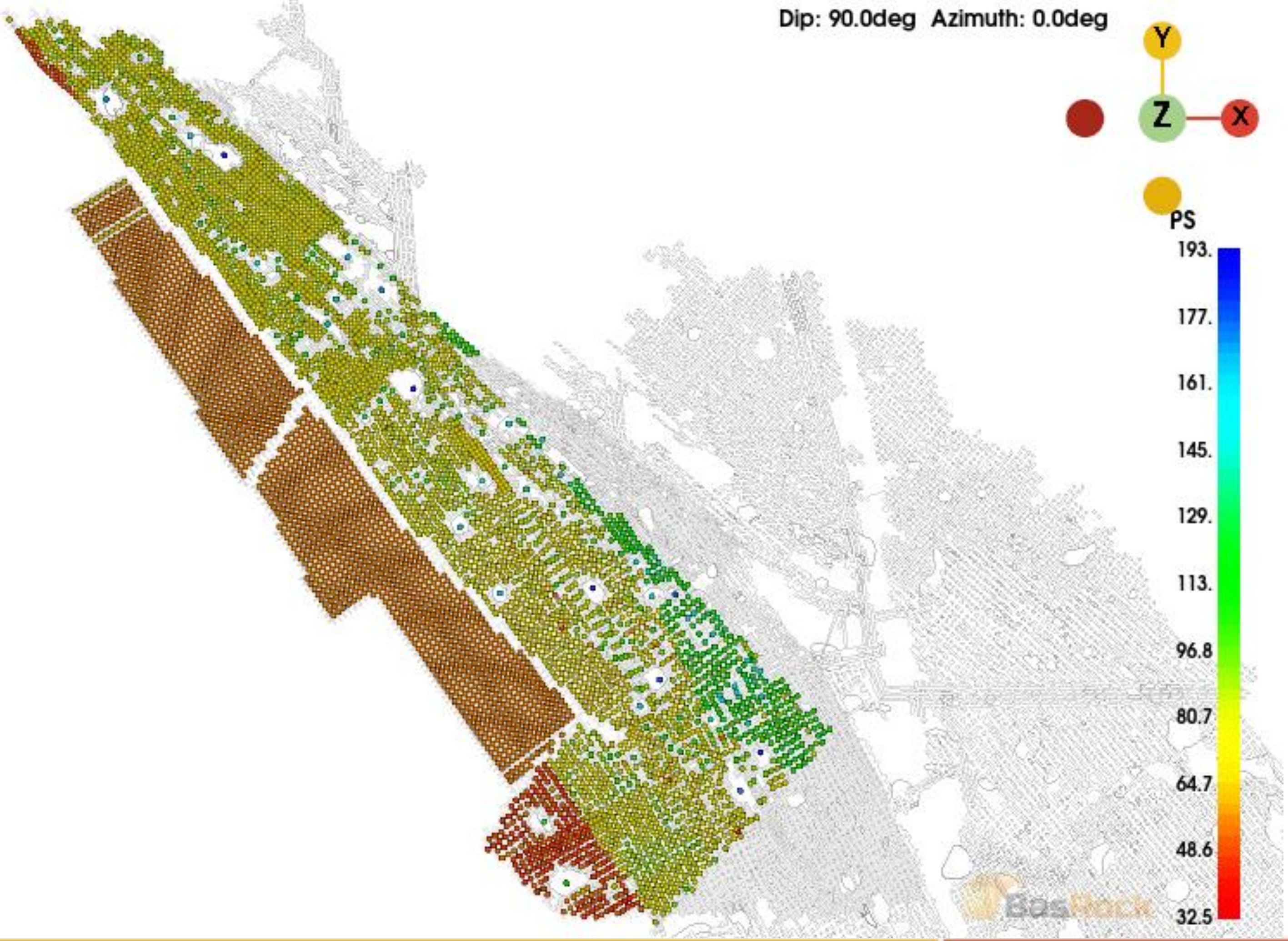
Model Results

Design Rock Mass Strength (DRMS)



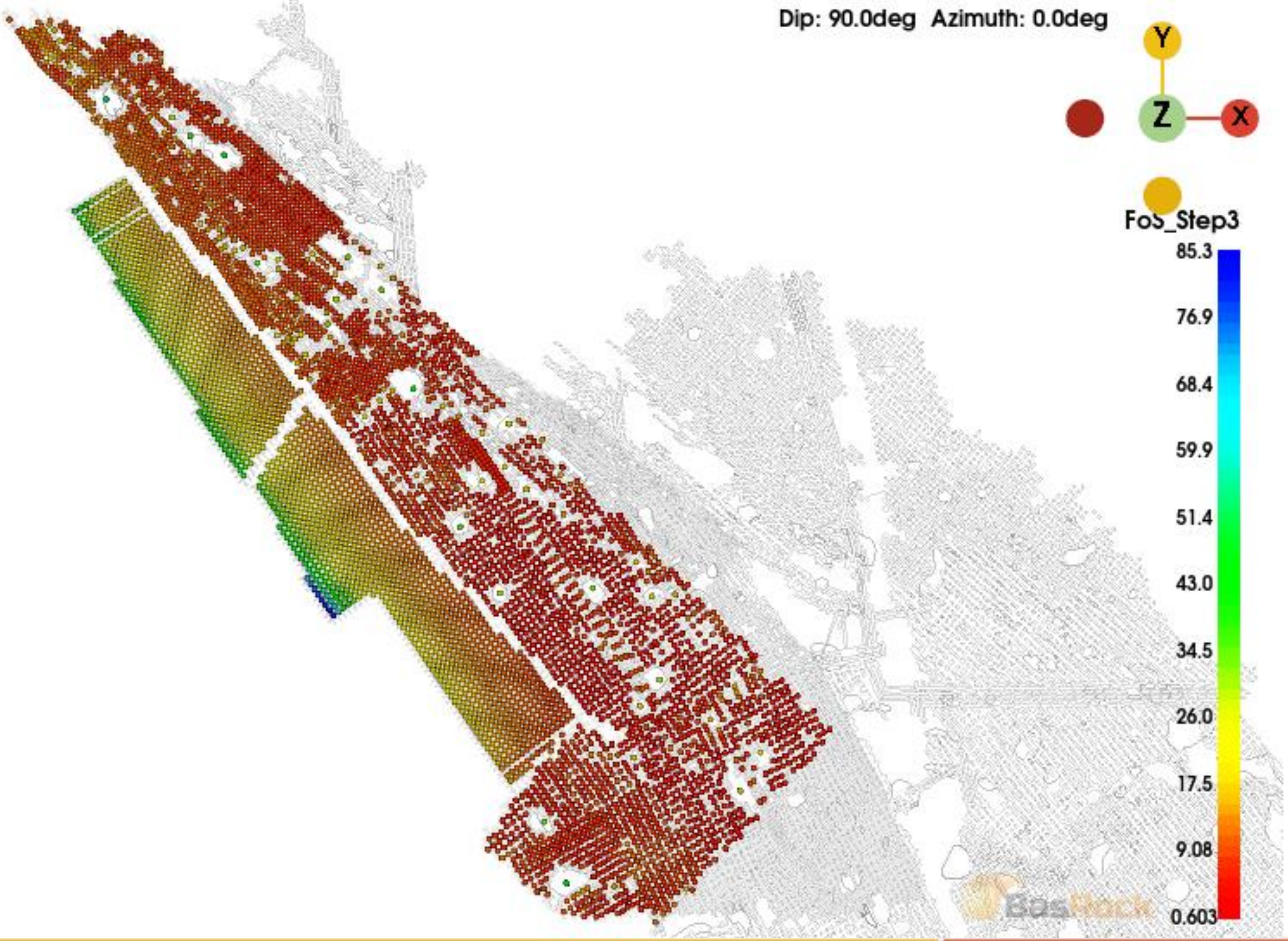
Model Results

Pillar Strength (MPa)



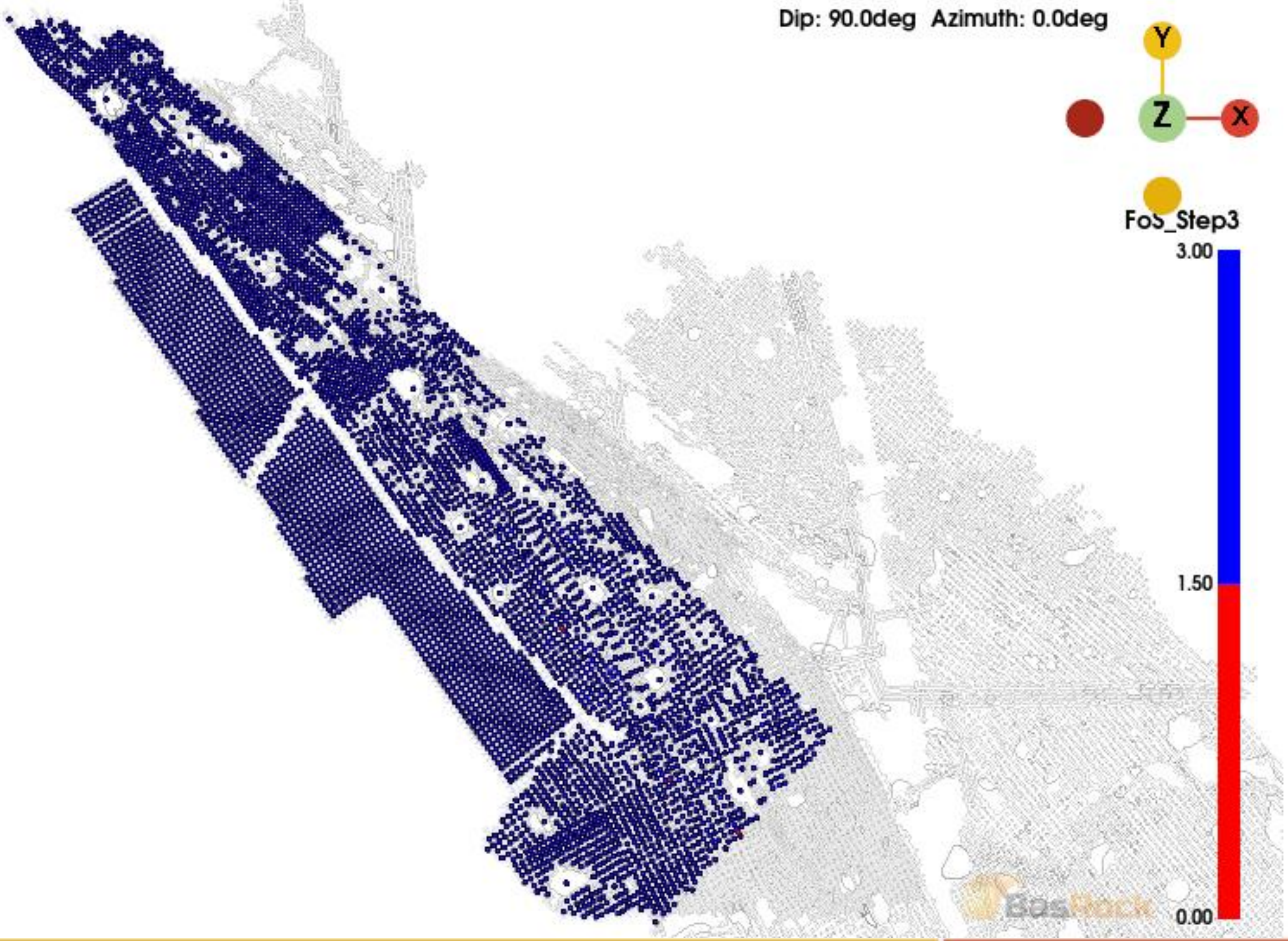
Model Results

Modelled Factor of Safety (FoS)



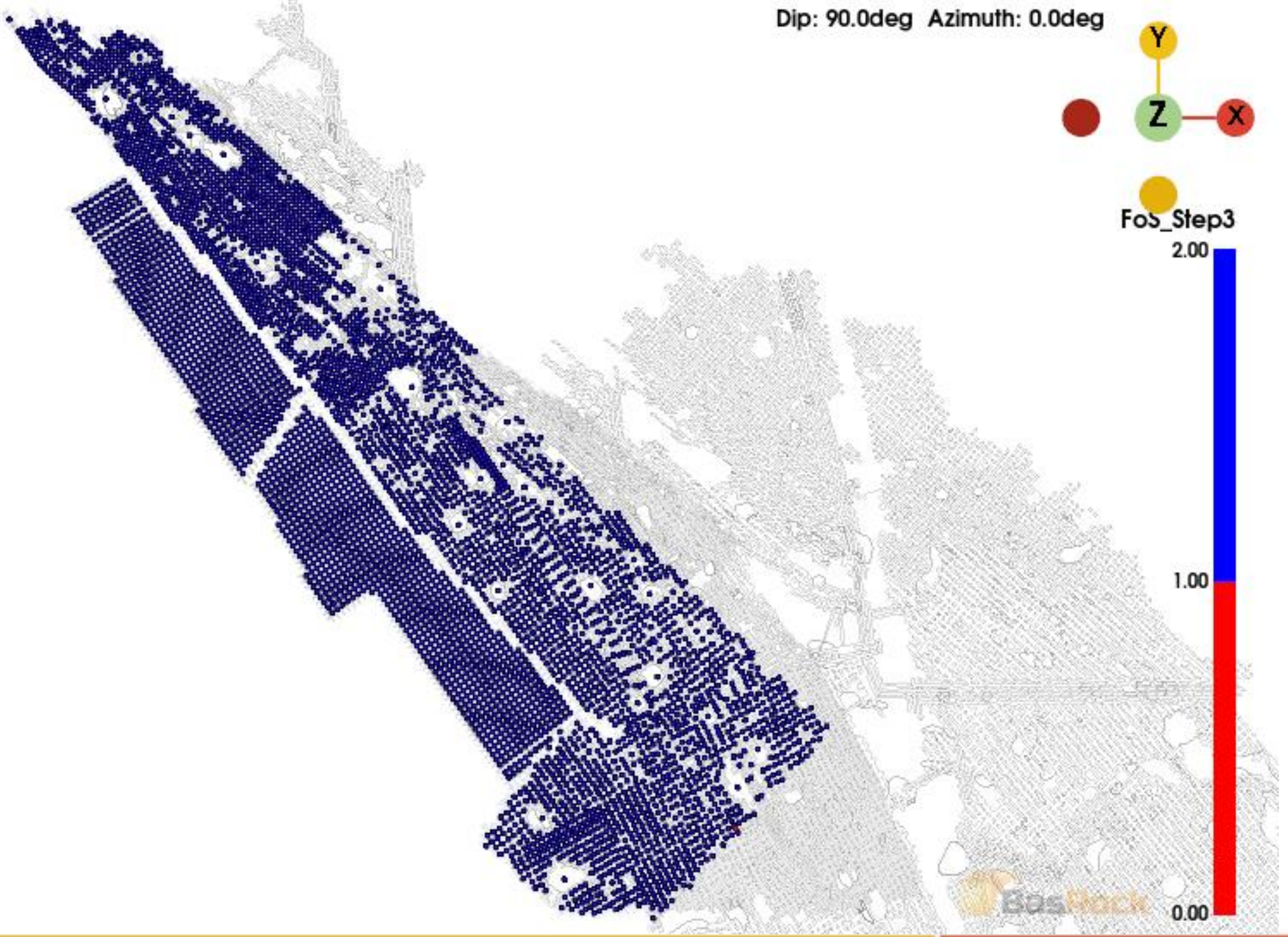
Model Results

Factor of Safety (FoS < 1.5)

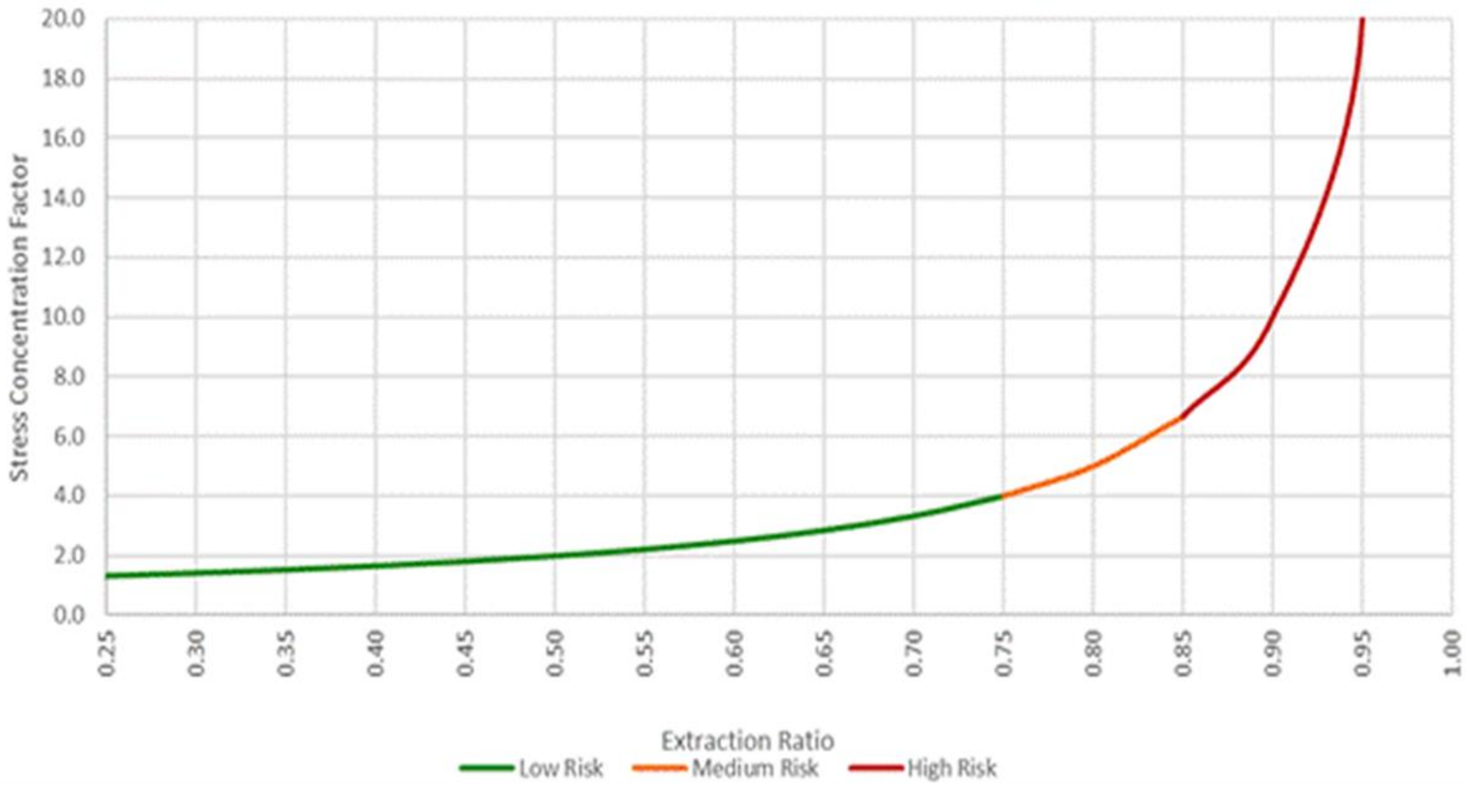


Model Results

Factor of Safety (FoS < 1.0)



Pillar Risk Based on Extraction Ratio



e < 0.75 = Low Risk 0.75 < e < 0.85 = Medium Risk e > 0.85 High Risk

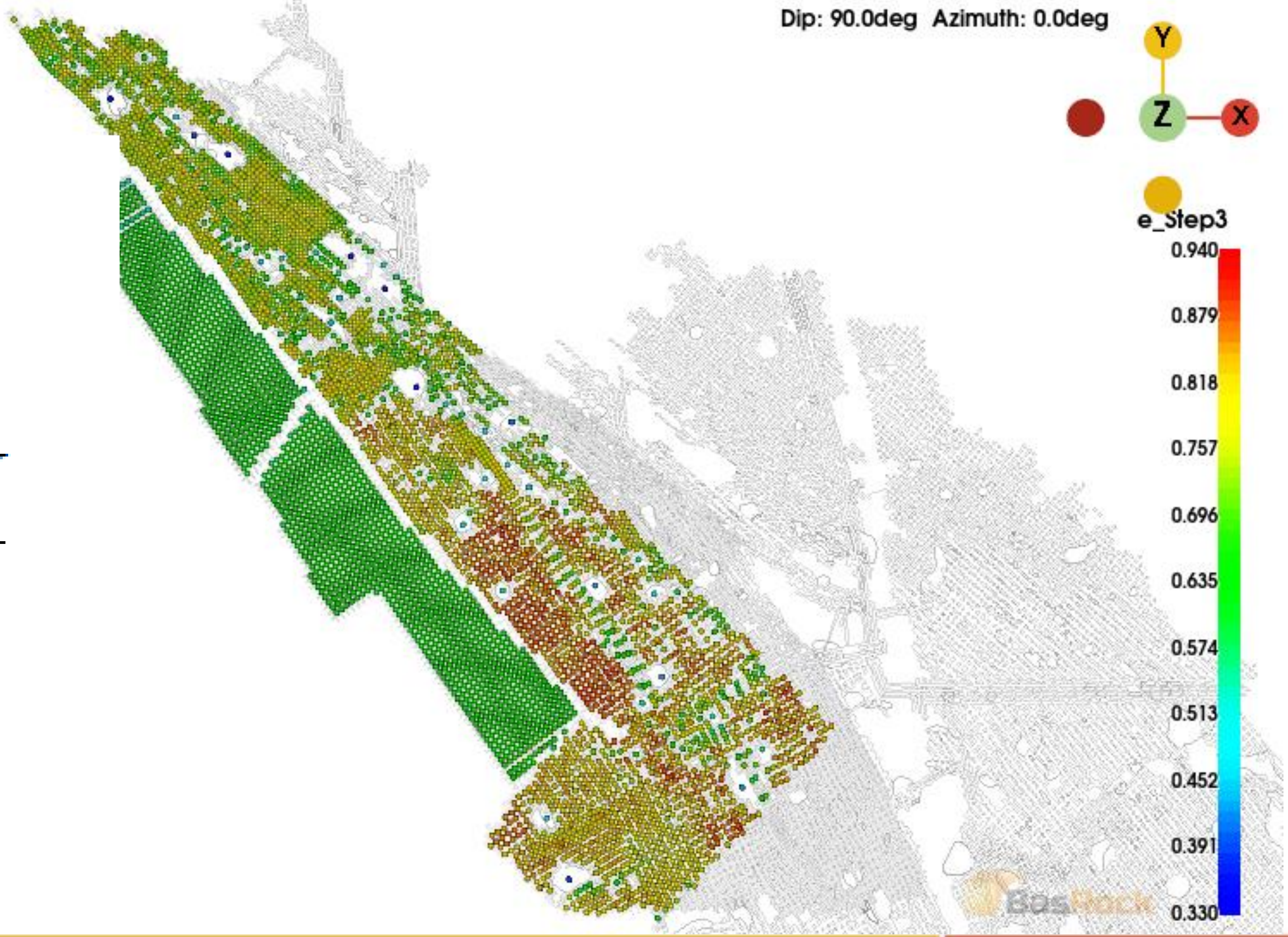
(Brady & Brown, 2004)

Model Results

Mining Extraction Ratio (e)

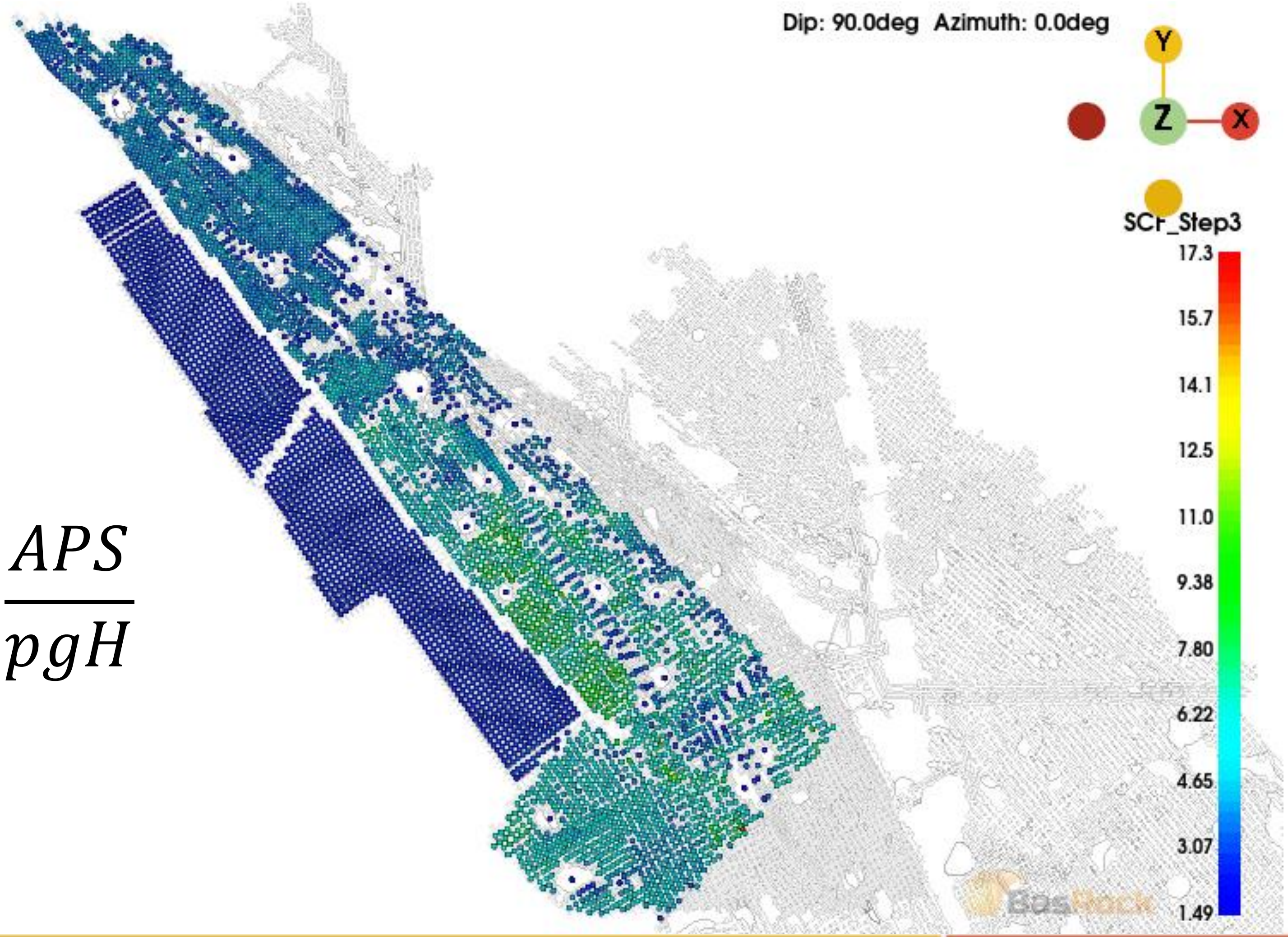
$$APS = \frac{\rho g H}{1 - e}$$

$$e = 1 - \frac{\rho g H}{APS}$$



Model Results

Future Mining Stress Concentration Factor (SCF)

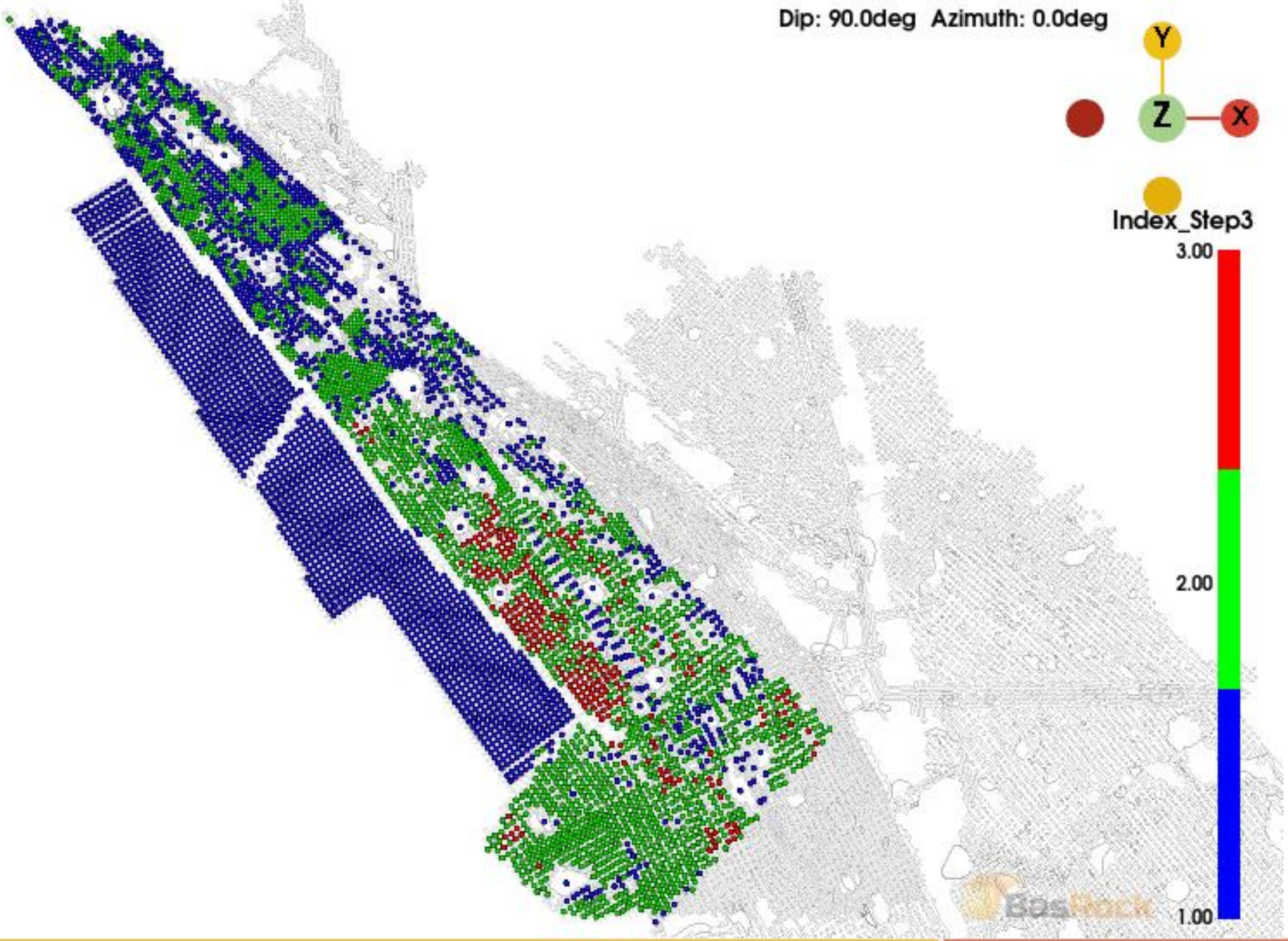


$$SCF = \frac{APS}{pgH}$$

OHMS

Model Results

Risk Related to Extraction Ratio



e > 0.85 High Risk

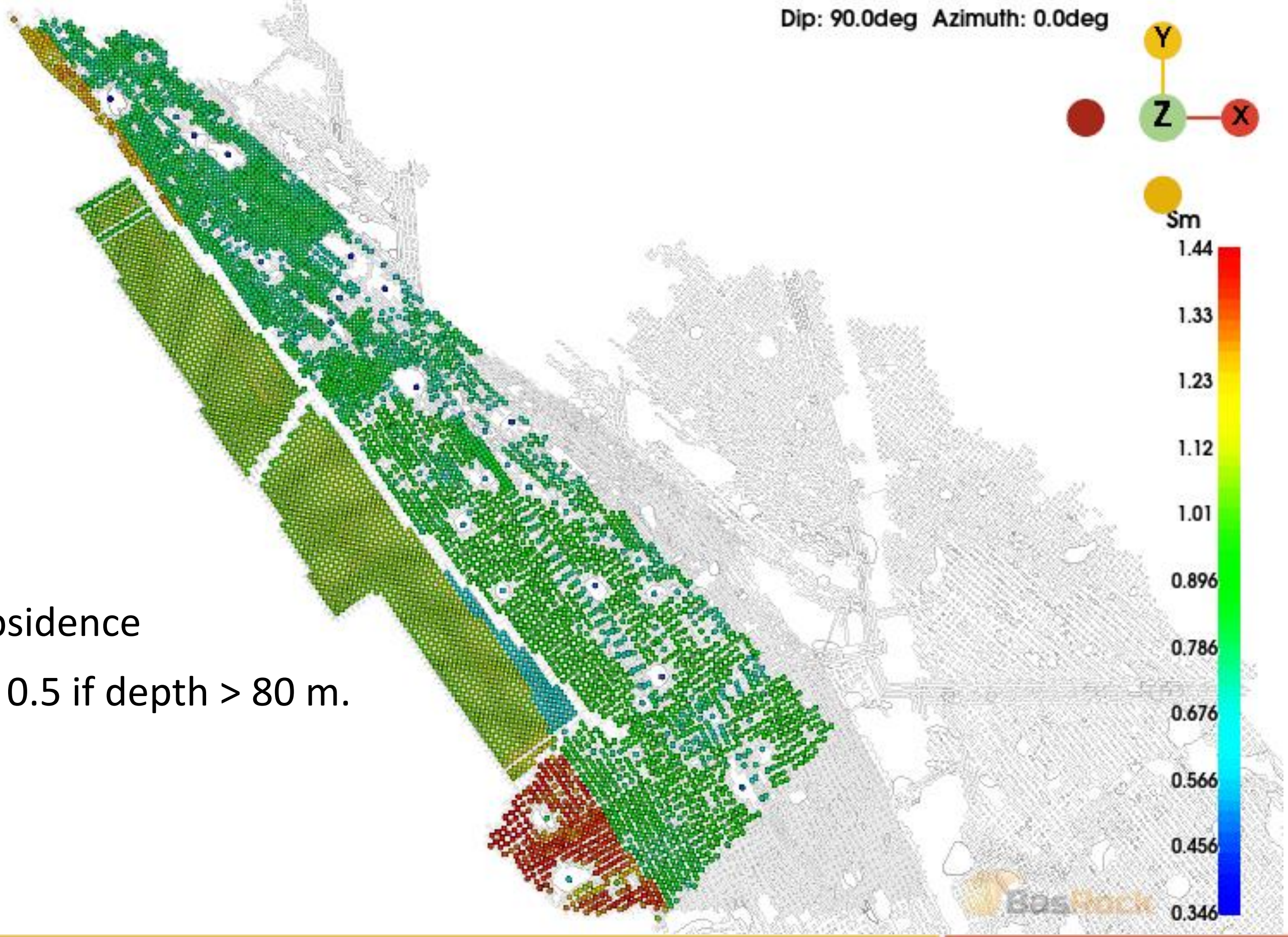
0.75 < e < 0.85 = Medium Risk

e < 0.75 = Low Risk

Worst-Case Subsidence (Theoretical Maximum Subsidence)

Model Results

Future Mining Maximum Expected Subsidence (Sm)



$$Sm = a \times h \times e$$

Where:

Sm = maximum expected subsidence

a = 0.8 if depth ≤ 80 m or a = 0.5 if depth > 80 m.

h is the mining height

e is the extraction ratio

(van der Merwe and Madden, 2002)

Classification of Subsidence Profiles

Class	Sm/H ratio	Description
A	Sm /H < 0.001	Barely noticeable, smooth, continuous profile, hair-line cracks
B	0.001 < Sm /H < 0.005	Difficult to notice, smooth profile, cracks 1–2 cm wide
C	0.005 < Sm /H < 0.02	Noticeable in flat terrain, smooth, cracks 2–10 cm wide, compression ridges 1 to 5 cm high
D	0.02 < Sm /H < 0.05	Noticeable in most terrains, visible vertical displacements across cracks, cracks 10 to 50 cm wide, compression ridges 5 to 50 cm high
E	Sm /H > 0.05	Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm

(van der Merwe and Madden, 2002)

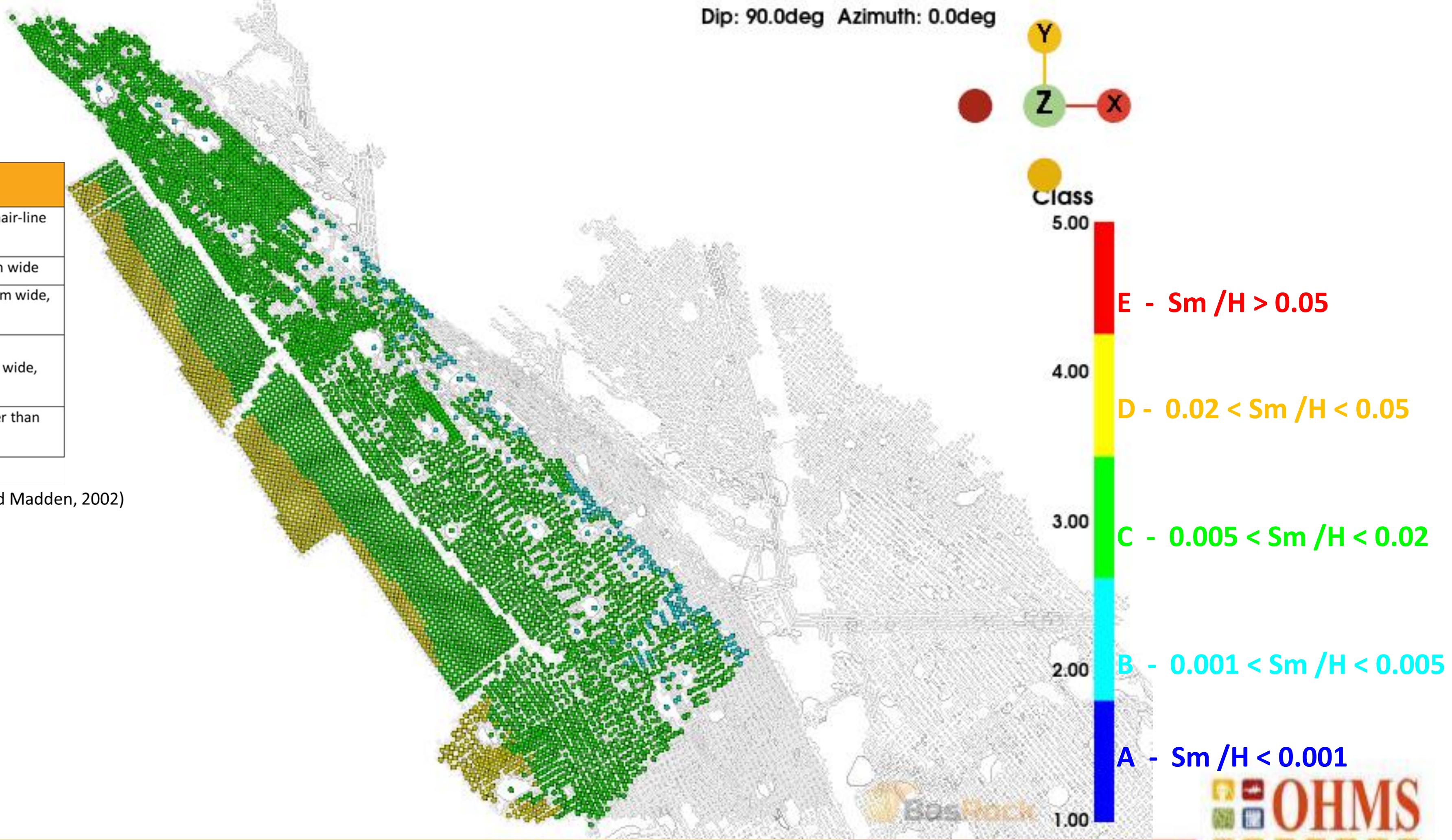
Model Results

Future Mining Maximum Expected Subsidence

Class	Sm/H ratio	Description
A	Sm /H < 0.001	Barely noticeable, smooth, continuous profile, hair-line cracks
B	0.001 < Sm /H < 0.005	Difficult to notice, smooth profile, cracks 1–2 cm wide
C	0.005 < Sm /H < 0.02	Noticeable in flat terrain, smooth, cracks 2–10 cm wide, compression ridges 1 to 5 cm high
D	0.02 < Sm /H < 0.05	Noticeable in most terrains, visible vertical displacements across cracks, cracks 10 to 50 cm wide, compression ridges 5 to 50 cm high
E	Sm /H > 0.05	Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm

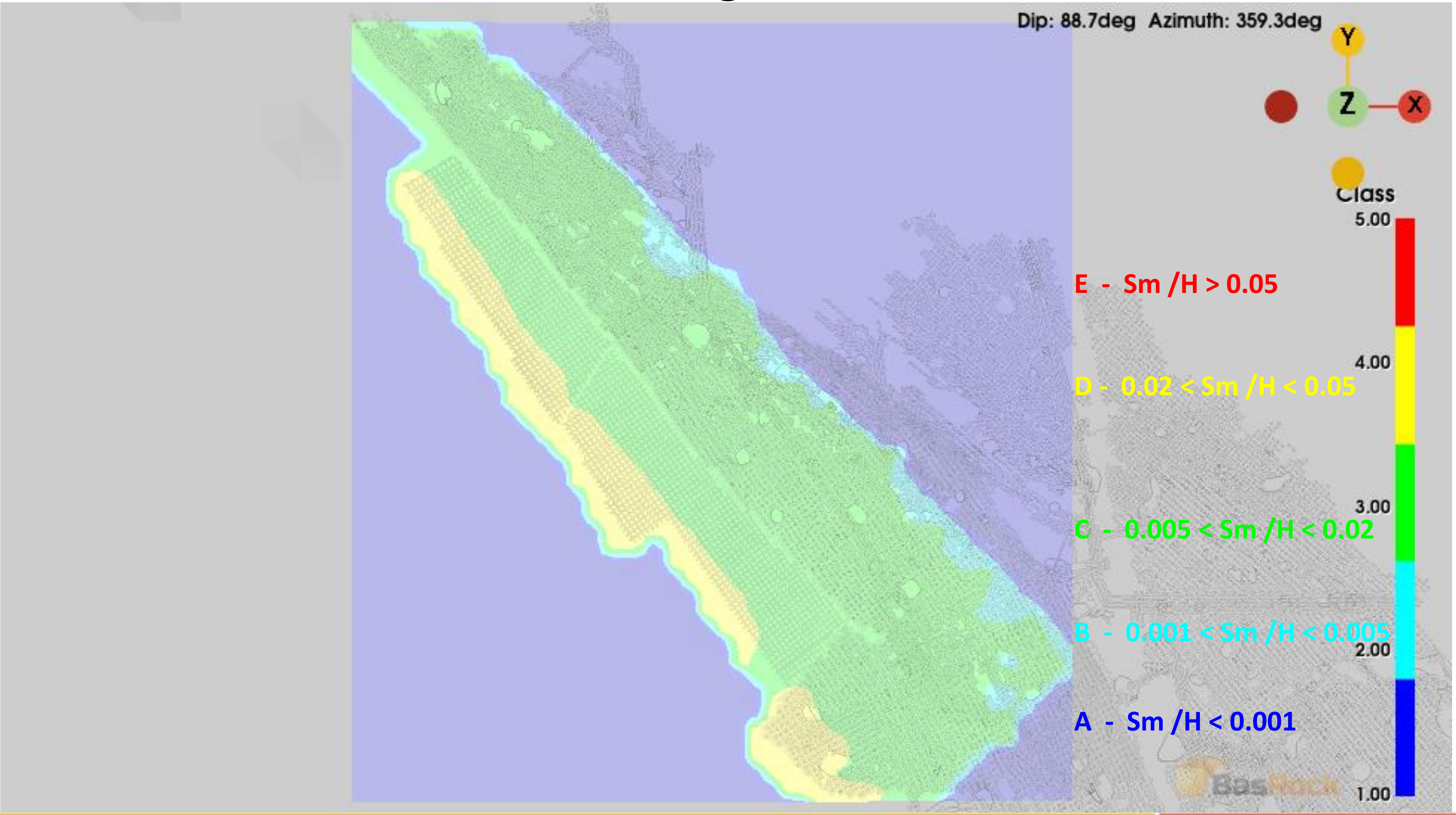
(van der Merwe and Madden, 2002)

$$Sm/H$$



Model Results

Future Mining Subsidence Profiles



OHMS

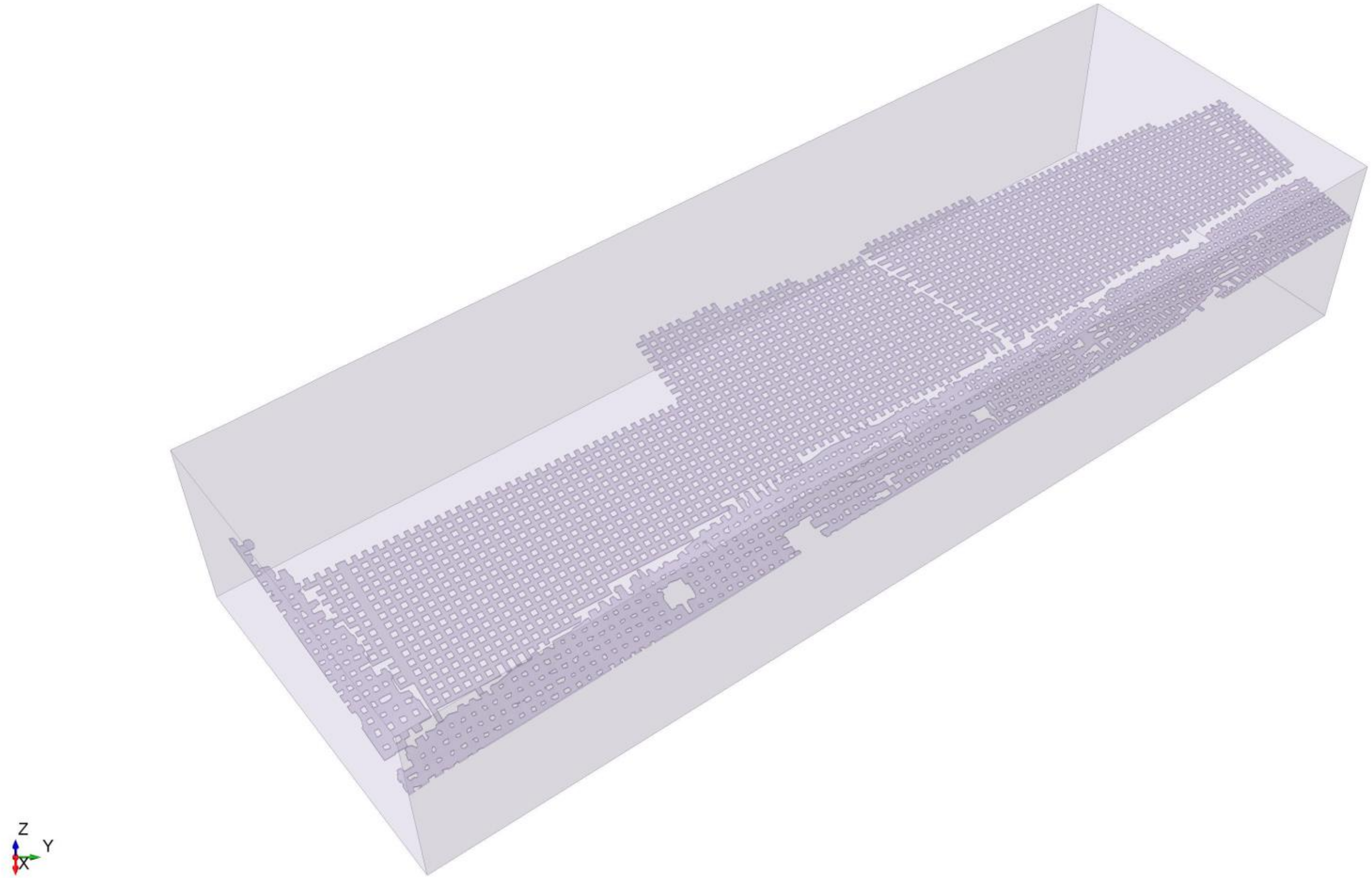
Expected Elastic Subsidence

Methodology

- 3D Finite Element Numerical model constructed from model built in previous Map3D assessment
- Pillars included as elastic rigid pillars since failure is not expected based on the outcome of previous assessment

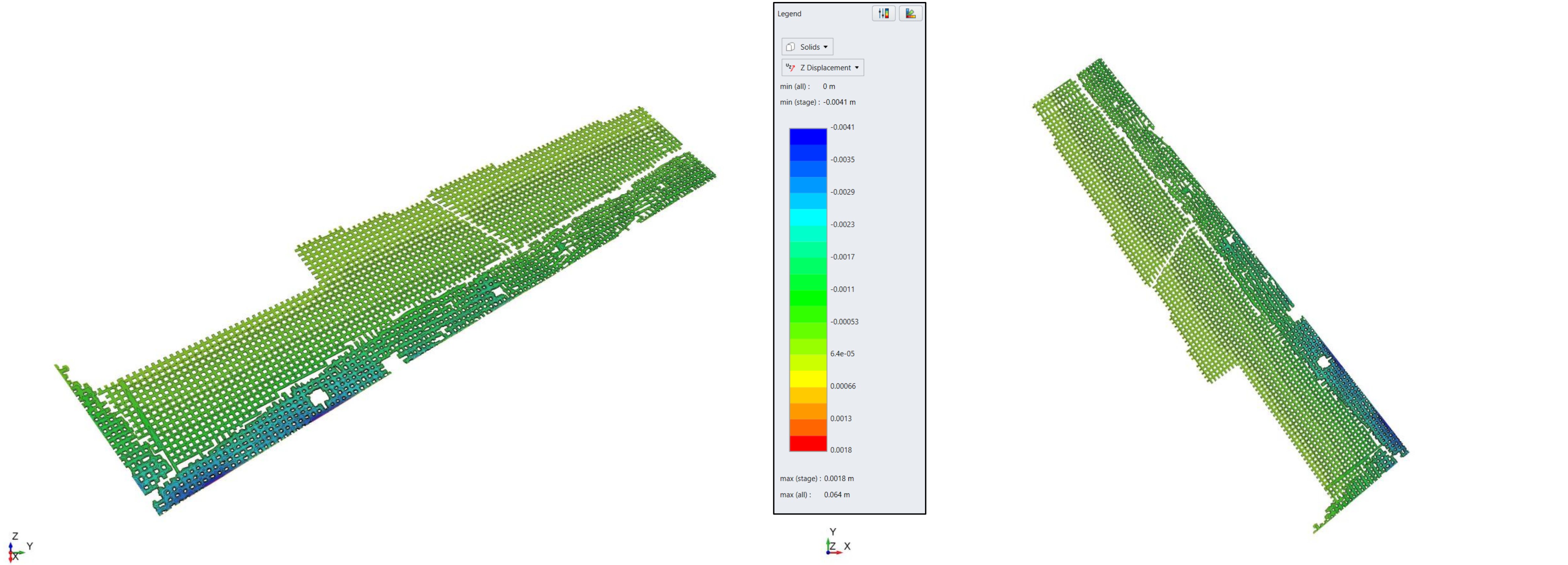
Model Geometry

Finite Element Model Including Surface Topography



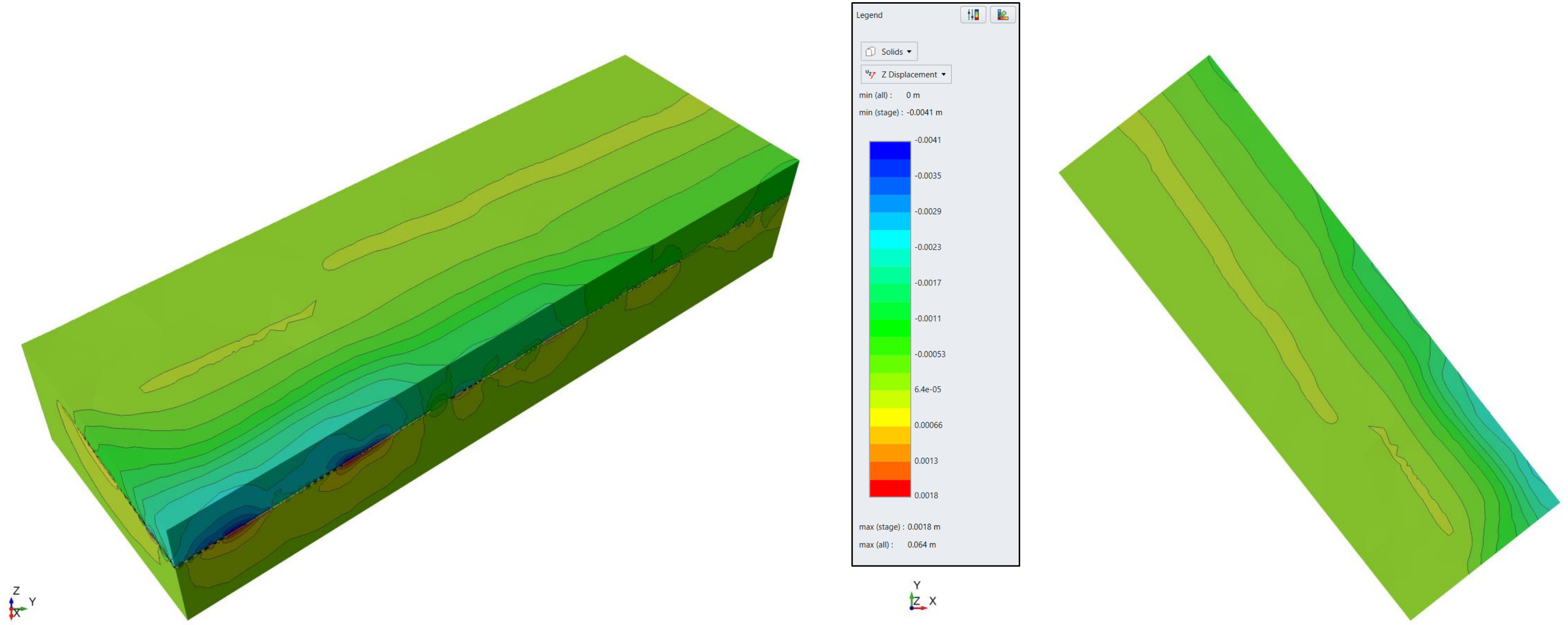
Model Results

Maximum Excavation Displacement (ZZ)



Model Results

Maximum Host Rock Displacement (ZZ)

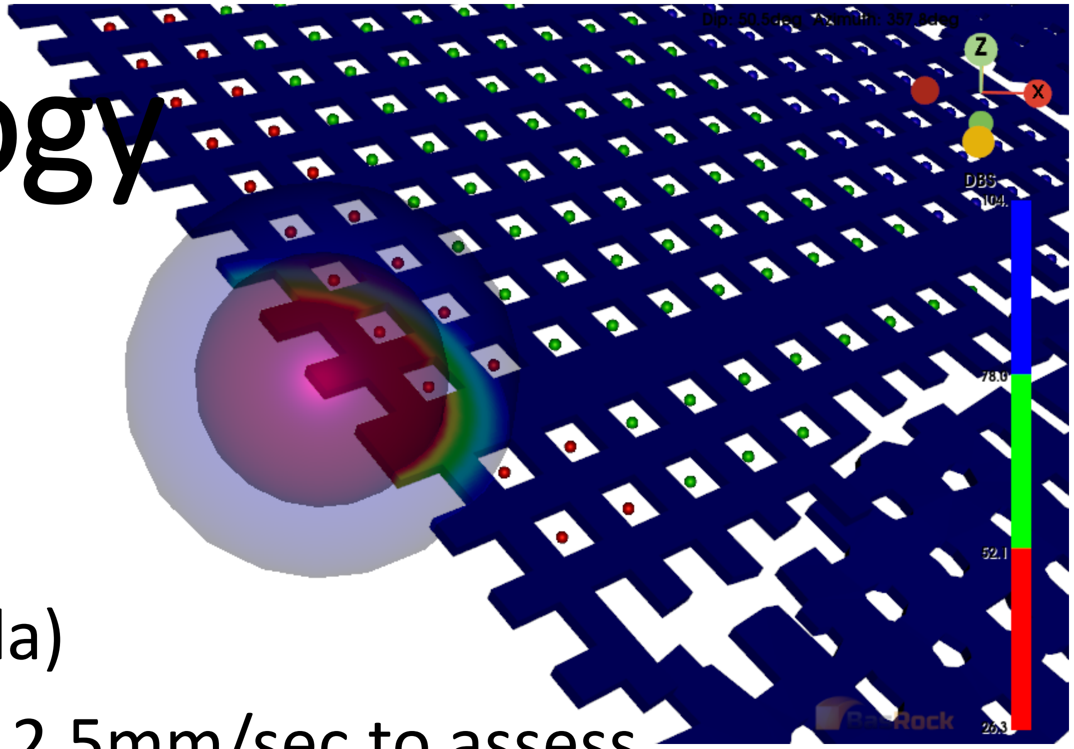


Maximum Expected PPV’s and PPV Limits

Methodology

- Blasting records perused and assessed to improve on previous assumptions (not successful)
- Update previous assessment (desktop assessment) to include most recent wireframes and known mining depths
- Assumed 38mm diameter blast holes of varying length
- Assumed emulsion density of 1000kg/m^3
- Establish blasting advance limitations based on expected PPV and surface infrastructure proximity

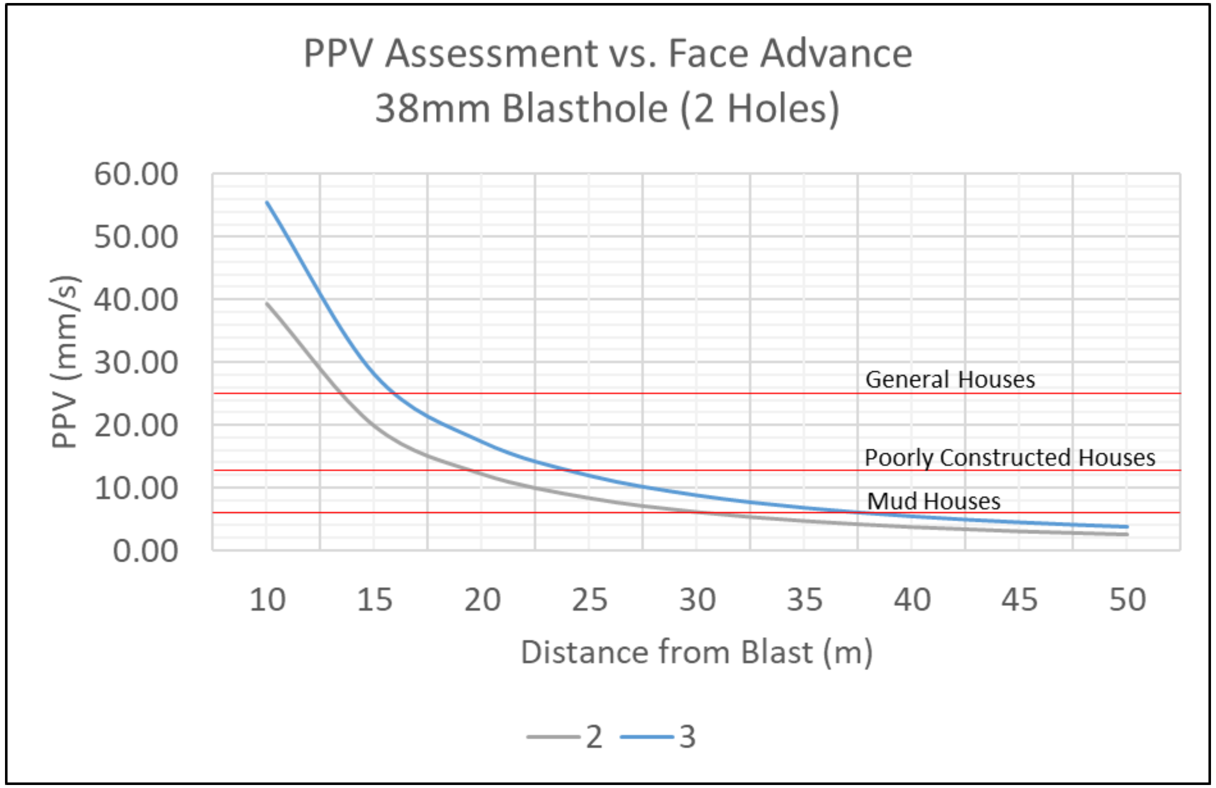
Continued Methodology



- Numerical model wireframes used to simulate blasts as proposed by analytical equation (USBM Generic Blasting Formula)
- Two zones delineated for 6mm/sec and 12.5mm/sec to assess zone of disturbance

Updated Analytical Assessment

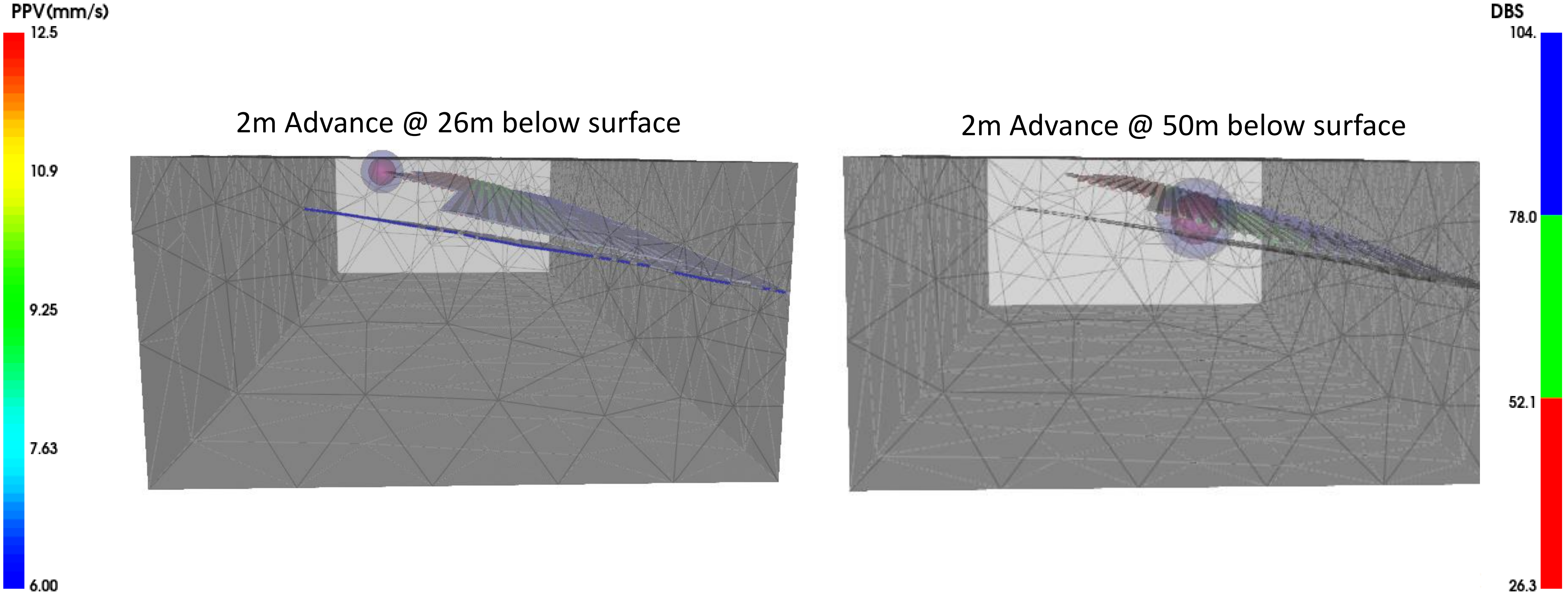
- Blasting records perused and assessed in order to improved on previous assumptions (not successful)



Structure Description	Ground Vibration Limit (mm/sec)
National Roads/Tar Roads	150
Electrical Line (Pylons)	75
Railways	150
Transformers	25
Gas/Fuel Lines	25
Water Wells	50
Telecoms Tower	50
General Houses of Proper Construction	25
Houses of Less Proper Construction	12.5
Rural Buildings – Mud Houses	6

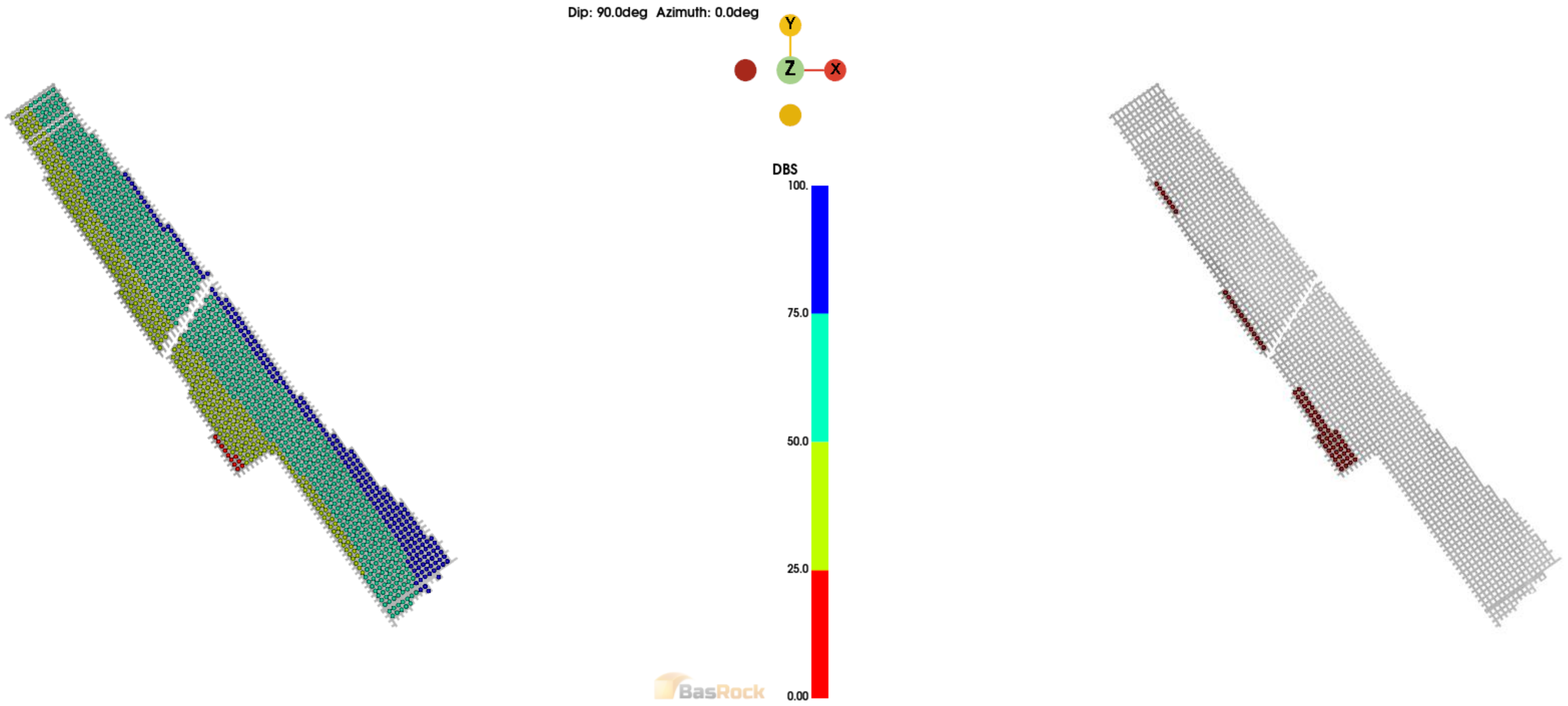
Model Geometry

PPV Modelling and Assessment



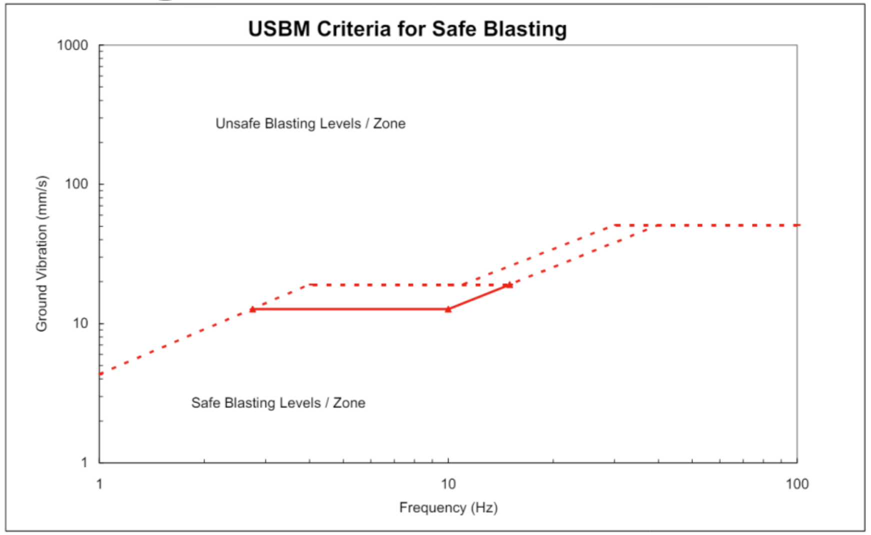
Model Geometry

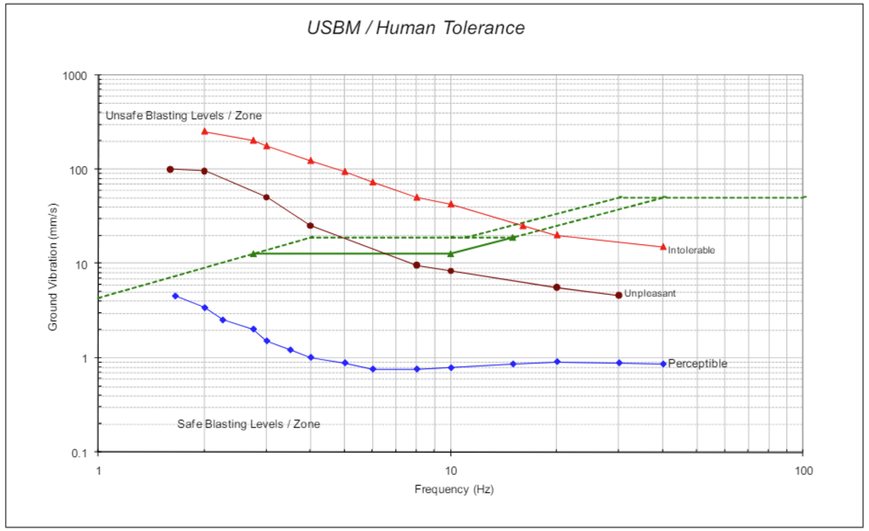
PPV Modelling and Assessment



Future Blasting Work

- Ground vibration limits is normally a function of ground velocity as well as frequency
- Low frequency vibrations are typically more damaging than high frequency vibrations
- When mining commence in the area, dedicated blast vibration measurement stations is envisaged to calibrate the PPV assessment





Future Blasting Work

- Air blast is not considered a concern, as blasting will only take place underground
- However, physical measurements will be taken during the project commencement to confirm this assumption (owing to ventilations shafts and other opening)

Level	Description
120 dB	Threshold of pain for continuous sound
>130 dB	Resonant response of large surfaces (roofs, ceilings). Complaints start.
150 dB	Some windows break
170 dB	Most windows break
180 dB	Structural Damage

$L = 165 - 24 \log_{10} (D/ E^{1/3})$

Where:

L = Air blast level (dB)

D = Distance from source (m)

E = Maximum charge mass per delay (kg)

Support Requirements

Methodology

- Previous methodology input parameters confirmed by means of underground inspections in shallow area
- Ground Penetrating Radar scans conducted during underground inspections, used to confirm initial support recommendations
- Additional comments regarding underground inspection and observations made

Support Update

Support Requirements Update

- Initially, the mine's general support standard was ought to be adequate for the Kwezi shallow area
- The above are to be updated by this assessment

Table 5-17: GCDs for Sibanye-Stillwater Mechanised Operations

No.	GCD Name	GCD description
1.	GCD A	Poor rock mass rating (RMR < 40, low angle features, prominent vertical features, water)
2.	GCD B	Transition zones from GCD A
3.	GCD C	Good ground conditions (RMR > 61)
4.	GCD D	Major fault zones e.g. Townlands fault
5.	GCD E	Good ground conditions (RMR > 61), single seam mining, leader seam > 1.3m above main seam
6.	GCD F	Good ground conditions (RMR > 61), dual seam mining, leader seam < 1.3m above main seam
7.	GCD G	Fair ground conditions (RMR 40 - 60), water influx (aquifer on triplets horizon), dual seam mining, leader <1.3
8.	GCD H	Poor ground conditions (RMR < 40), prominent low angle geological features, rolling reef, dual seam mining, leader <1.3

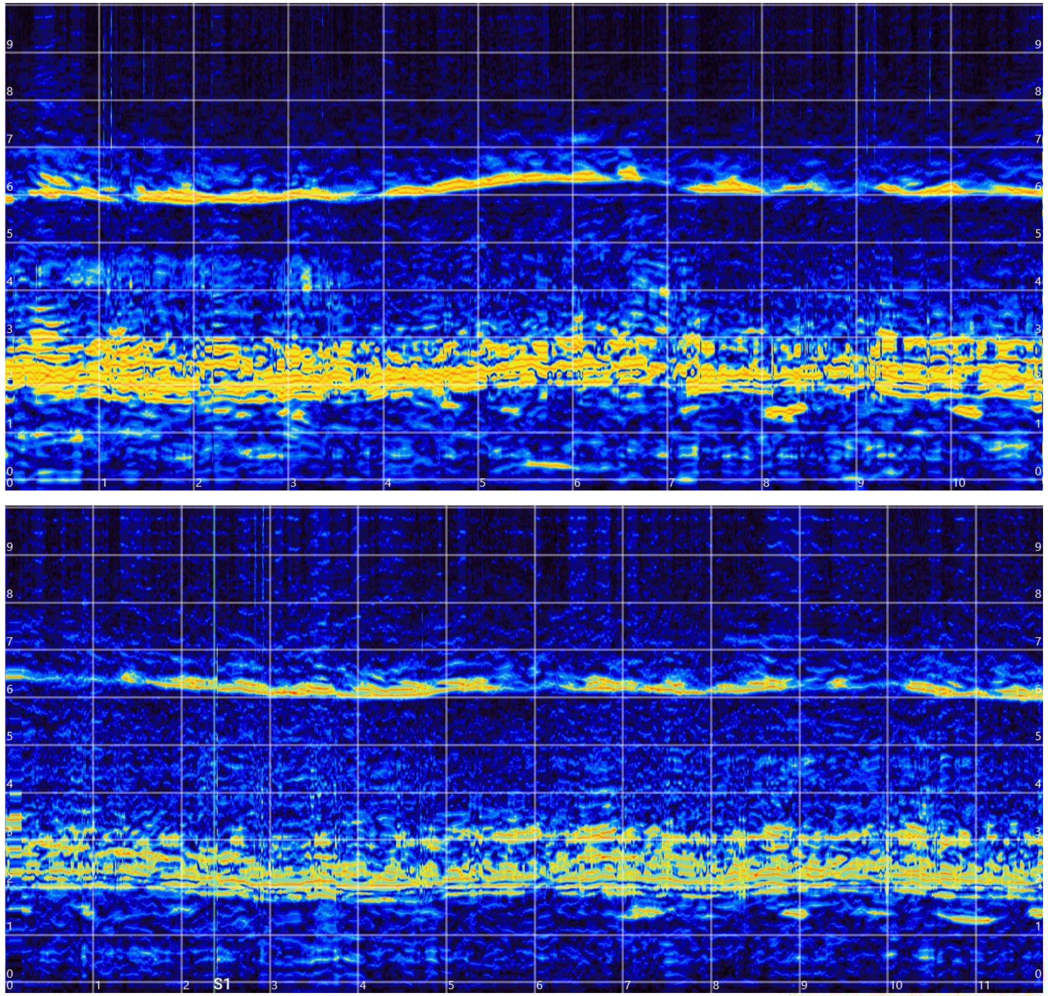
Table 5-18: Minimum bord width and support specification defined for GCDs

GCD	Span	Support (Kroondal Operations)	Support (Rustenburg Central Operations)
A	6m	3.0m anchors on 1.5m x 1.5m pattern	3.0m bolts on 1.5m x 1.5m pattern
B	6m -8m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
C	8m -10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
D	6m	Special area. Site specific support instructions	Special area. Site specific support instructions
E	10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
F	10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
G	10m	1.5m bolts 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern
H	6m	1.5m bolts on 1.5m x 1.5m pattern	1.6m bolts 1.5m x 1.5m pattern

Support Update

Support Requirements Update

- From GPR scans, triplets are observed at 2.0m characterized by more than one parting, and some noise brought about by reflections between stringers
- Second contact observed at ~6.0m thought to be Anorthosite contact (to be verified by borehole?). Single, sharp contact observed in all the scans



Support Update

Support Requirements Update

- Compared to expected geology, the first parting may be the Leader however, the Leader is visible in the panels where observations were made
- Position of first parting and assumption of it being the triplets is confirmed by the expected geology as per the COP

*Perhaps isopach of Anorthosite contact to be included into COP's

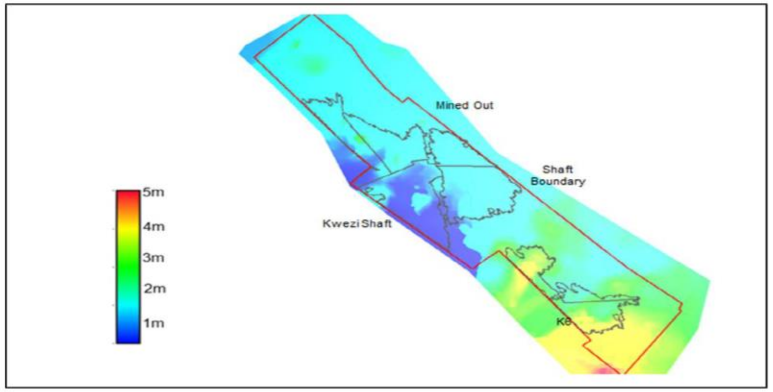


Figure 5-13: Kwezi and K6 isopach plan indicating position of Leader Seam in the hanging wall

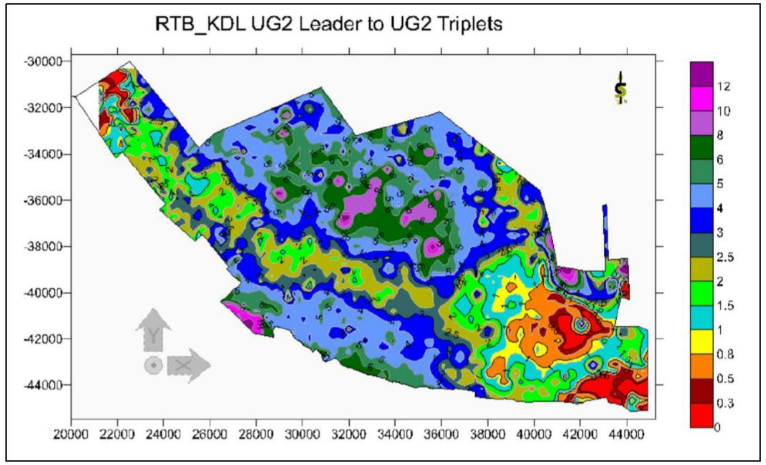


Figure 5-12: Kroondal isopach plan indication position of Doublets or Triplets in hanging wall

Support Update

Support Requirements Update

- Consideration is given to the fact that falls of ground to the 2.0m contact has not occurred readily to date (although falls have been recorded)
- However, weathering on any structure is expected to be more pronounced at depth < 40m
- In addition, clamping forces in the hangingwall reduces with a decrease in mining depth below surface
- Support will need to cater for the 2.0m hanging wall contact when weathering is confirmed on the contact

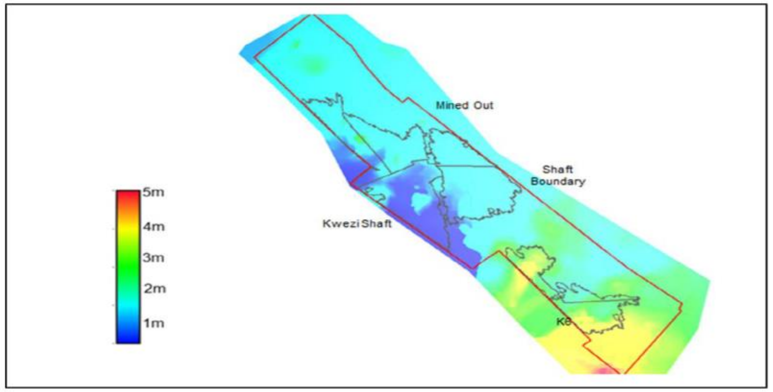


Figure 5-13: Kwezi and K6 isopach plan indicating position of Leader Seam in the hanging wall

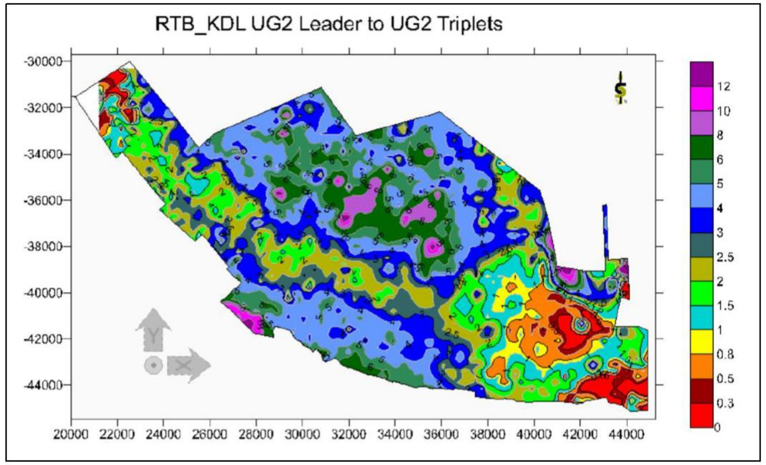


Figure 5-12: Kroondal isopach plan indication position of Doublets or Triplets in hanging wall

Conclusions

Geotechnical Conclusions

- Anticipated Ground Conditions:
  - Similar to previous study conclusions,
  - Based on underground observations, water present at areas <50m from surface,
  - Where water is present, hanging wall parallel contacts will most likely be weathered.
- Pillar Design:
  - Square 8m wide pillars yielding satisfactory factors of safety,
  - Mining layout proposed yields a low-risk when considering extraction ratio and attained factors of safety.
- Subsidence:
  - In the event of a catastrophic failure (which is unlikely given the design), subsidence of up to 1.2m can be expected on surface causing up to 10cm wide cracks and 5cm ridges,
  - Anticipated elastic subsidence on surface is < 1mm and will not be noticeable on surface.
- Blasting & Vibration:
  - Two 2m advance blast holes within 8 milli-second window will result in 8mm/second damage criteria being exceeded at 30m, but not at 35m (8mm/second criteria relates to mud-house damage),
  - Two 3m advance blast holes within 8 milli-second window will result in 8mm/second damage criteria being exceeded at 30m, but not at 45m (8mm/second criteria relates to mud-house damage),
  - Suggested to limit 3m advances to 50.0m below surface (where ground conditions permit).

Geotechnical Recommendations

The proposed mine geometry is fit for purpose, with the following adjustments required:

- Update the mine plan to exclude any mining < 35.0mbs as a minimum.
- Limit advance per blast to 3.0m up to a minimum depth below surface of 50.0m (considering a factor of safety of around 1.4).
- Limit advance per blast to a maximum of 2.0m between 35.0mbs and 50.0ms.
- Ensure that primary support caters for a fall-out thickness equal to the distance up to the triplets (established to be 2.0m in the area of interest) plus an additional length to cater for adequate anchorage into the solid rock.
- Ensure that a monitoring and instrumentation program is developed that is specific to the shallow mining area that considers at least:
  - The condition of the hanging wall parallel contacts.
  - Increase or decrease of water flow/presence.
  - Rock mass conditions, and suitability of support to cater for conditions.
  - Ground vibration (including frequencies) and air-blast.
  - High resolution monitoring of surface deformation for comparison to expected vertical displacement.

Kroondal West Mineral Deposit Geotechnical Study

Prepared for:	The General Manager Sibanye Stillwater Kroondal West Operations Rustenburg

Prepared by:	Quintin Grix Senior Consulting Geotechnical Engineer Open House Management Solutions Potchefstroom

Reviewed by:	Koos Bosman Principal Consulting Geotechnical Engineer Open House Management Solutions Potchefstroom

Date & Versions:	31 August 2021 11 November 2021 (revision 1.0)
Reference Number:	QLG_SP_KW1_rev1.0
Distribution:	Sibanye Stillwater – PDF Copy Open House Management Solutions – PDF Copy

OHMS

Ω β ε Δ Ø λ σ

Table of Contents

List of Figures

List of Tables

1. Introduction

Open House Management Solutions (OHMS) was contracted by Sibanye Stillwater (The Client) to conduct a geotechnical study of the Kroondal West shallow mining deposit. OHMS was required to assess the geotechnical feasibility of mining below surface structures at depths ranging from 60m to 80m below surface, as required by the DMRE regulation 17.7 and regulation 17.8.

The investigation had to include a study on three proposed mining blocks namely Block A, Block B and Block C located on farms Rustenburg Townland 272JQ, and Waterval 306 JQ near the town of Rustenburg.

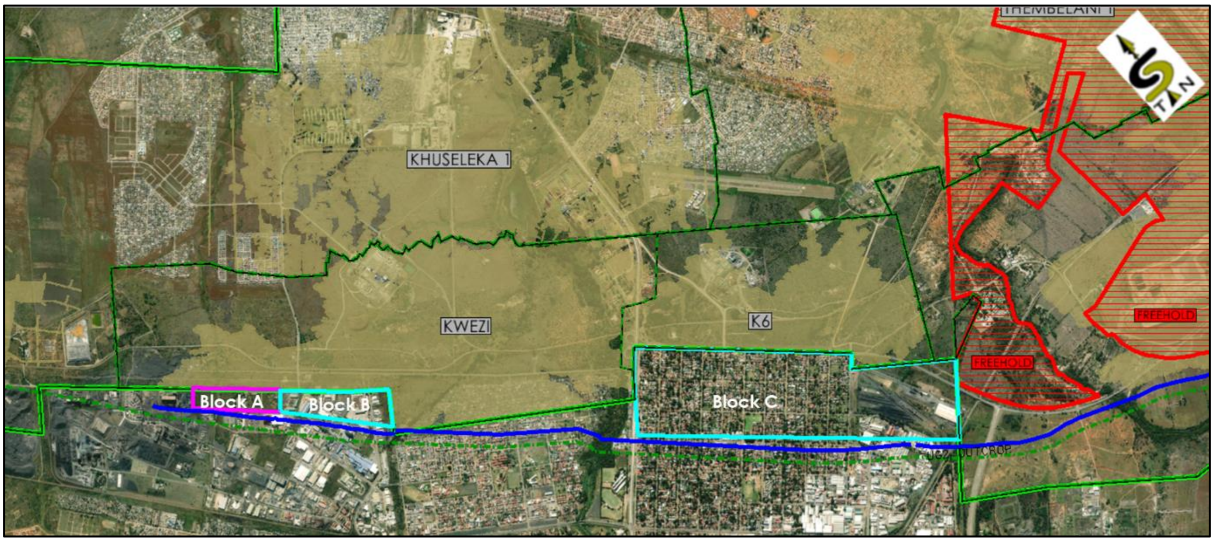


Figure 1: Three blocks under scrutiny (Sibanye-Stillwater, 2021)

Block A

Block A has an area of 130 473 square meters. The UG2 mineral deposit target depth ranges from 40m to 80m. There are no building structures directly below Block A, however the block is within the 100m horizontal mining limit to the Glencore Chrome Smelter, several warehouses, some electrical and water service infrastructure. There is evidence of renewed building activity in this block, for example new fencing and landscaping clearing the empty stands.

Block B

This mineral deposit block has area of 219 663 square meters. Like Block A, the UG2 mineral deposit target depth ranges from 40m to 80m. This area is highly developed and has several warehouses and office blocks directly above the target UG2 mineral deposit.

Block C

Block C consists of an area of 1 852 287 square meters. Block C is highly developed and has approximately 250 residential properties, a school, and a business complex along the southern boundary.

2. Scope of Work

The scope of work agreed to between The Client and OHMS is as follows:

- OHMS will render a geotechnical study, as an independent contractor, to The Client on the farm Rustenburg Town and Townland 272 JQ, and Waterval 306 JQ near Rustenburg town,
- OHMS is required to establish safe mining depths below existing structures as indicated in the scope of work document,
- OHMS is required to establish critical mining spans at the assessed safe mining depth as indicated by the study,
- OHMS is required to establish pillars factor of safety at the depths deemed safe to mine,
- OHMS is required to recommend a blasting methodology to minimise ground vibrations,
- OHMS is required to recommend/design a ground vibration monitoring system, and
- OHMS is required to include the effect of ground water on the stability of board and pillars in the study.

3. Methodology

The methodology agreed between The Client and OHMS considered the following key activities:

- Site visit, data collection and data familiarization:
  - Data collection, site familiarization and review,
  - Visit to all underground and surface project areas.

- Geotechnical desktop assessment:
  - Assess collected data and observations from site visit,
  - Construct geotechnical model of sites and establish required geotechnical domains,
  - Based on industry accepted empirical methods, establish safe mining depths, critical mining spans, factors of safety of pillars,
  - Include the effect of ground water on abovementioned assessments.
  - Based on assessment outcome, recommend a ground vibration monitoring program considering both vibration, and subsidence monitoring.

- Reporting
  - Feedback presentation and written report of process, design findings and recommendations

4. Site Visits

Three days was spent on site in order to assess the underground, surface and core condition. The days spent was as follows:

- 16 & 17 August underground at Kwezi's Eastern and Western sections,
- 17 August afternoon inspection of surface infrastructure, and
- 20 August spent at Sibanye core yard to inspect core related to the project.

4.1 Underground Inspections

Two days were spent underground at Kwezi shaft in order to:

- Inspect areas as close to the project area as possible,
- Inspect areas to the far east, and far west of the mine in order to assess the need for separate ground control districts/domains,
- General presence/absence and trend of discontinuity sets,
- Change in discontinuity sets as a result of localized geology,
- Weathering profiles, where visible, between shallow areas and deeper areas,
- Water ingress along geological structures,
- Effect of weathering on different geological features and discontinuities,
- General mining practice i.e., blasting, compliance, support efficacy etc.

A plan view of the Kwezi underground operations overlayed on a surface map is depicted in Figure 2. The areas that were visited and where data was collected is marked with red spheres. Further note that the project areas are also indicated as A, B and C. The areas towards the South-East (East) were visited on day 1, whereas the areas towards the North-West (West) were visited on day 2.

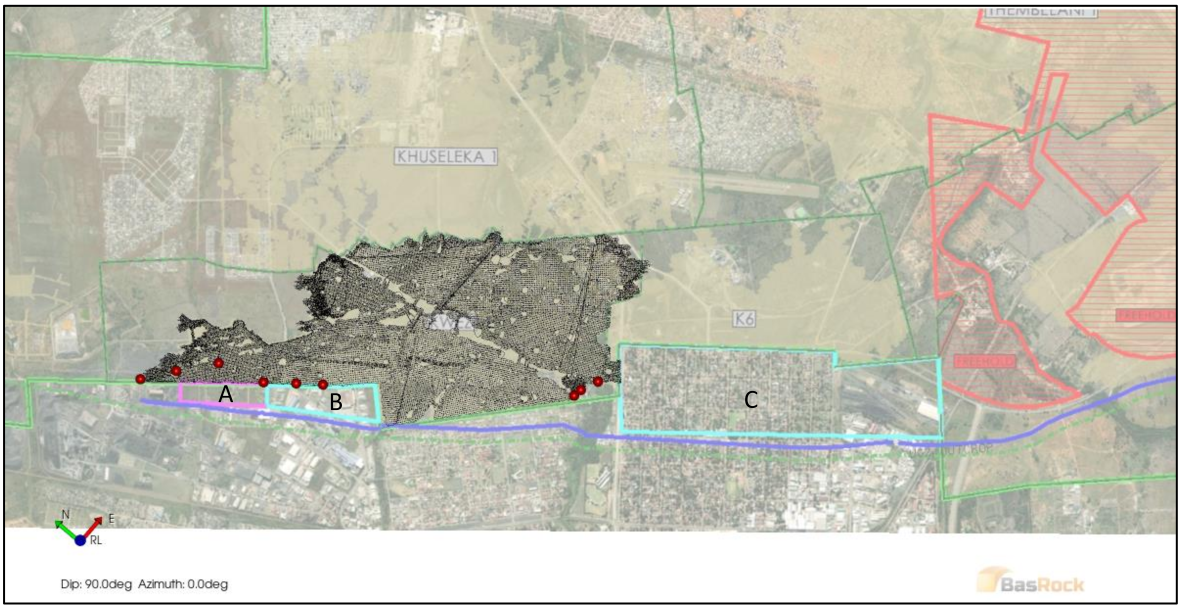


Figure 2: Plan view of Kwezi underground operations, with visited areas marked with red spheres

4.1.1 Day 1 Observations

The areas visited on day 1 is approximately 200m below surface. The general ground conditions towards the Eastern sections, which are in close proximity to project areas of Block B and C, are good. The section is traversed by the Townlands fault striking approximately North. A splay-fault, believed to be associated with the Townlands fault is also traversed and strikes approximately South-East. The position of the faults, relative to the areas where data was collected can be seen in Figure 2Figure 3.

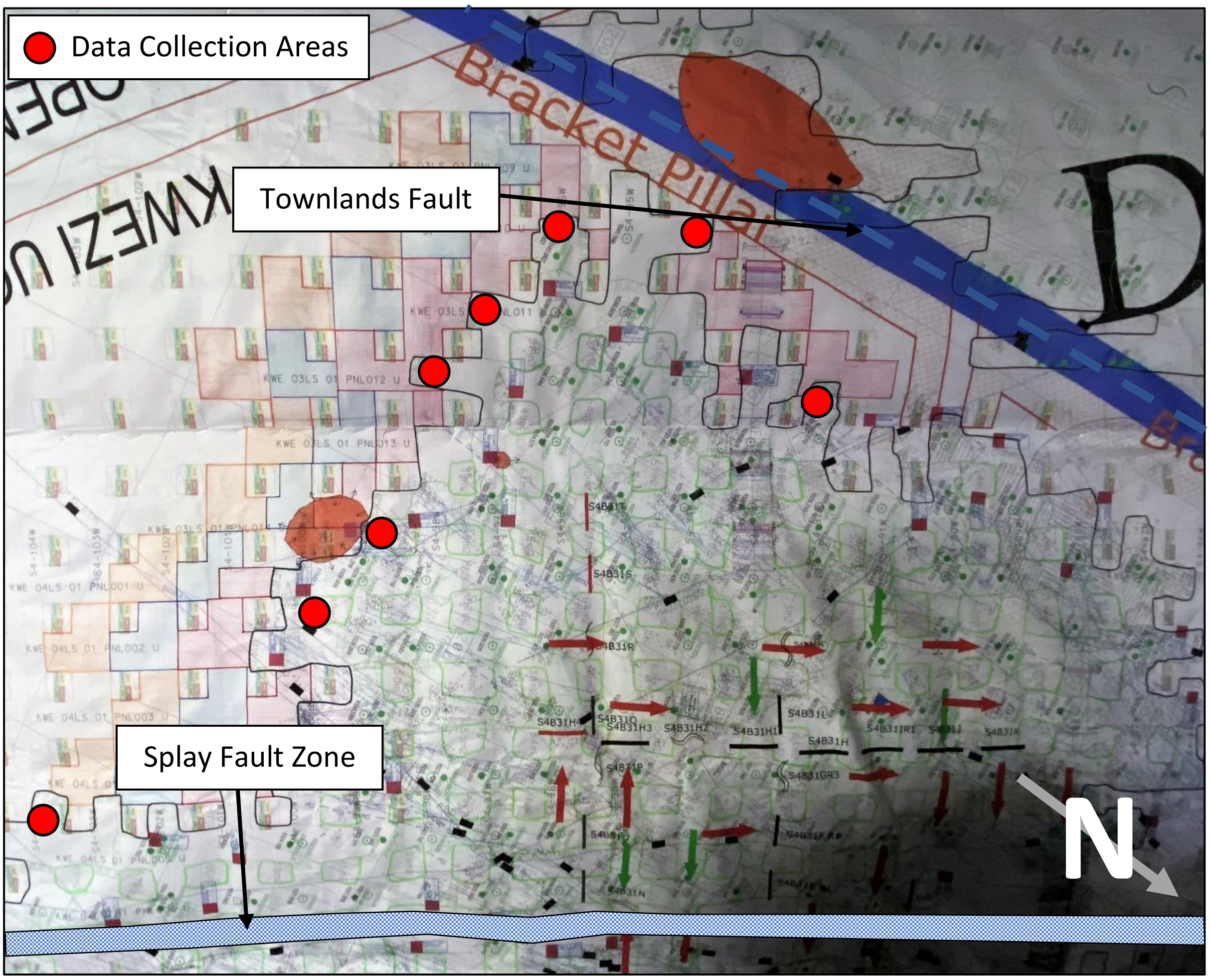


Figure 3: Plan view of the Eastern section visited, note the annotated Townlands fault, as well as the splay and areas where data was collected

Where mining took place close to (< 10.0m) the Townlands fault, or the splay-fault, ground conditions deteriorate rapidly. The areas of influence of weathering and deteriorated discontinuity surfaces appears to be in the region of 10.0m. In these regions, it is not uncommon to see slicken-sided, polished and weathered joint surfaces (Figure 4). Joints with orientations sympathetic to the Townlands fault as well as the splay-fault are present across the entire section. Some 115 individual joints were mapped in the Eastern section on day 1. A lower hemispherical stereographic projection of the joints was constructed in order to assess the typical joint orientations in the section, as well as for comparison to the joints mapped during day 2. The stereographic projection is depicted in Figure 5. Note from Figure 5, that from the 115 joints mapped, at least three joint sets could be identified. A summary of the mapped sets is tabulated in Table 1.

Figure 4: Ground conditions in close proximity, and within the splay-fault.

Table 1: Day 1 joint orientation statistics

	Joint Dip		Joint Dip Direction	
	Mean	Standard Deviation	Mean	Standard Deviation
Joint Set 1 (Bedding)	10	3	101	29
Joint Set 2	77	6	216	9
Joint Set 3	84	5	298	11
Random Joints	Random	NA	Random	NA

Where mining is outside of the zone of influence of the faults present in the section, very little weathering is observed, even where pegmatite/biotite fillings are present. It was noted however, that joints associated with Joint Set 2, generally has inferior contact conditions when compared to joints from Set 3. Some water seepage was evident on recently installed cable anchors however, no weathering was noted on discontinuities or rock fabric in these areas.

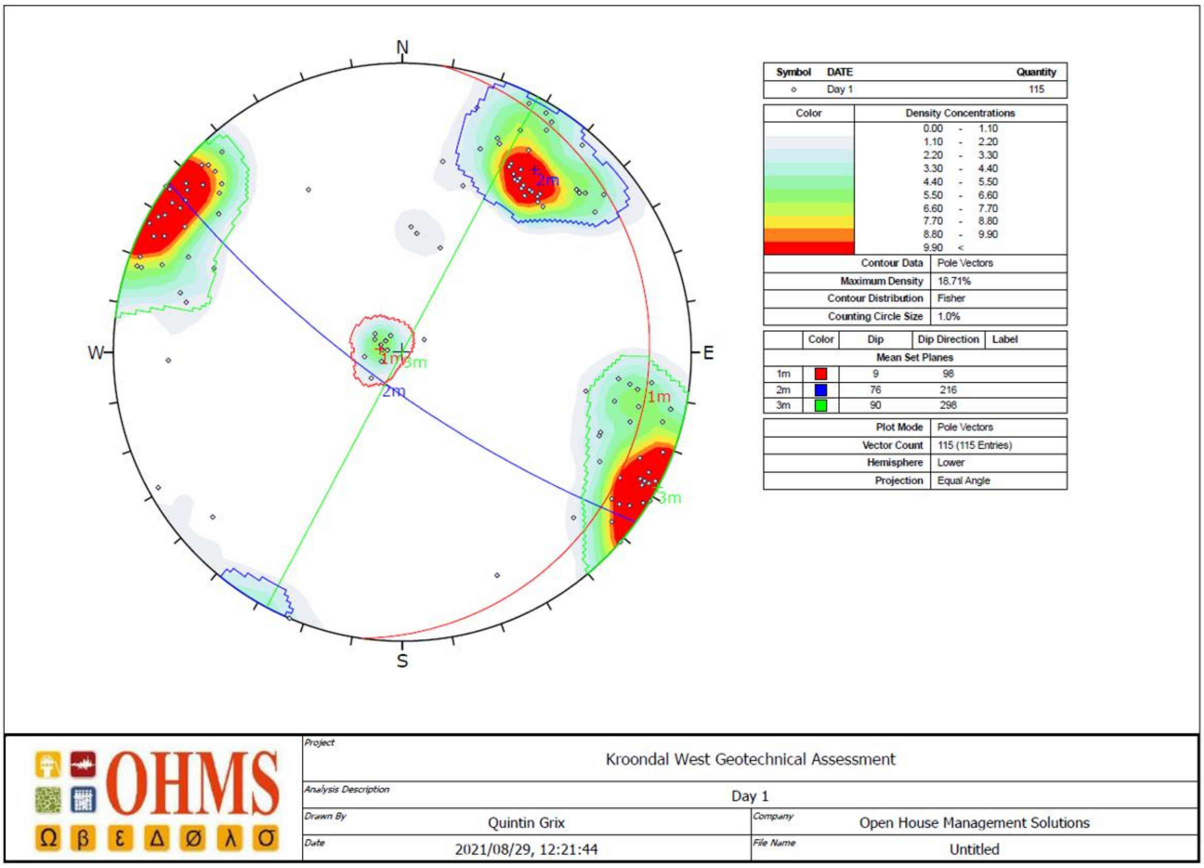


Figure 5: Lower hemispherical stereographic projection of joints mapped on day 1.

The condition of pillars in the eastern sections visited is excellent. Not only the execution of mining these pillars, but also the rock material and structure of which the pillar in general consists of (Figure 6). The same observation was made for face areas of panels situated outside the zone of influence of faults (Figure 7).

Figure 6: General condition of pillars in the Eastern sections visited

Figure 7: General face conditions of panels outside the zones of influence of faults

4.1.2 Day 2 Observations

The areas visited on day 2 is considerably shallower than those towards the East and visited on day 1. The shallowest area visited during day 2 is approximately 80.0m below surface, although the depth ranged between 80.0m and 180.0m.

The general condition of the sections towards the West appeared blockier compared to the observations made towards the East. This appeared to be as a result of a particular joint set with a flatter dip angle, resulting in small wedges dislodging presumably during the blast, and resulting in a rough hanging wall (Figure 8). This joint set turns flatter towards the East and the resulting wedges being created can become quite large. It was further noted that the same joint set striking North, is almost always weathered. However, the weathered joint set was spaced much further apart than the other sets and had a true joint spacing of > 10.0m.

Figure 8: Typical hanging wall conditions associated with a flatter joint set resulting in rough hanging wall conditions.

In total, 165 joints were mapped on day 2. The lower hemispherical stereographic projection of the mapped joints, and selected joint sets are depicted in Figure 9. As in the areas towards the East, three joint sets were noted. A summary of the statistics of the joint sets identified is tabulated in Table 2.

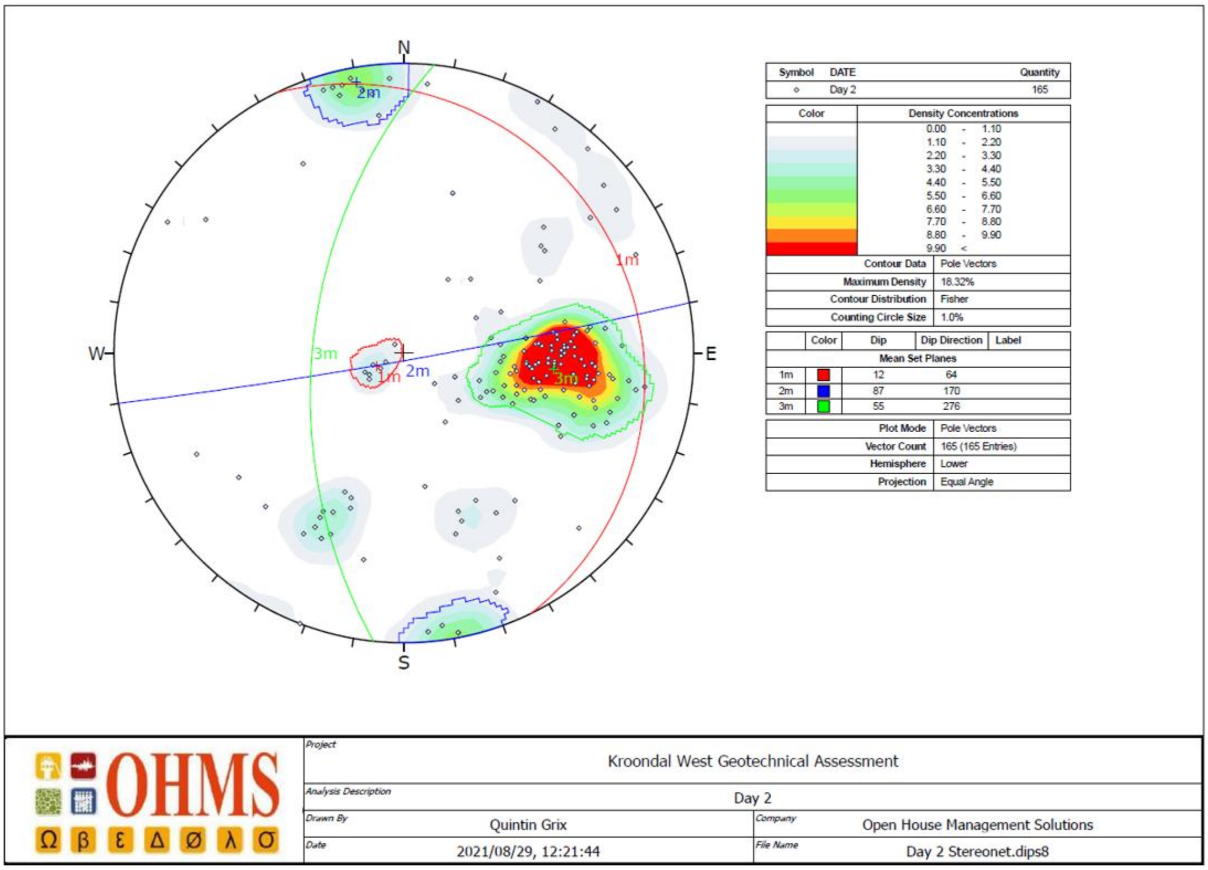


Figure 9: Lower hemispherical stereographic projection of joints mapped on day 12.

Table 2: Day 2 joint orientation statistics

	Joint Dip		Joint Dip Direction	
	Mean	Standard Deviation	Mean	Standard Deviation
Joint Set 1 (Bedding)	12	5	71	28
Joint Set 2	86	3	170	8
Joint Set 3	56	11	276	10
Random Joints	Random	NA	Random	NA

Water seepage was observed during the visit to the Western panels but appear to migrate with the advancing faces, that may in some cases impact installed support close to the face. Very little to no water seepage was present in the old back areas, with the exception of water observed around an old fault contact. As in the areas towards the East, the physical rock fabric is not weathered where this migrating water seepage was experienced.

Although pillar condition towards the West is, as in the East, relatively good. Well defined horizontal contacts within the pillars (associated with the foliation) appear to result in deterioration when pillar dimensions are compromised by over-mining. Pillars towards the West thus appear less forgiving than those observed towards the East (Figure 10).

Figure 10: Deteriorating pillar along well-defined horizontal contacts.

4.1.3 Underground Visit Conclusions

The intact rock appears less weathered than typically expected for the depth under consideration, when compared to experience in Bushveld rocks in the Eastern Bushveld. It is believed that this may be a result of the thick clay (weathered Norites) that typically overlies the Bushveld rock in the Western Bushveld (this topic will be further discussed on the core observations). Weathering associated with particular joint sets is however present.

It appears as though horizontal contacts are better developed as one mine closer to surface. This results in pillars being less forgiving when overmined, or when major geological structures traverse them.

Where significant or out of the ordinary geological discontinuities are encountered (faults, shears, dykes, etc.), their associated areas of influence appear to be greater than in deeper parts of the mine.

Although the same three joint sets are present in both the Eastern, and Western sections of the mine, the orientation of the various joint sets differ towards the East and West (Figure 11).

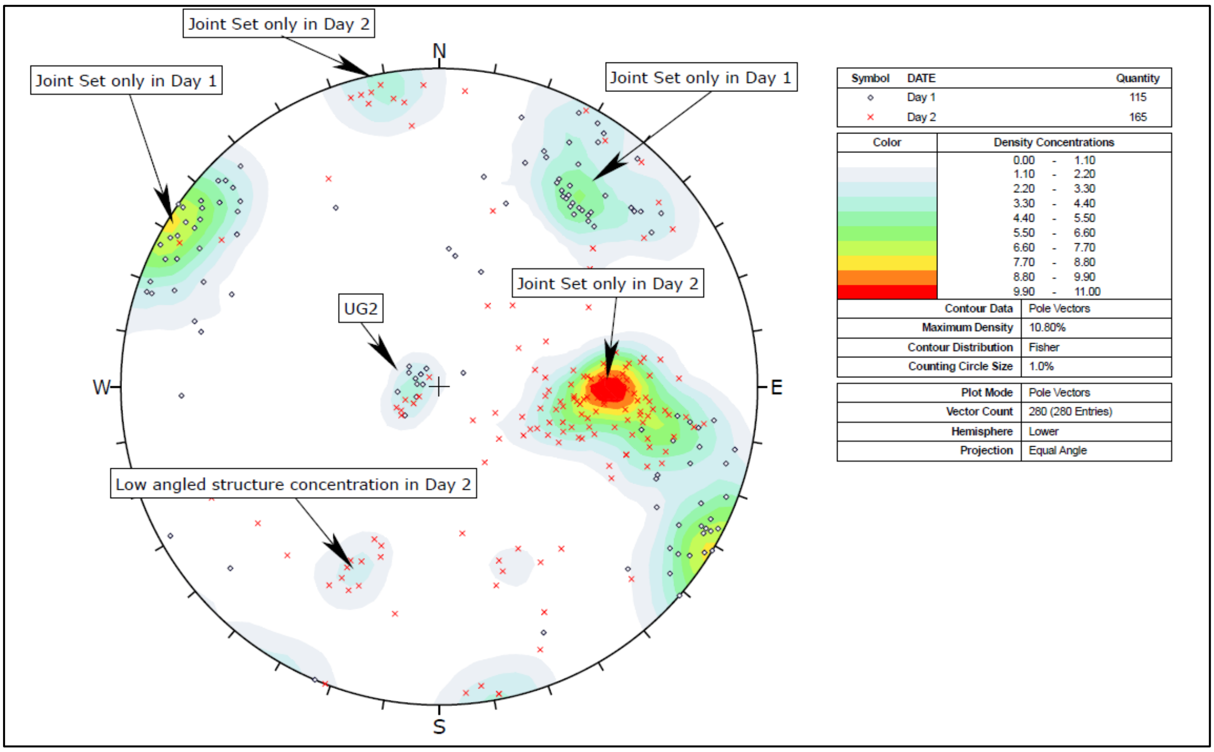


Figure 11: Summary of joint sets between the Eastern and Western sections

4.2 Surface Inspections

As part of the site visits, surface inspections were conducted in the project areas. Google earth was further employed to assist with the presentation of the findings:

4.2.1 Block A

Block A comprise some 130 473 square meters, with an elongated rectangular footprint. The targeted depth of the UG2 in Block A ranges between 40m and 80m. At the time of the visit, no permanent building structures were present on the area denoted as Block A (Figure 1). Although no structures are present directly above the proposed Block A, there are considerable structures within a 100m horizontal distance from Block A. Structures include offices, warehouses, roads and a smelter. It should further be noticed that there is evidence of renewed activity on the land above the proposed block, this includes new fences being put up, and diggings that appear to be foundations.

A Google Earth image of the proposed Block A is depicted in Figure 12. Note the proposed mining block highlighted with a red rectangle.

Figure 12: Google image of Block A (annotated in red)

4.2.2 Block B

Block B comprise 219 663 square kilometers in an elongated rectangle footprint. Similar to Block A, the targeted UG2 lies between 40m and 80m below surface. Considerable development has taken place directly above Block B. Development includes warehouses, offices and infrastructure such as electrical and road installations.

A Google Earth image of the proposed Block B is depicted in Figure 13. Note the proposed mining block highlighted with a blue rectangle.

Figure 13: Google image of Block B (annotated in blue)

4.2.3 Block C

Block C comprise of an area of 1 852 287 square meters219 663 square kilometers in an elongated rectangle footprint. The targeted UG2 lies between 40m and 160m below Block C. As with Block B, considerable development is situated above the proposed mining block. However, development is more residential inclined, with more than 250 houses, a school, and some offices located directly above the proposed block.

A Google Earth image of the proposed Block C is depicted in Figure 14. Note the proposed mining block highlighted with a green rectangle.

Figure 14: Google image of Block C (annotated in green)

4.2.4 Surface Site Visit Conclusions

- The following is noted from the surface inspection:
  - In all three Blocks under scrutiny, current or future development is present,
  - In Blocks A and B, development is confined to businesses/commercial properties,
  - In Block C, development includes mostly residential properties, but also some businesses.
- These aspects are particularly important for the following reasons:
  - Subsidence and/or tilt tolerances are different for different property types and/or applications (residential house vs. six-story plant tower/silo),
  - Blasting time exposure, and perceived vibration and/or air-blast will be different from residential, to commercial properties.

4.3 Core Inspections

Geological and/or geotechnical core is not available for any of the three areas of interest. As an alternative, and to inspect weathering profiles, the first 50.0m of six exploration holes were laid out for inspection by OHMS. The holes were from the Bathopele project located East of the project area under consideration. The holes inspected were:

- WV333 TRAY 1-6
- WV589 TRAY 1-6 – Tray 5 & 6 Missing
- WV584 TRAY 1-5 – Tray 4 Missing
- WV585 TRAY 1-4 – Tray 3 Missing
- WV604 TRAY 1-6
- WV605 TRAY 1-6

Although not all the holes under scrutiny were complete, making assessing of weathering profiles difficult, it was possible to make some observations relating to the core:

- Weathering extends up to a depth of around 20m – 25m below surface for the holes that was observed,
- Weathering profile is dependent of the rock type at the exposed surface, i.e., Anorthosite appear to be more competent than Norite, as the weathering depth in Norite appear to extend deeper,
- Norite weathers to form clay, in some cases up to 3m thick, clay act to seal the rock below off from water and thereby delaying weathering of the material,
- Water is still able to penetrate discontinuities cutting across various rock units, albeit to a lesser extent when clay is present.

5. Geotechnical Stability Assessment

This section assesses the likely safe minable spans, pillar sizes and probable local support requirements. Because span, and pillar sizes are mutually dependent, maximum stable spans will be assessed prior to assessing the required pillar sizes for the stable spans that were selected.

5.1 Stable Spans

In order to determine a suitable starting point for the design of safe minable spans in between pillars, the Stability Graph Method was employed. The method was developed by Potvin in 1988 and modified on numerous occasions throughout the years. The empirical formulae and various required input parameters are explained as part of this report in Appendix A. In 2003, Watson and Roberts (Watson, 2003) found good correlation between stable and unstable cases predicted by the Stability graph, and Bushveld Platinum mine cases.

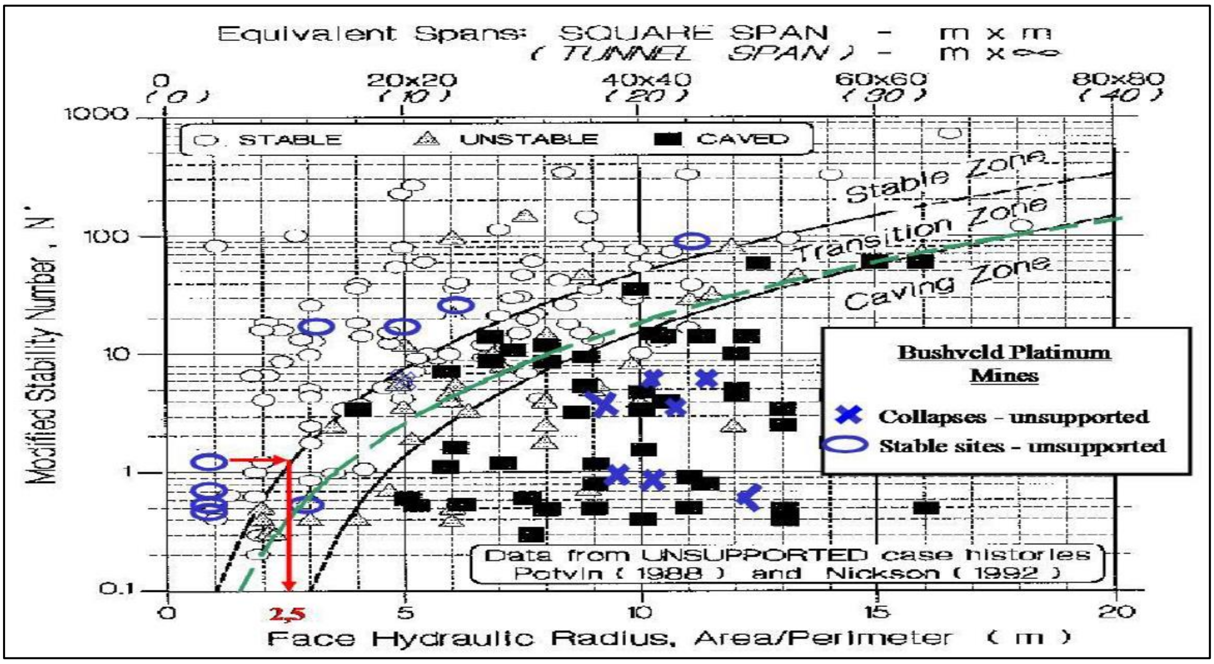


Figure 15: Stability graph method with Bushveld Platinum mine cases plotted (Watson, 2003)

The x-axis on the Stability Graph represents the hydraulic radius of a particular excavation. The hydraulic radius is a shape factor that considers the ratio between the area, and perimeter of an excavation. Once the ratio between the span and length of an elongated excavation is > 5, the impact on hydraulic radius is minimal. Typical spans considered in Bushveld bord and pillar mines ranges between 4m and 12m wide. The subsequent hydraulic radii of these excavations (considering a length 5 times the span) are tabulated in

Table 3.

Table 3: Tabulating calculated hydraulic radii for various stope spans

Span	Length	HR
4m	20m	1.7

6m	30m	2.5
8m	40m	3.3
10m	50m	4.2
12m	60m	5.0

By plotting these hydraulic radii values on the Stability Graph, a range of Stability Numbers required to honor the particular stope spans are attained. From Figure 16, it is evident that Stability numbers of between 0.25 and 7.3 is required to mine bord spans of between 4.0m and 12.0m.

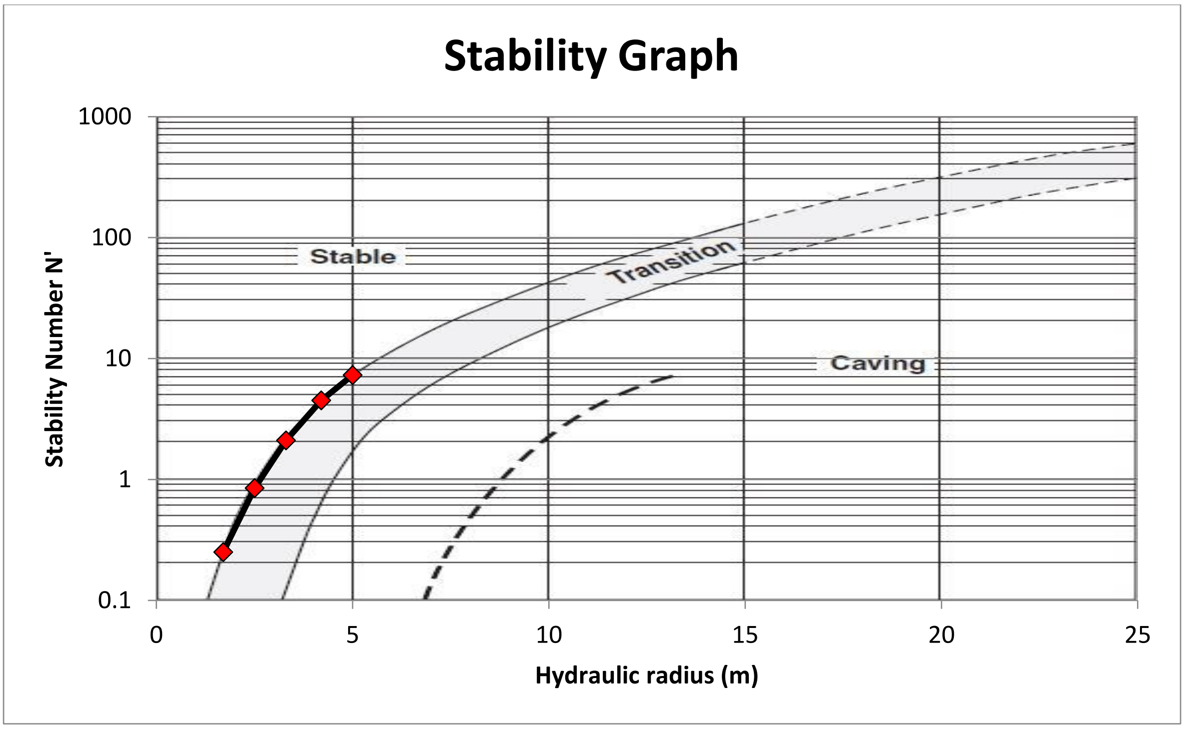


Figure 16: Required Stability Numbers for each of the span under scrutiny

The Client has made available the Mine's rock mass classification database for incorporation into the design. The database contained numerous spreadsheets with rock mass classification data captured on a daily basis by the Strata Control Officers on the mine. In order to assess the likely Stability Numbers closest to the project areas, the data was filtered so as to calculate the Q' values of section North 1 (considered the closest to the Western project areas Block A and Block B) and South 4 (considered closest to the Eastern project area Block C). In total, some 318 data points was used in the assessment. Histograms of the attained Q' values are depicted in Figure 17 and Figure 18. The derived Q' value for various confidence levels is tabulated in Table 4. Note that the selected Q' (and Q values earlier in the report) was informed by the distribution of the histograms, where higher confidence levels were selected where data permits.

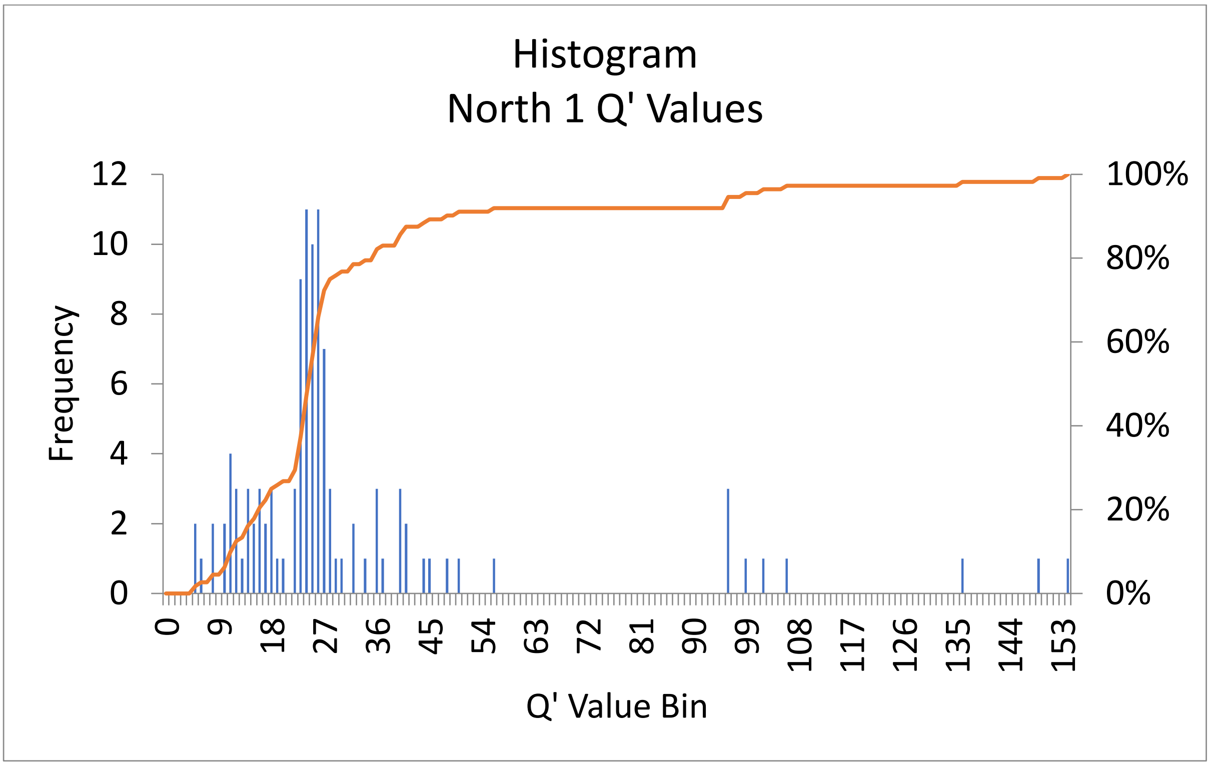


Figure 17: Histogram of North 1 Q' values representing the Western areas of the project area

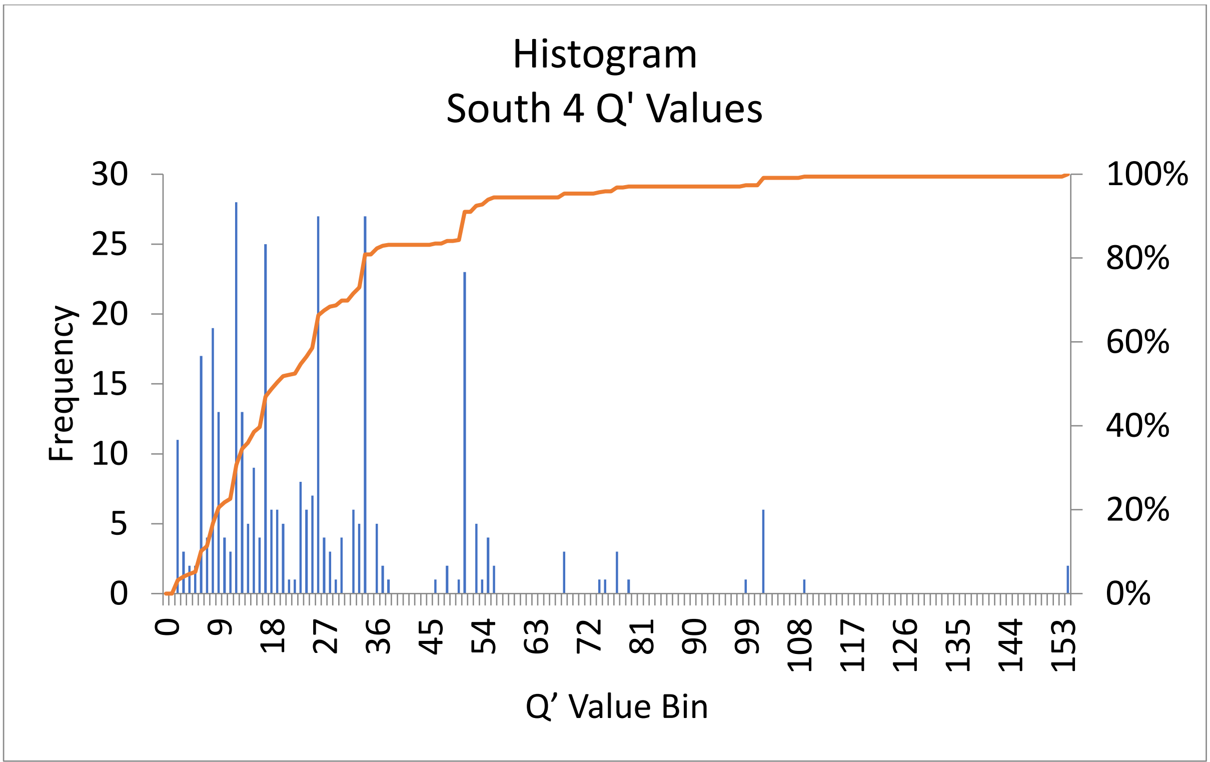


Figure 18: Histogram of South 4 Q' values representing the Eastern areas of the project area

Table 4: Tabulating Q' values for various confidence levels

Confidence Level	Q' Value North 1	Q' Value South 4
99%	4.6	1.4
95%	9.0	5.0
50%	24.6	18.5

The A parameter required for the derivation of the Stability Number was assessed by assigning a UCS of the hanging wall material of 135MPa (Sibanye Stillwater, 2020). A conservative maximum induced stress of 10MPa was assumed to obtain a ratio between UCS and Induced Stress of 13.5, resulting in an A Factor of 1 (Figure 19).

The B parameter requires a measurement of the most critical joint set, and the hanging wall. Because there is foliation/bedding present, these structures will be oriented parallel to the hanging wall and thus the true angle between the 'face' and discontinuity will be 0 degrees, resulting in a B Factor of 0.4 (Figure 19).

The C parameter is simply the dip of the design service under scrutiny. In the case of this assessment, the dip is in the region of 12 degrees, and therefor a C Factor of 4 is attained (Figure 19).

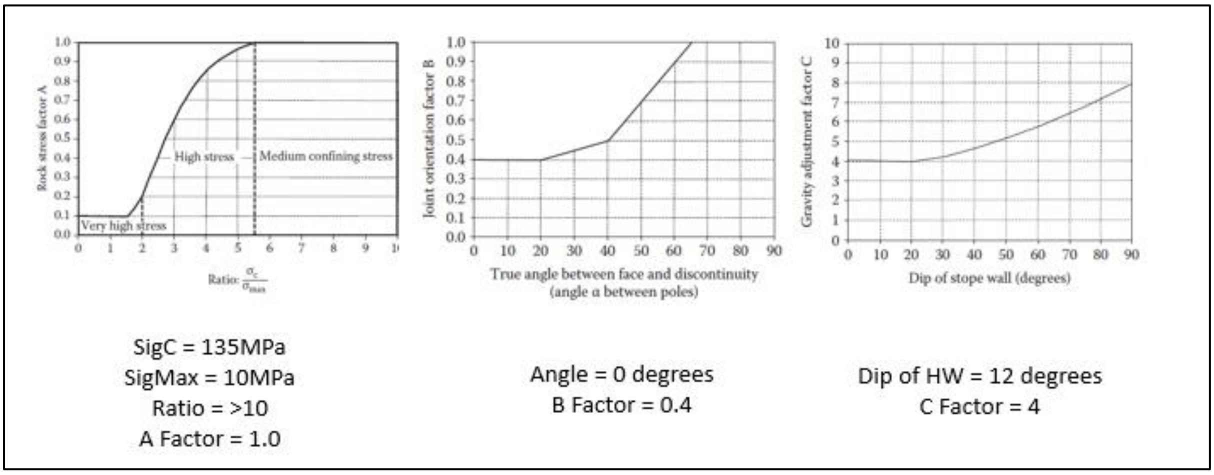


Figure 19: Derivation of A, B and C Factors

The calculation of the Stability Number N' is tabulated in Figure 5. The N' value is simply the product of Q', A Factor, B Factor and C Factor for the North 1, and South 4 sections. From Table 5, it is evident that the N' parameter for the Eastern sections is in the region of 2.2, and 7.4 for the Western Sections.

Table 5: Tabulating the calculation of N' for the two cases

	North 1 (Western Sections)	South 4 (Eastern Sections)
Q'	4.6	1.4
A Factor	1.0	1.0
B Factor	0.4	0.4
C Factor	4.0	4.0
N'	7.4	2.2

Plotting these values on the Stability Graph provides stable hydraulic radii of 3.3m for the Eastern sections, and 5.0m for the Western sections (Figure 20). Referring to Table 3, a hydraulic radius of 3.3m amounts to a panel span of 8.0m, and hydraulic radius of 5.0m to a panel span of 12.0m.

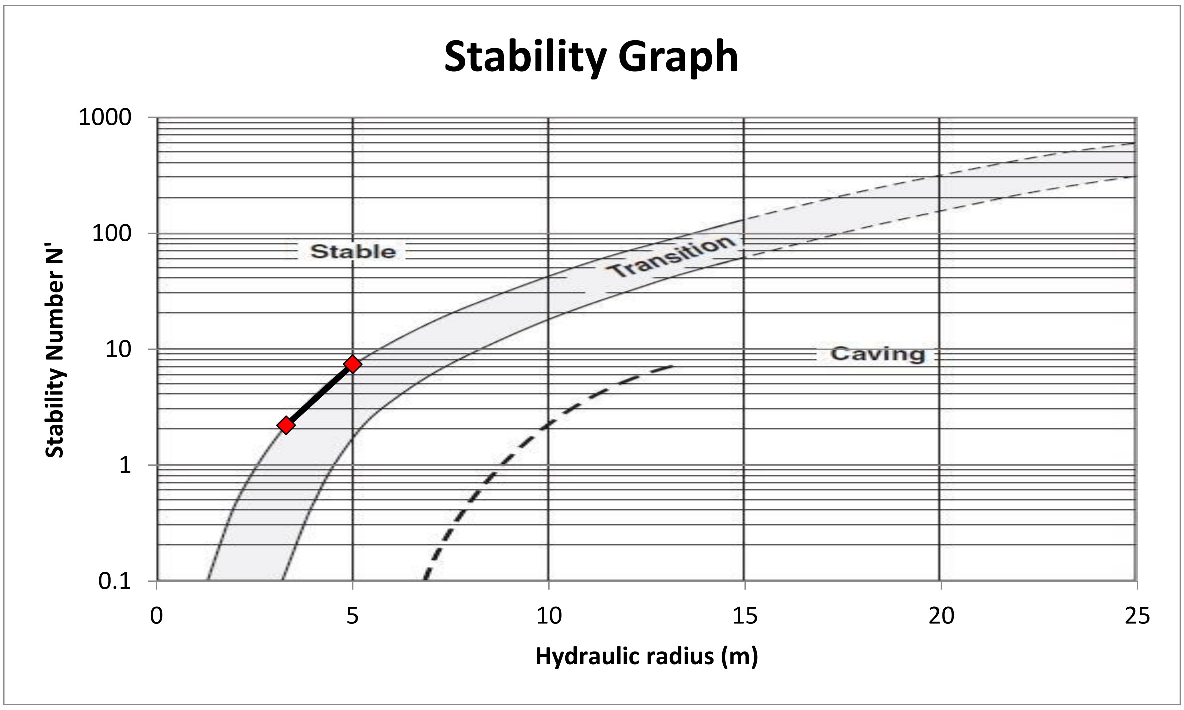


Figure 20: Achieved stable hydraulic radii for Stability Numbers of 2.2 and 7.4

It must be noted that the Stability Graph method was originally developed for non-entry method and unsupported open stopes. Furthermore, the method does not consider the influence of water on stability. Therefore, as standard practice and as recommended by numerous experts, more than one rock mass classification, as well as empirical approaches need to be used in the design of excavations.

A method proposed by Barton (Barton N. R., 1988) considers the no-support limit for various spans based on the importance of the excavation (ESR). For this, the Q-rating is required. The calculated Q ratings derived from the database is tabulated in Table 6. Note that as a start, dry conditions are considered however, considering water will reduce the derived Q ratings to 66% of the dry value assuming that medium inflow of water will be present with occasional outwash of joint fillings (many drips/”rain”). The wet Q values are tabulated in Table 7.

Table 6: Tabulating derived dry Q ratings for various confidence levels.

Confidence Level	North 1 (Western Sections)	South 4 (Eastern Sections)
99%	3.1	0.9
95%	6.0	3.3
50%	14.0	12.3

Table 7: Tabulating derived wet Q ratings for various confidence levels.

Confidence Level	North 1 (Western Sections)	South 4 (Eastern Sections)
99%	2.0	0.6
95%	4.0	2.2
50%	9.2	8.1

The 95% confidence Q values was plotted on the design chart proposed by Barton. The outcome of the assessment is depicted in Figure 21 with dry conditions depicted in red, and wet conditions depicted in blue. Note that an ESR of 1.6 was selected based on the description on the proposed chart, i.e., permanent mine openings. For a 95% confidence, the graph suggests panel spans of between 5.9m and 7.5m for dry conditions and an ESR of 1.6, and spans of between 5m and 6.5m for wet conditions and an ESR of 1.6.

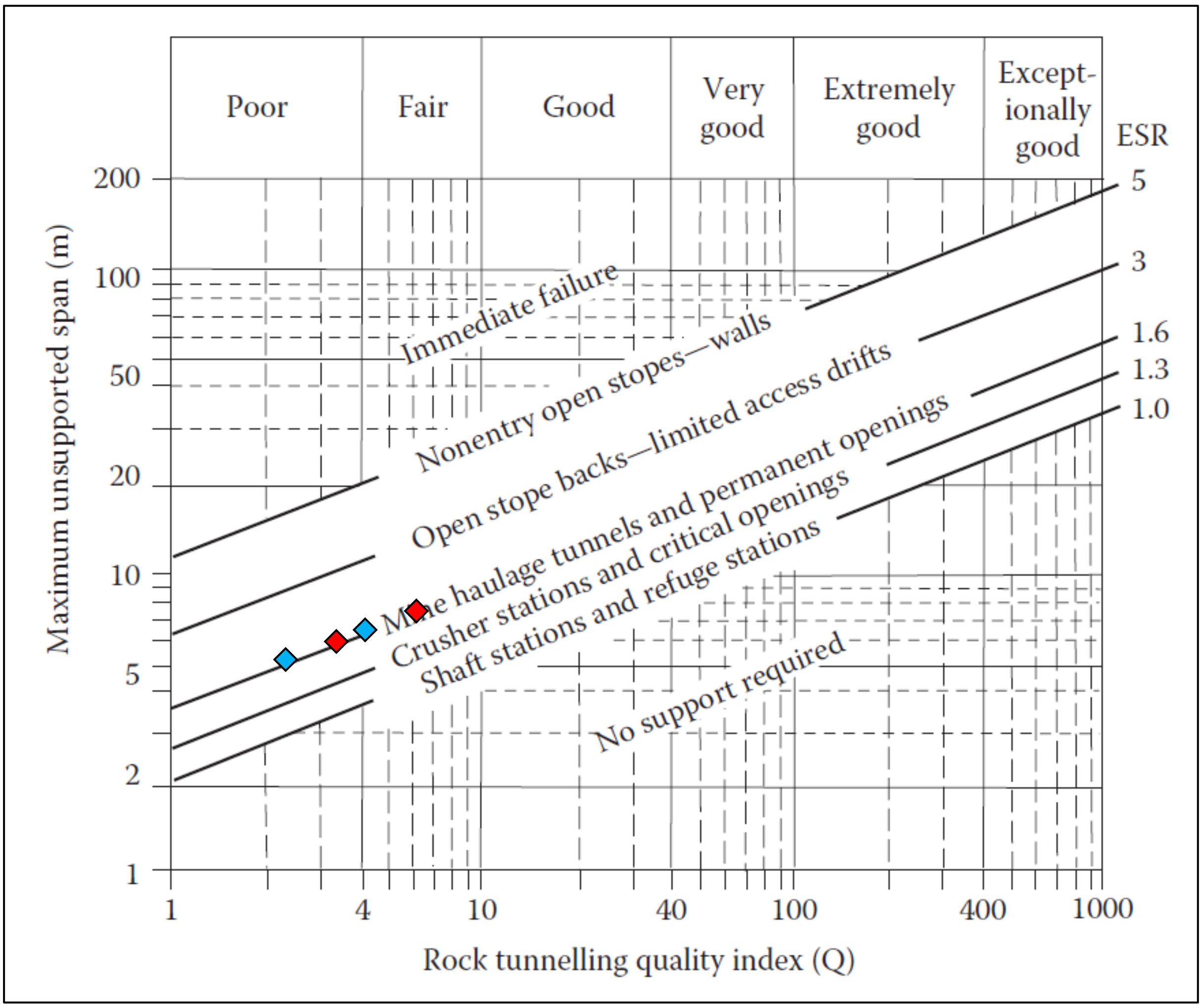


Figure 21: Maximum unsupported span assessment (Barton N. R., 1988)

The methodologies considered proposed maximum stable unsupported spans however, it does not provide an indication of the stand-up time. Stand-up times is important as sufficient time must be available between blasts to enable support to be installed. To assess the likely standup times for the given spans, the methodology proposed by Bieniawski (Bieniawski, 1989) was utilized. However, RMR is required. These were assessed from the rock mass classification database, and the dry results tabulated in Table 8, with wet results tabulated in Table 9.

Table 8: Tabulating dry RMR values from the mine database vs. confidence level.

Confidence Level	North 1 (Western Sections)	South 4 (Eastern Sections)
99%	38	40
95%	43	43
50%	50	60

Table 9: Tabulating wet RMR values from the mine database vs. confidence level.

Confidence Level	North 1 (Western Sections)	South 4 (Eastern Sections)
99%	34	36
95%	40	40
50%	45	55

The 95% confidence level dry RMR for the Western and Eastern sections is 43, and wet RMR 40. These values were plotted on the graph proposed by Bieniawski (Bieniawski, 1989) at the minimum panel span (5.0m), and maximum panel span (12.0m) based on the assessments of Figure 20 and Figure 21, and the outcome is depicted in Figure 22.

From the outcome of the stand-up time assessment, it is evident that at a panel span in excess of 7.0m, the stand-up time is less than one day for dry conditions, and less than a day for a panel of more than 5.0m in wet conditions.

It follows that dry conditions can have a maximum span of 6.0m, with an unsupported standup time of 1 day, and a maximum span of 4.0m with a standup time of 1 day. Consequently, a wet excavation can be mined at a 6.0m span but will need to be supported within approximately half a day.

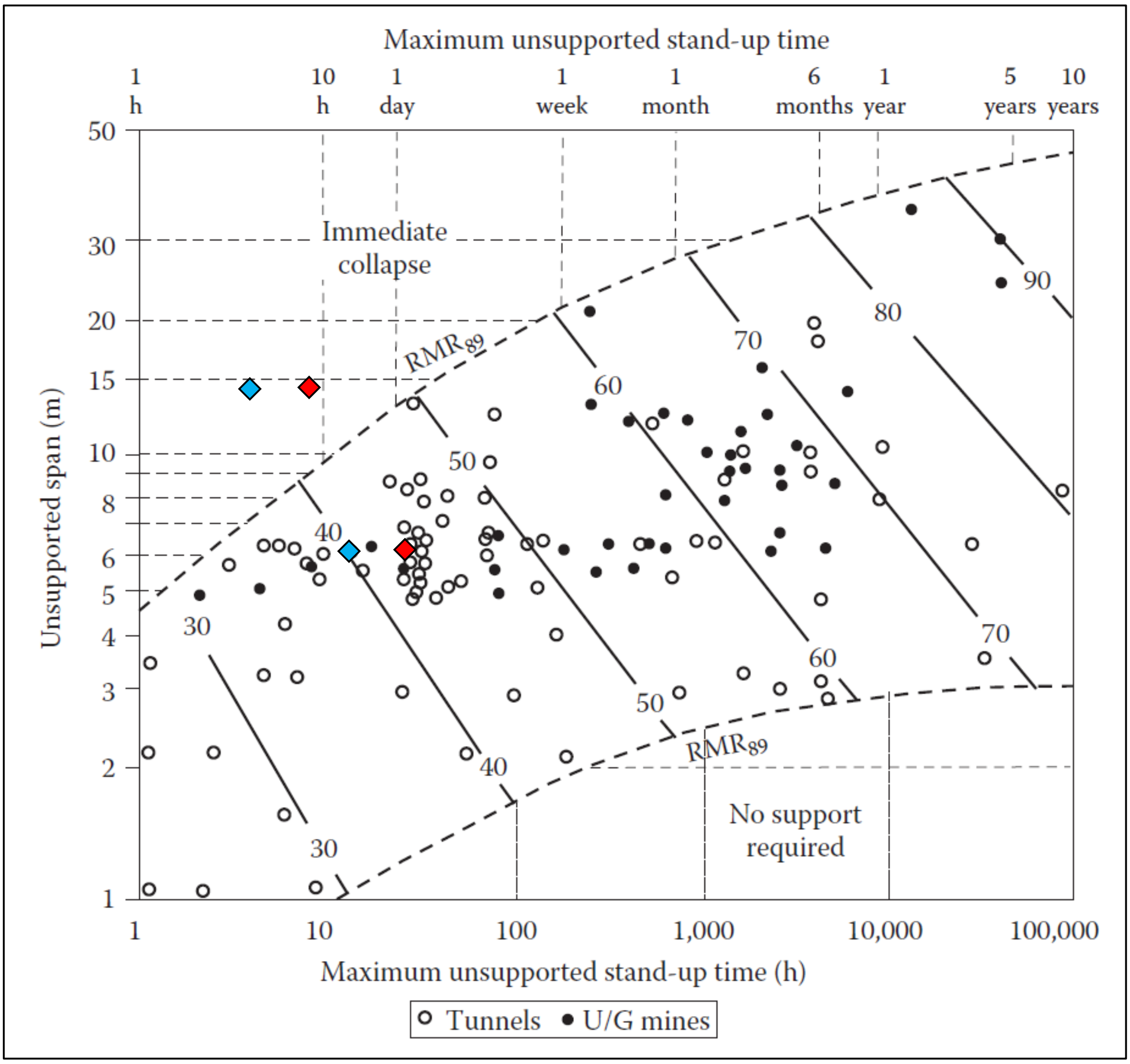


Figure 22: Stand-up time design chart (Bieniawski, 1989)

5.1.1 Stable Span Conclusions

Empirical assessments recommend stable spans of between 5m and 12m. However, considering water, and a minimum stand-up time of 1 day prior to supporting requires a maximum panel span of 6.0m.

Where water is intersected in a 6.0m panel, support will need to be installed within one shift. Where this is not feasible, panels spans need to be reduced to 4.0m.

5.2 Stable Pillars

A literature survey was conducted in order to assess typical design criteria used in the Bushveld rocks for pillar design. The outcome of the survey is tabulated in Table 10.

Table 10: Tabulating literature survey design criteria

Min. FOS	Min. W:H	Max. Extraction	Source	Comment
2	5	85%	Baker, 1991	Based on success with previous studies in Bushveld rocks
2.5	NA	NA	Harvey, 2004	Based on success with previous studies in Bushveld rocks
NA	5	NA	Ozbay & Ryder, 1995	Based on success with previous studies in Bushveld rocks

It must be noted that the typical stoping width where the literature survey was conducted is around 1.0m resulting in pillars of approximately 5.0m wide. In the case of Kroondal West, the stoping width will be closer to 2.0m. In the author's experience, UG2 pillars with a minimum width to height ratio of 3.0 will be sufficient in a non-yield pillar layout (resulting in minimum 6.0m wide pillars), especially if the other two criteria (extraction ratio and factor of safety) are also met.

The Hedley-Grant (Hedley & Grant, 1972) pillar strength methodology was followed to assess pillar stability for the areas under consideration. For the interested reader, the methodology is explained in Annexure B to this report. The input parameters for the assessment were sourced from the min's COP (Sibanye Stillwater, 2020) and is tabulated in Table 11.

Table 11: Pillar design input parameters

	Value	Source	Comment
Rock Density	2,850kg/m3	COP, 2018	
Material Strength	54MPa	COP, 2018	Used for mining depths < 150m.
Stoping Width	2.0m	COP, 2018	
UCS UG2	76MPa	COP, 2018	Lower bound SicCi for reef

Although the COP prescribes the use of 54MPa as the material strength for depths below 150m (i.e., K parameter in the Hedley-Grant method), OHMS assessed an additional value of 28MPa, derived after downgrading the UCS by means of a RMR value of 40 (refer to Appendix B for calculations).

Using the input parameters, the pillar strength could be calculated for various width to height ratios. The outcome of this assessment is depicted in Figure 23.

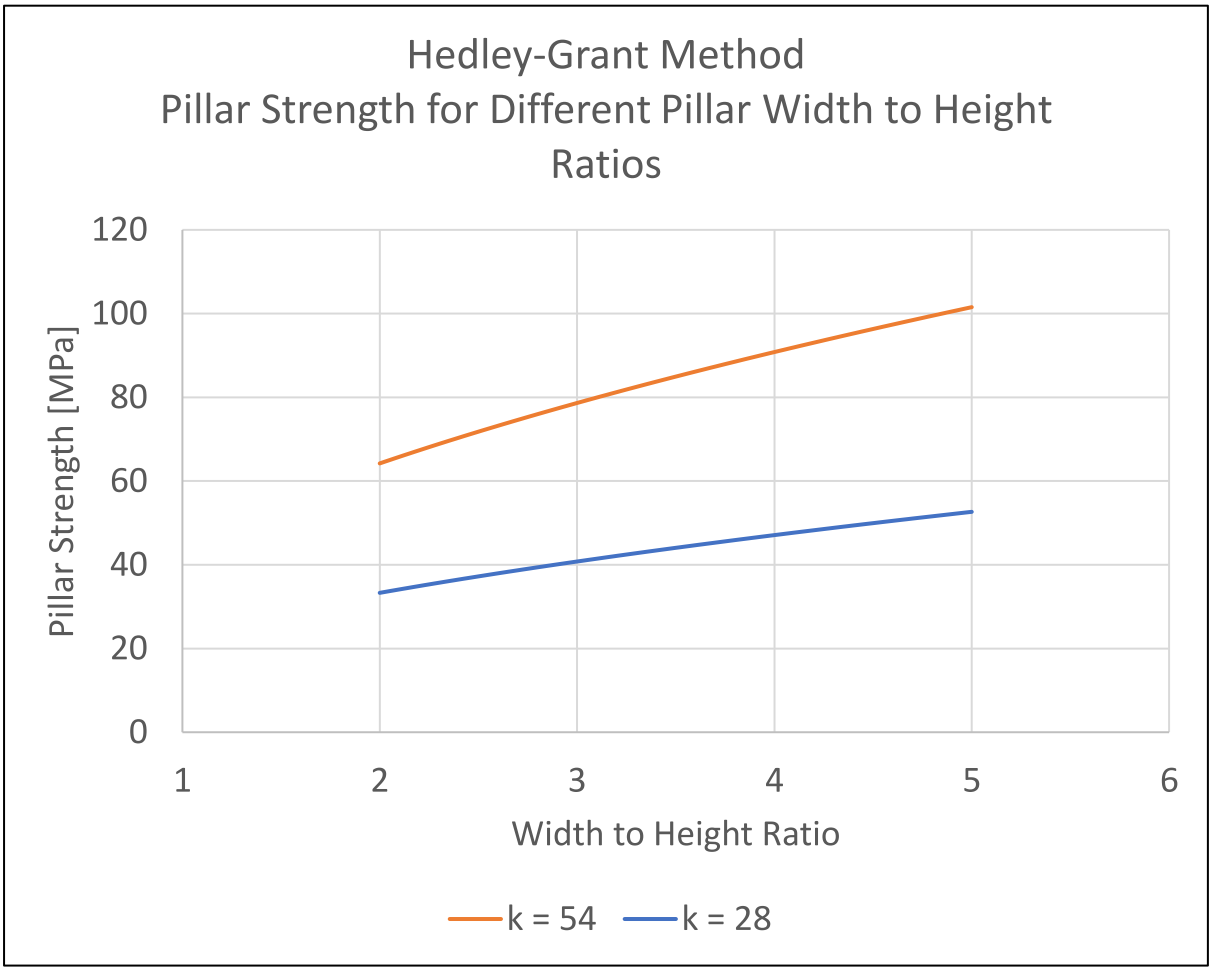


Figure 23: Pillar strength as a function of Width to Height ratio for two material strengths

Assuming the worst-case scenario, that each pillar carries the load up to surface, the factor of safety for pillars with width to height ratios of 3, and 4 was calculated. The outcome of the assessment is presented in Figure 24. It is evident from the analyses, that the worst-case factor of safety at a depth of 80.0m is around 5 and increases to around 9 at a depth of 40.0m.

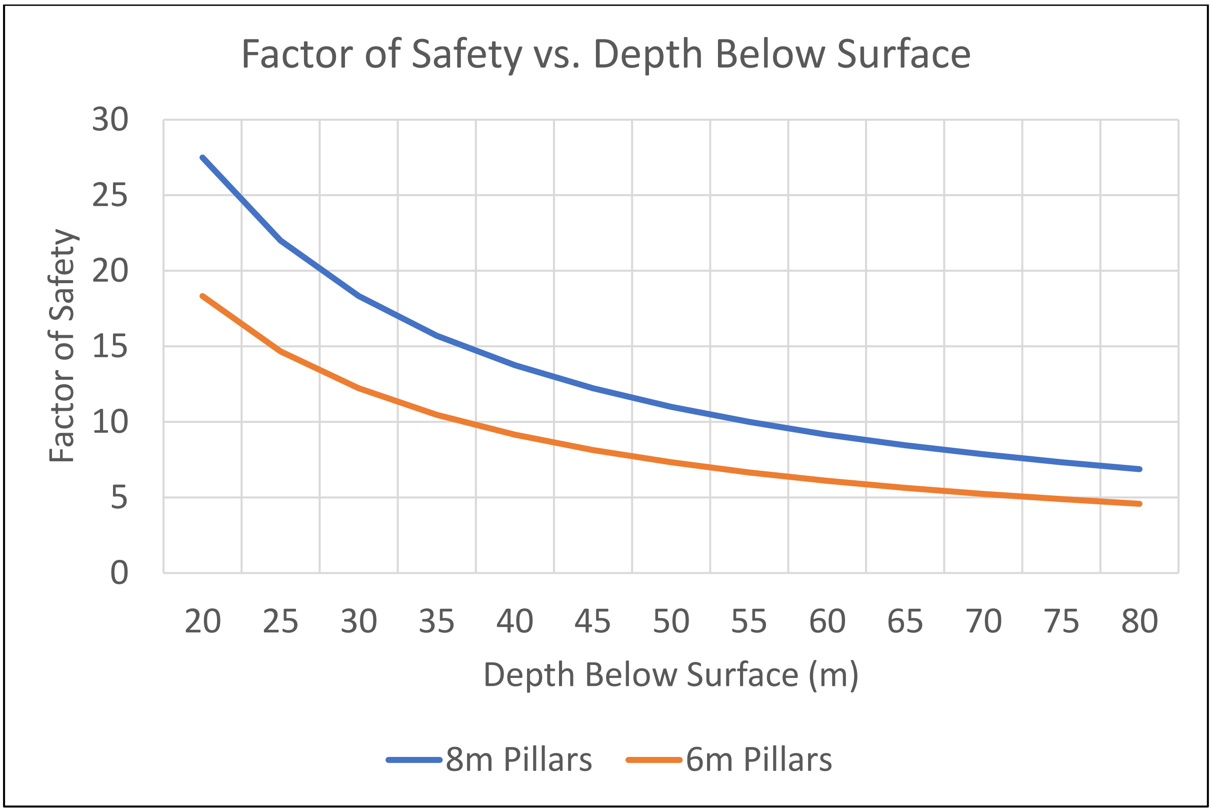


Figure 24: Factor of Safety vs. Depth Below Surface

5.2.1 Stable Pillars Conclusion

- From the stable pillar assessment, the following is concluded:
  - Although historic industry guidelines suggest pillars with width to height ratios of > 5 be employed, these were based on stoping widths of typically 1m, and conventional stopes,
  - More recent suggestions in the Bushveld Complex suggest that pillars with width to height ratios > 3 is deemed acceptable for bord and pillar mines,
  - Thus, 8m wide pillars employed in the project areas yield width to height ratios > 3, with sufficient margin for overmining, both in terms of pillars, and stoping width,
  - Factors of safety attained for 8m pillars are > 6.6 at a depth of 80.0m increasing to some 14 at a depth of 40.0m below surface.

6. Blasting and Vibration

Undermining surface structures by means of drilling and blasting will result in the said surface structures experiencing some form of vibration. These vibrations are typically measured as peak particle velocities, and reported in mm/sec. In South Africa, guidelines in terms of maximum allowable PPV's is not readily available and thus, the guidelines set out by the United States Bureau of Mines (USBM) are typically used. The guidelines prescribed by the USBM is tabulated in Table 12.

Table 12: Ground vibration limits as per USBM

Structure Description	Ground Vibration Limit (mm/sec)
National Roads/Tar Roads	150
Electrical Line (Pylons)	75
Railways	150
Transformers	25
Gas/Fuel Lines	25
Water Wells	50
Telecoms Tower	50
General Houses of Proper Construction	25
Houses of Less Proper Construction	12.5
Rural Buildings – Mud Houses	6

Empirical and theoretical calculations exist that can be used to assess the likely PPV caused by a blast hole. It is generally accepted, that blast holes initiated > 8 milliseconds apart can be assessed individually. However, once the delay becomes shorter i.e., < 8 milliseconds, vibrations will be a function of the sum of the two explosive charges.

PPV's were calculated for various face advances using a single 30mm diameter blast hole and repeated for two holes being set of with delays less than 8 milliseconds. The outcome of the analyses is depicted in graphical form in Figure 25 and Figure 26.

Given the fact that mining is not planned closer than 40.0m from surface, the 40.0m below surface point on the graph can be regarded as the worst-case scenario.

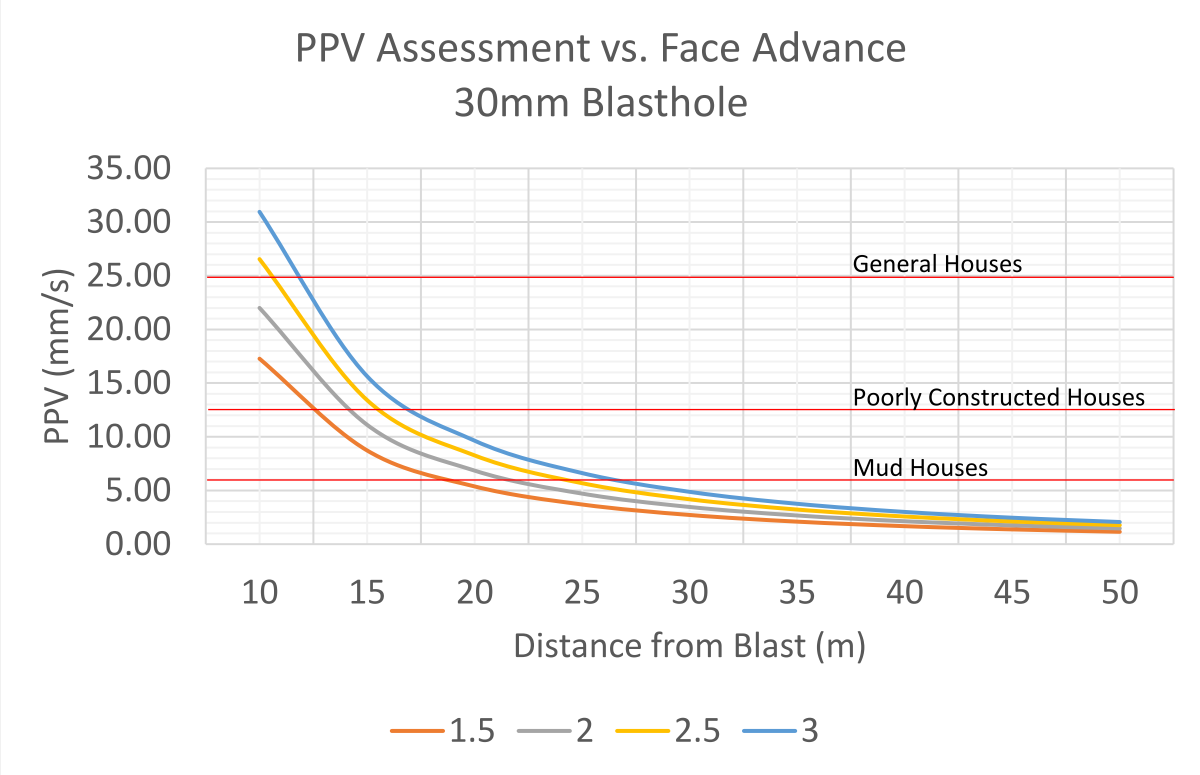


Figure 25: PPV for a single 30mm blasthole as a function of distance and face advance.

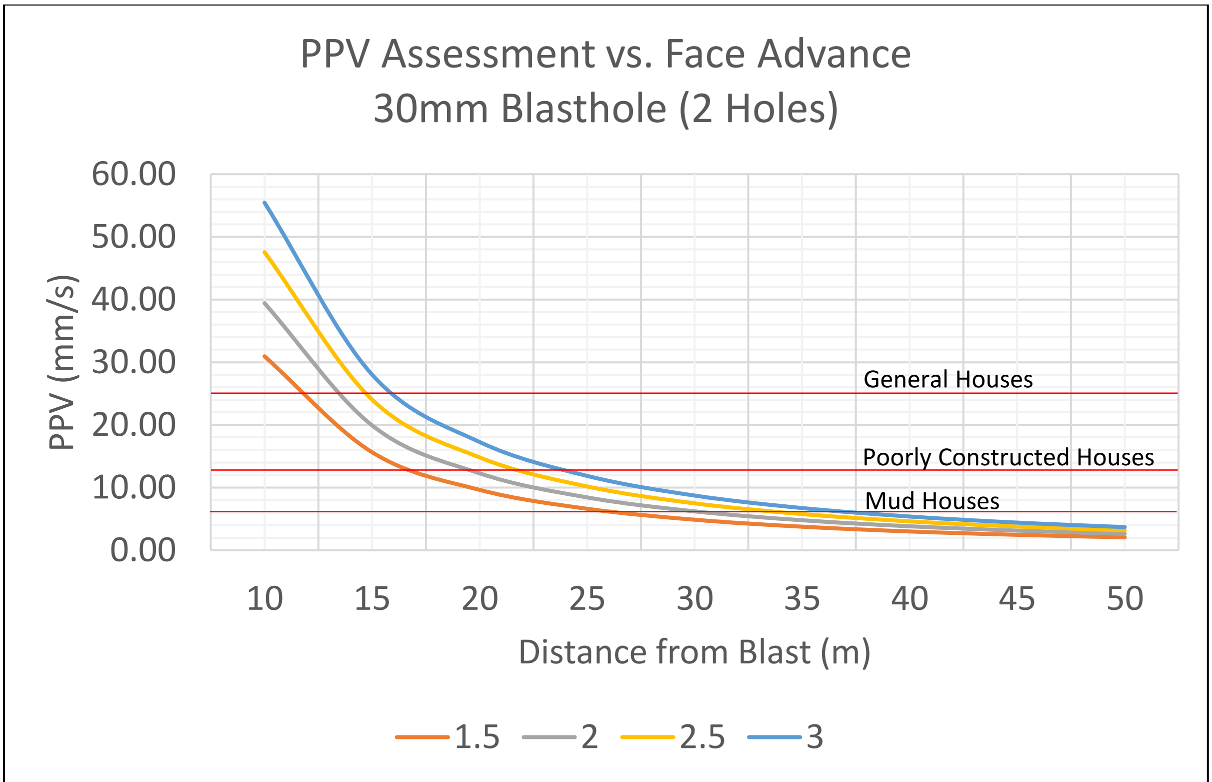


Figure 26: PPV for double 30mm blastholes as a function of distance and face advance.

6.1.1 Blasting Vibration Monitoring

It is prudent that blast vibration monitoring takes place throughout the project for the following main reasons:

- To calibrate blast vibration data with the empirical and theoretical calculations, and update the design and recommendations where and when required, and
- To assist with any public queries and/or claims that damage to housing or infrastructure is caused by mining activity.

The number of sensors required for the project will rely heavily on the number of isolated sections mining. At least one sensor per half level mined (over an area of some 8 panels), located as close as possible, vertically above the mining. Additional sensors will be required at the position of key buildings and infrastructure. These includes:

- The Smelter in Block B,
- The Silo just South of Block B,
- Selected houses in the neighbourhood of Block C,
- The school,
- Key position along the railway line,
- And any sensitive point of interest.

With the knowledge available at the time of this report, it is envisaged that at least 12 sensors be required, of which at least 8 will be permanent fixtures, and four mobile. Typical sensors used for this purpose, along with parameters and specifications, are attached to this report as Appendix C.

6.1.2 Blast Vibration Conclusions

For a single blast hole, none of the face advances exceed any of the damage criteria set by the USBM at a depth of 40.0m. The 6mm/sec criteria are however exceeded at a depth of 20.0m for a 1.5m advance, and at a depth of 28.0m for a face advance of 3.0m.

For blasts where to holes are set off within an 8-millisecond window, only the 3.0m advance rate exceeds the 6mm/sec criteria at a depth of 40.0m. The 6mm/sec criteria are exceeded at 25.0m for a 1.5m face advance, and at 37.0m at a 3.0m face advance.

Some 12 vibration sensors, similar to those detailed in Appendix C is envisaged for a project of this magnitude, 8 of which will be permanent installations.

7. Project Conclusions

This section summarizes the conclusions of the assessment:

7.1 Underground Inspection

The intact rock appears less weathered than typically expected for the depth under consideration, when compared to experience in Bushveld rocks in the Eastern Bushveld. It is believed that this may be a result of the thick clay (weathered Norites) that typically overlies the Bushveld rock in the Western Bushveld (this topic will be further discussed on the core observations). Weathering associated with particular joint sets is however present.

It appears as though horizontal contacts are better developed as one mine closer to surface. This results in pillars being less forgiving when overmined, or when major geological structures traverse them.

Where significant or out of the ordinary geological discontinuities are encountered (faults, shears, dykes, etc.), their associated areas of influence appear to be greater than in deeper parts of the mine.

Although the same three joint sets are present in both the Eastern, and Western sections of the mine, the orientation of the various joint sets differ towards the East and West.

7.2 Surface Inspection

In all three Blocks under scrutiny, current or future development is present and in Blocks A and B, development is confined to businesses/commercial properties. In Block C, development includes mostly residential properties, but also some businesses.

These aspects are particularly important as subsidence and/or tilt tolerances are different for different property types and/or applications (residential house vs. six-story plant tower/silo), and blasting time exposure, and perceived vibration and/or air-blast will be different from residential, to commercial properties.

7.3 Stable Spans

Empirical assessments recommend stable spans of between 5m and 12m. However, considering water, and a minimum stand-up time of 1 day prior to supporting requires a maximum panel span of 6.0m.

Where water is intersected in a 6.0m panel, support will need to be installed within one shift. Where this is not feasible, panels spans need to be reduced to 4.0m.

In all three Blocks under scrutiny, current or future development is present and in Blocks A and B, development

7.4 Stable Pillars

Although historic industry guidelines suggest pillars with width to height ratios of > 5 be employed, these were based on stoping widths of typically 1m, and conventional stopes. More recent suggestions in the Bushveld Complex suggest that pillars with width to height ratios > 3 is deemed acceptable for bord and pillar mines.

Thus, 8m wide pillars employed in the project areas yield width to height ratios > 3, with sufficient margin for overmining, both in terms of pillars, and stoping width. Factors of safety attained for 8m pillars are > 6.6 at a depth of 80.0m increasing to some 14 at a depth of 40.0m below surface.

7.5 Blast Vibration and Monitoring

For a single blast hole, none of the face advances exceed any of the damage criteria set by the USBM at a depth of 40.0m. The 6mm/sec criteria are however exceeded at a depth of 20.0m for a 1.5m advance, and at a depth of 28.0m for a face advance of 3.0m.

For blasts where to holes are set off within an 8-millisecond window, only the 3.0m advance rate exceeds the 6mm/sec criteria at a depth of 40.0m. The 6mm/sec criteria are exceeded at 25.0m for a 1.5m face advance, and at 37.0m at a 3.0m face advance.

Some 12 vibration sensors, similar to those detailed in Appendix C is envisaged for a project of this magnitude, 8 of which will be permanent installations.

Appendix A – Stability Graph

The Stability Graph Method was used to quantify the state of stability of the various stope walls. The Stability Graph Method is effectively a modification of the Q system (Barton, Lien, & Lunde, Engineering classification of rock masses for the design of tunnel support, 1974). The method relates a stability number (N') to a stope wall hydraulic radius by means of various design curves, which are based on empirical data. Based on where the stope lies on the curve, a level of stability can be predicted.

The stability number is defined as follows:

$$\boldsymbol{N = Q' \times A \times B \times C} \qquad [1]$$

Where

Q'	is the NGI Q rock mass classification value with SRF and JW denoted 1
A	is a stress factor
B	is a rock defect orientation factor
C	is a design surface orientation factor

Date: 19/08/2021

Working Place: North 1

Cavability Calculation:

Stability Number formula:

N'=Q'ABC

Calculate Q':

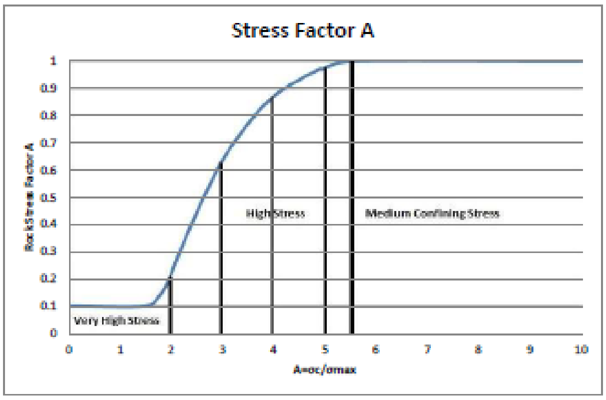
$$Q' = \frac{RQD}{J_n} \times \frac{J_r}{J_a}$$

Q'=	0	0
	0	0
Q'=	4.6	

Parameter	Value
RQD	
Jn	
Jr	
Ja	

You need to provide the mapping info for the orebody.

Result: 4.6



Calculate A:

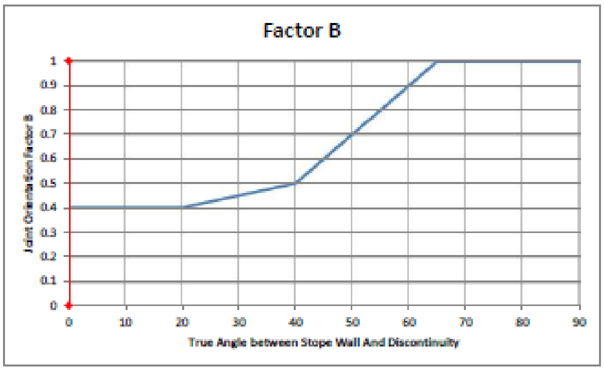
A=	σc	
	σmax	
A=	135	
	10	
A=	13.5	

Parameter	Value
σc	135
σmax	10

Graph

X	Y
13.5	0
13.5	1

Result: 1



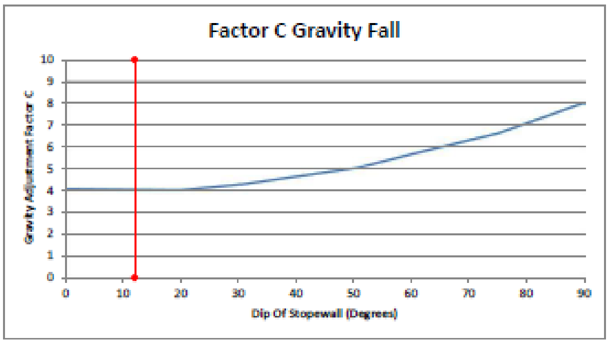
Calculate B:

True Angle between discontinuity and a stope wall: 0

Graph

X	Y
0	0
0	1

Result: 0.4



Calculate C:

Gravity fall or slabbing:

Dip of stope wall: 12

Graph

X	Y
12	0
12	10

Result: 4

Calculate Stability Number:

For Gravity Fall

N'=	Q'ABC
N'=	7.4

Graph

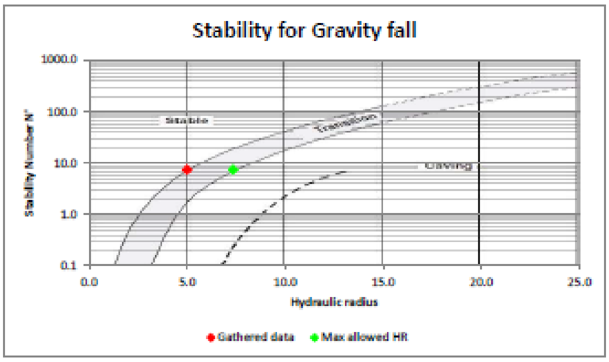
X	Y
5.0	7.4

Calculate Hydraulic Radius:

HR=	H*L / 2(H+L)
HR=	720 / 144
HR=	5.0

Parameter	Value
Length	60
Width	12

Result: 5.0



Maximum Hydraulic Radius:

$HR_{allowed}$= 7.3

Parameter	Value
N'	7.4
Exponent 1	0.573
Exponent 2	0.338

$$HR_{allowed} = 10^{[0.573+0.338 \log N']}$$

Maximum stope length:

L=	2(H)(HR) / H-2(HR)
L=	881.4261832 / 45.30956361
L=	19.5

Signatures:

Name	Designation	Sign

Date:	19/08/2021
Working Place:	South 4

Cavability Calculation:

Stability Number formula:

N'=Q'ABC

Calculate Q':

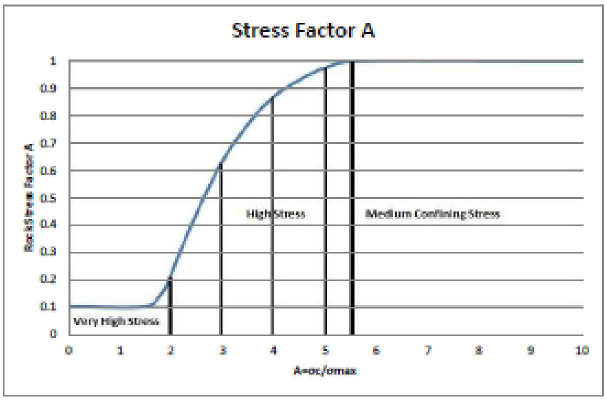
$$Q' = \frac{RQD}{J_n} \times \frac{J_r}{J_a}$$

Q'=	0	0
	0	0
Q'=	4.6	

Parameter	Value
RQD	
Jn	
Jr	
Ja	

You need to provide the mapping info for the orebody.

Result: 1.4



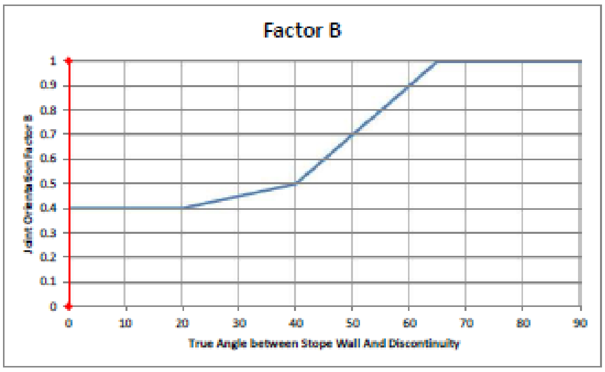
Calculate A:

A=	σc
	σmax
A=	135
	10
A=	13.5

Parameter	Value
σc	135
σmax	10

Graph	
X	Y
13.5	0
13.5	1

Result: 1



Calculate B:

True Angle between discontinuity and a stope wall:

0

Graph	
X	Y
0	0
0	1

Result: 0.4

Calculate C:

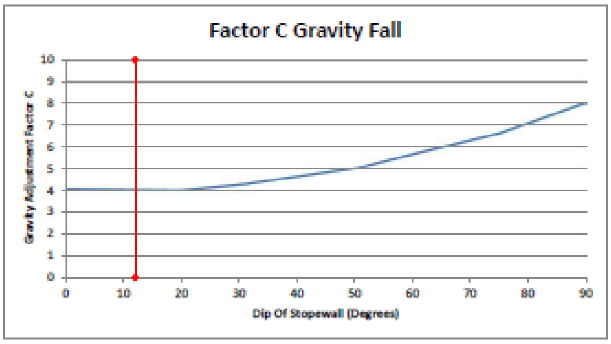
Gravity fall or slabbing:

Dip of stope wall:

12

Graph	
X	Y
12	0
12	10

Result: 4



Calculate Stability Number:

For Gravity Fall

N'=	Q'ABC
N'=	2.2

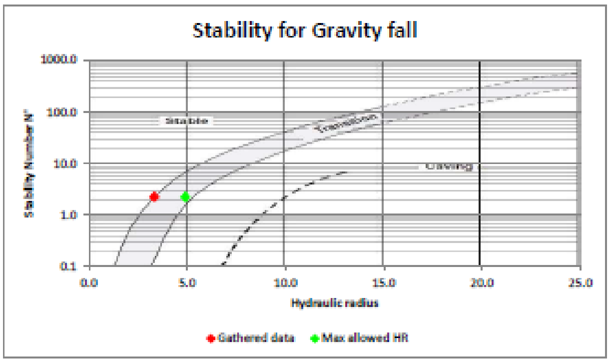
Graph	
X	Y
3.3	2.2

Calculate Hydraulic Radius:

HR=	H*L
	2(H+L)
HR=	320
	96
HR=	3.3

Parameter	Value
Length	40
Width	8

Result: 3.3



Maximum Hydraulic Radius:

$HR_{allowed}$= 4.9

Parameter	Value
N'	2.2
Exponent 1	0.573
Exponent 2	0.338

$$HR_{allowed} = 10^{[0.573+0.338 \log N']}$$

Maximum stope length:

L=	2(H)(HR)
	H-2(HR)
L=	393.0735465
	30.17316134
L=	13.0

Signatures:

Name	Designation	Sign

Appendix B – Hedley-Grant Pillar Design

$$Pillar\ Strength = DRMS \times \frac{{W_{eff}}^{\propto}}{H^{\beta}}$$

Where:

$DRMS$	Design Rock Mass Strength
W_{eff}	Effective Pillar Width (equal to pillar width for square pillars)
α	constant equal to 0.5
β	constant equal to 0.75

$$DRMS = UCS \times \frac{MRMR - R_{UCS}}{100}$$

Where:

UCS	Intact uni-axial compressive strength of pillar material
$MRMR$	Mining rock mass rating
R_{UCS}	Rating given for UCS as part of the RMR calculation (refer to table below)

<table>
<tr><th colspan="2">Parameter</th><th colspan="11">Range of Values</th></tr>
<tr><td rowspan="2">1</td><td>RQD</td><td colspan="2">100-97</td><td>96-84</td><td>83-71</td><td>70-56</td><td>55-44</td><td>43-31</td><td>30-17</td><td>16-4</td><td colspan="2">3-0</td></tr>
<tr><td>Rating (= RQD x 15/100)</td><td colspan="2">15</td><td>14</td><td>12</td><td>10</td><td>8</td><td>6</td><td>4</td><td>2</td><td colspan="2">0</td></tr>
<tr><td rowspan="2">2</td><td>UCS (MPa)</td><td>185</td><td>184-165</td><td>184-165</td><td>164-145</td><td>144-125</td><td>124-105</td><td>104-85</td><td>84-65</td><td>44-25</td><td>24-5</td><td>4-0</td></tr>
<tr><td>Rating</td><td>20</td><td>18</td><td>16</td><td>14</td><td>12</td><td>10</td><td>8</td><td>6</td><td>4</td><td>2</td><td>0</td></tr>
<tr><td rowspan="2">3</td><td>Joint Spacing</td><td colspan="11">Refer Figure 9</td></tr>
<tr><td>Rating</td><td colspan="6">25</td><td colspan="5">0</td></tr>
<tr><td rowspan="2">4</td><td>Joint Condition Including Groundwater</td><td colspan="11">Refer Table 9</td></tr>
<tr><td>Rating</td><td colspan="6">40</td><td colspan="5">0</td></tr>
</table>

Appendix C – Ground Vibration Monitoring

[As per attached document]

Curriculum Vitae of Quintin L Grix

Name:	QL Grix	**Date of Birth:**	7th March 1988
Profession:	Rock Engineer	**Nationality:**	South African
Years with the firm:	14		

Qualification/ education

Institution	Degree(s) or Diploma(s) obtained	Date obtained
Chamber of Mines	Certificate in Strata Control (588)	2010
Chamber of Mines	Certificate in Rock Engineering (RMC505)	2013
University of the Witwatersrand M.Sc.	Advanced Rock Engineering Cert. Cont. Introduction to Mining Engineering Rock Mass Classification in Rock Engineering Mechanics and Design of Major Rock Slopes Advanced Mechanics of Solids Mechanical Properties of Rocks	2015 – Current
NOSA	SAMTRAC Certificate in Health and Safety Incident and Accident Investigation Applying SHE principles and procedures	2008 - 2010

Employment

From – To (year)	Employer	Positions and description of duties
2010 to 2015	Open House Management Solutions Pty Ltd (OHMS)	Quality Control Officer, Strata Control Officer, Shaft Rock Engineer
2015 to 2016	South Deep Gold Mine (Goldfields)	Manager Rock Engineering
2016 to Current	Open House Management Solutions Pty Ltd (OHMS)	Senior Consulting Geotechnical Engineer

Languages and degree of proficiency

	Speaking	Reading	Writing
English	Excellent	Excellent	Excellent
Afrikaans	Excellent	Excellent	Excellent

Membership of Professional Associations

SANIRE (Member)
SAIMM (Member)

Industry involvement

1. Elected Chairman of the SANIRE North-West Branch
2. COM Strata Control Moderator and Examiner
3. COM Rock Engineering Moderator and Examiner
4. COM Strata Control Course Presenter
5. COM Rock Engineering Course Presenter

Following is a list of recent work experience related to underground and open pit mines:

Open Pit and Underground	Year	2023
	Location	Various
	Client	Various
	Name of Project	Subsurface Scanning Using Ground Penetrating Radar
	Main project features	Making use of OHMS's GPR, scanning for sub-surface anomalies in various underground and open pit mines. Conducting training on the use of the technology on various operations.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2023
	Location	DRC
	Client	STL Mine
	Name of Project	Waste Dump Reclamation Modelling
	Main project features	Modelling of the proposed reclamation sequence of a waste dump. Data collection, laboratory testing, QA/QC of results and modelling of waste dump reclamation using 3D finite element modelling.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2023
	Location	Brazil
	Client	ERO Copper
	Name of Project	Phase 2 Deepening Project
	Main project features	Modelling of actual overbreak to establish a design criterion for future use. Modelling planned mining in deepening part of massive open stop mine. Assessment of support, stable spans, excavation placement etc.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2023
	Location	Brazil
	Client	ERO Copper
	Name of Project	Mina Caraiba Crown Pillar Failure Investigation
	Main project features	Investigation of failed crown pillar into mined out areas. Data collection, assessment and interpretation including satellite and radar data. Numerical modelling of before and after failure including zone of influence modelling and specifying monitoring requirements based on modelling outcomes.
	Position held	Senior Consulting Geotechnical Engineer
	Year	2023
Underground	Year	2023
	Location	Brazil
	Client	ERO Copper
	Name of Project	Mina Caraiba Shaft Project
	Main project features	Data analyses, interpretation, and assessment of client-gathered geotechnical data. Numerical model construction, computing, and interpretation of results. Assessment of excavation placement, geometry, support requirements, stand-up times, etc.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2023
	Location	Brazil
	Client	Hatch Brazil (Hawiah Alemao)
	Name of Project	Update of executable raise bore reliability and design.

	Main project features	Review and update of methodology, modelling and findings and recommendations pertaining to the assessment of planned raise bored shafts in squeezing and poor rock mass conditions.
	Position held	Senior Consulting Geotechnical Engineer
Underground & Open Pit	Year	2023
	Location	Kazahkstan, India, Brazil & Mexico
	Client	ArcelorMittal – Iron
	Name of Project	Corporate Geotechnical Audits and Gap Analyses
	Main project features	Travelling to different mine sites in order to conduct geotechnical audits on systems, designs, and the geotechnical function.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2023
	Location	South Africa – Free state
	Client	Harmony Gold
	Name of Project	On-site hanging wall assessment by means of ground penetrating radar.
	Main project features	Underground investigation, ground penetrating radar scanning and results interpretation to guide support requirement and optimisation. Efficacy assessment of preconditioning using GPR.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2023
	Location	South Africa - Rustenburg
	Client	Northam Platinum
	Name of Project	Shaft and Decline Stability Assessment
	Main project features	Geotechnical data review and update, analyses, numerical model construction analyses and mine, and pillar design verification. Assessment of support requirements.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2023
	Location	South Africa - Rustenburg
	Client	Royal Bafokeng Resources
	Name of Project	Update of Mine Pillar Design and Routine Modelling
	Main project features	Assessment of pillar response and routine modelling of board and pillar operations.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2023
	Location	South Africa - Rustenburg
	Client	Royal Bafokeng Resources
	Name of Project	Review of the performance of Styldrift Mine stope spans, panel support and pillar designs
	Main project features	Data analyses, underground investigations, span, pillar and support design reviews.
	Position held	Senior Consulting Geotechnical Engineer
Under groun	Year	2023
	Location	South Africa - Orkney

	Client	PCDS EPCM
	Name of Project	Prefeasibility study of Weltevreden Gold Mine
	Main project features	Data collection, core logging, analyses, support-, mine-, pillar design and numerical modelling.
	Position held	Senior consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Limpopo
	Client	Impala Platinum
	Name of Project	Feasibility Study of Greenfields Massive Mine
	Main project features	Geotechnical data analyses and interpretation, geotechnical block model construction. Numerical modelling of possible mining methods along with pillar, span and support assessments and designs.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2022
	Location	South Africa – Northern Cape
	Client	Vedanta Zinc International
	Name of Project	Geotechnical Database Update and Pit Stability Assessment
	Main project features	Expansion of geotechnical database to include recent drilling and laboratory test results. Re-assessment op pit stability based upon updated geotechnical block model.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	Brazil
	Client	Hatch Brazil (Hawiah Alemao)
	Name of Project	Review of raise bore reliability and design.
	Main project features	Review of data acquisition, methodology, modelling and findings and recommendations pertaining to the assessment of planned raise bored shafts in squeezing and poor rock mass conditions.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	Burkina Faso
	Client	Nantou Perkoa
	Name of Project	Planned secondary stope extraction and design.
	Main project features	Numerical modelling of planned extraction of a secondary stope in difficult production conditions.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	Burkina Faso
	Client	Nantou Perkoa
	Name of Project	Geotechnical and GCMP review.
	Main project features	Review of the geotechnical function and Ground Control Management Plan of the mine.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Gold
	Client	Pan African Resources
	Name of Project	Review of planned shaft pillar extraction methodology and findings.

	Main project features	Review of the methodology, numerical modelling and findings and recommendations pertaining to the extraction of the Evander 8 Shaft pillar extraction.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Platinum
	Client	Sibanye Stillwater
	Name of Project	Saffy Shaft DFS Mine Design and Modelling
	Main project features	Modelling of the proposed mining and pillar layout assessing panels spans, pillar geometry, off reef excavation stability, shaft stability and ore pass stability.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Platinum
	Client	Sibanye Stillwater
	Name of Project	Saffy Shaft DFS Mine Design and Modelling
	Main project features	Modelling of the proposed mining and pillar layout assessing panels spans, pillar geometry, off reef excavation stability, shaft stability and ore pass stability.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Platinum
	Client	Sibanye Stillwater
	Name of Project	Kroondal West Geotechnical Study
	Main project features	Assessing the impact on surface infrastructure due to shallow mining (< 70m) along with recommendations for the execution of the mine. Includes blasting and PPV assessments.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Diamonds
	Client	De-Beers - Venetia
	Name of Project	De-Beers High Risk Excavation Design Review
	Main project features	Review of numerous large excavation designs, data collection and numerical modelling.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	India - Gold
	Client	ABGlobal (Vedanta)
	Name of Project	Ostapal PFS Mine Design
	Main project features	Numerical modelling and design of portal within existing pit high-wall, crown pillar design beneath open pit, stope span design, rib, sill and regional pillar design.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Zinc
	Client	Vedanta Resources – Black Mountain Mine
	Name of Project	Numerical Modelling and Review of Swartberg Mine Design
	Main project features	Span design verification, data collection and numerical modelling of planned stoping for the Swartberg longhole open stoping mine.
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2022
	Location	South Africa - Gold

	Client	Harmony Gold - Bambanani
	Name of Project	Ground Penetrating Radar Scanning of Stope Faces
	Main project features	Ground Penetrating Radar Scanning of Stope Faces extracting the shaft pillar to assess the degree of fracturing prior to implementing preconditioning.
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2022
	Location	South Africa - Platinum
	Client	Impala Platinum – Cactus Project
	Name of Project	Feasibility Study Update of Large Underground Mine
	Main project features	Zero base feasibility study focussing on data QA/QC, analyses and interpretation. Open stope span and pillar design. Crown and sill pillar designs and numerical modelling of the final proposed layout.
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2022
	Location	South Africa – Platinum
	Client	Master Drilling – Styldrift Mine
	Name of Project	Raise bore Reliability Assessment and Recommendations
	Main project features	Data collection through geotechnical logging of drilled core, numerical modelling and raise bore reliability assessment making use of the Stacey McCracken methodology. Recommendations pertaining to support requirements where deemed necessary.
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2022
	Location	South Africa – Platinum
	Client	Master Drilling – Styldrift Mine
	Name of Project	Raise bore Reliability Assessment and Recommendations
	Main project features	Data collection through geotechnical logging of drilled core, numerical modelling and raise bore reliability assessment making use of the Stacey McCracken methodology. Recommendations pertaining to support requirements where deemed necessary.
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2022
	Location	Rwanda – Tin
	Client	Trinity Metals – Piran Resources
	Name of Project	Site Visit for Geotechnical Inspection
	Main project features	Site visits in order to audit underground working and provide rock engineeinrg support where required. Training in basic Strata Control of mine's geology teams.
	Position held	Senior Consulting Geotechnical Engineer

Open Pit	Year	2022
	Location	India - Gold
	Client	ABGlobal (Vedanta)
	Name of Project	Ostapal PFS Mine Design
	Main project features	Assessment of waste dump and open pit high wall stability following in-pit portal establishment and underground mining.
	Position held	Senior Consulting Geotechnical Engineer

Open Pit	Year	2022
	Location	DRC - Copper
	Client	Anvil Mining – Kapulo Open Pit
	Name of Project	Kapulo Open Pit Slope Failure Assessment

	Main project features	Assessment of causes and rehabilitation of medium-sized wall instability. Included data collection, interpretation, kinematic assessments and numerical modelling.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2022
	Location	DRC - Copper
	Client	ERG Africa – Frontier Mine
	Name of Project	Ramp Instability Assessment
	Main project features	Assessment of the likely cause of ramp instability including data analyses and interpretation, ground penetrating radar scans and kinematic assessments.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2022
	Location	South Africa - Zinc
	Client	Vedanta Resources - Gamsberg
	Name of Project	South Pit Wall Failure Investigation
	Main project features	Investigation of a large scale wall failure in the South Pit. Project included data collection, interpretation, kinematic assessment and numerical modelling.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2022
	Location	South Africa - Zinc
	Client	Vedanta Resources - Gamsberg
	Name of Project	Stage 2 Pit Optimisation
	Main project features	Optimisation of the Stage 2 Mega Pit included data collection QA/QC, interpretation, block model construction, kinematic assessments and numerical modelling. Study further included a gap analyses for future focus.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2019
	Location	Rwanda - Musha
	Client	Piran Resources
	Name of Project	Fatal slope failure investigation and remedial measures
	Main project features	On-site accident investigation, data collection, analyses and remedial measures for continue mining
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2019 - Current
	Location	Rwanda - Musha
	Client	Piran Resources
	Name of Project	Routine Visit
	Main project features	Routine visits to facilitate knowledge transfer, training, underground mines, and open pit inspections
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2019
	Location	South Africa - Rustenburg
	Client	Impala Platinum
	Name of Project	Gem4D Training

	Main project features	Training in the Gem4D software program to facilitate geotechnical block model construction a presentation
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2019
	Location	South-Africa
	Client	Goldfields
	Name of Project	Review of support efficacy and methodologies in highly stressed, and squeezing rock mass,
	Main project features	Assessment of the mine's methodology and support performance of modified split sets in a squeezing rock mass with very high closure rates.
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2018
	Location	DRC
	Client	ERG Africa
	Name of Project	Pit stability analyses following the intersection of large voids
	Main project features	In-situ investigation, data analyses, 3D interpretation geotechnical block model construction to facilitate decision making
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2016 - 2018
	Location	DRC
	Client	ERG Africa
	Name of Project	Routine quarterly visits to Frontier open pit
	Main project features	In-situ investigation, stability analyses, radar assessment, feedback
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2016
	Location	DRC
	Client	ERG Africa
	Name of Project	Frontier Cut 2 and Cut 3 pit slope stability assessment and optimisation
	Main project features	Data collection, QA/QC, core logging, analyses, interpretation, construction of 3D geotechnical block model, 2D finite element modelling
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2018
	Location	DRC
	Client	ERG Africa
	Name of Project	Update and optimisation of Cut3 open pit slope geometries
	Main project features	Drone data analyses and interpretation, 2D finite element modelling, statistical kinematic assessment, fall body assessment, phreatic surface sensitivity assessment
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2016 - 2019
	Location	Zambia - Copperbelt
	Client	Mopani Copper
	Name of Project	Routine monthly visits to Mopani Copper Mine operations

	Main project features	Pit stability assessments, underground investigation, 3D & 2D numerical modelling, knowledge transfer and training, underground support optimisation and design
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2019
	Location	Zambia - Copperbelt
	Client	Mopani Copper
	Name of Project	Mining method trade-off study (SLC vs. VCR) for Sinclinorium Shaft
	Main project features	Data collection and interpretation, underground investigation, mapping and core logging, laboratory data analyses, 3D numerical modelling, backfill requirement assessment, stable span analyses.
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2019
	Location	South Africa - Northern Cape
	Client	Vedanta Resources
	Name of Project	Detailed geotechnical review of the geotechnical aspects of Black Mountain Mine
	Main project features	Data collection, interpretation and assessment
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2019
	Location	Zambia - Copperbelt
	Client	Mopani Copper
	Name of Project	Ground control management plan review and update for Mindola, Mufulira, SOB and Sinclinorium Shafts
	Main project features	Support design, pillar design and optimisation, mining method optimisation.
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2019
	Location	Zambia - Copperbelt
	Client	Mopani Copper
	Name of Project	Design and modelling of Sinclinorium shaft bottom infrastructure
	Main project features	Underground investigation and data collection, 2D & 3D numerical modelling, stable span design
	Position held	Senior Consulting Geotechnical Engineer

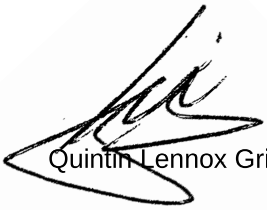
Open Pit	Year	2018
	Location	DRC
	Client	Boss Mining
	Name of Project	Investigation and optimisation of Mupapala open pit
	Main project features	In-situ instability investigation and failure assessment, data collection, mapping and interpretation, 2D numerical modelling
	Position held	Senior Consulting Geotechnical Engineer

Underground	Year	2018
	Location	South Africa - Northern Cape
	Client	Vedanta Resources
	Name of Project	Blast hole brow instability assessment at Black Mountain Mine
	Main project features	Underground investigation, data collection, assessment, 2D numerical modelling, support design

	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2018
	Location	South Africa - Northern Cape
	Client	Vedanta Resources
	Name of Project	43 Level crown pillar extraction investigation and optimisation
	Main project features	Underground investigation, data collection, mapping, 3D numerical modelling construction and assessment
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2018
	Location	South Africa - Northern Cape
	Client	Vedanta Resources
	Name of Project	Analyses and review of Black Mountain Mine's open stope design process
	Main project features	Data collection, underground investigation, 3D numerical modelling, stope and support design
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2019
	Location	South Africa - Northern Cape
	Client	Vedanta Resources
	Name of Project	Review of aerial support requirement on Swartberg and Deeps shafts
	Main project features	Underground investigation, data collection, mapping and support design
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2018
	Location	Zambia - Copperbelt
	Client	Mopani Copper
	Name of Project	Desktop level assessment of the proposed open stoping mining method at Mufulira Shaft
	Main project features	Data collection and analyses, 3D numerical modelling, pillar design, stable span design
	Position held	Senior Consulting Geotechnical Engineer
Underground	Year	2018 - 2019
	Location	Zambia - Copperbelt
	Client	Mopani Copper
	Name of Project	5 - Year LOM modelling of Mufulira, SOB, Sinclinorium and Mindola Shafts
	Main project features	Underground investigations, data collection, QA/QC, 3D numerical modelling, stable span design, pillar design
	Position held	Senior Consulting Geotechnical Engineer
Open Pit	Year	2017
	Location	Tanzania - Rukwa
	Client	Kibo Mining
	Name of Project	Feasibility study of the Rukwa Coal to Power Open pit
	Main project features	Core logging, mapping, data analyses, laboratory test result QA/QC, slope design, 2D finite element modelling, slope optimisation
	Position held	Senior Consulting Geotechnical Engineer

Certification

I, the undersigned, certify that to the best of my knowledge and belief, this data correctly describes me, my qualifications, and my experience.



Quintin Lennox Grix Date: November 2023

Curriculum Vitae of Jacobus D (Koos) Bosman

Name:	JD Bosman	**Date of Birth:**	12th October 1966
Profession:	Rock Engineer	**Nationality:**	South African
Years with the firm:	23		

Qualification/ education

Institution	Degree(s) or Diploma(s) obtained	Date obtained
University of Johannesburg	NDip (Metalliferous Mining)	1990
University of Johannesburg	NHD (Rock Eng)	1991
Chamber of Mines of SA	Certificate in Rock Mechanics (No. 252)	1991
Chamber of Mines of SA	Certificate in Advanced Rock Engineering (No. 29)	1997
University of the Witwatersrand	GDE (Rock Eng)	1998
University of the Witwatersrand	M.Eng (Rock Eng)	2005

Employment

From – To (year)	Employer	Positions and description of duties
2000 to 2022	Open House Management Solution Pty Ltd (OHMS)	Director, Shareholder and Principal
1987 to 2000	Hartebeestfontein Gold Mine	Rock Engineering Manager

Languages and degree of proficiency

	Speaking	Reading	Writing
English	Excellent	Excellent	Excellent
Afrikaans	Excellent	Excellent	Excellent

Membership of Professional Associations

SANIRE (Fellow)
SAIMM (Member)
ISRM
SACNASP (Pr.Nat.Sci)

Industry involvement

1. Served in various positions on the Council of SANIRE between 1994 and 2002.
2. Served on the organising committee of numerous international symposia arranged by SANIRE and SAIMM.
3. Current member of the SA Minerals Council - Rock Engineering Technical Committee.
4. Member of the MHSC Rockburst task team.
5. Industry representative as subject matter expert for SIMRAC

Involvement with Universities and Institutes

1. Registered external examiner for Post Graduate thesis at the University of Witwatersrand
2. Registered external examiner for Post Graduate thesis at the University of Pretoria
3. Lecturing of Post Graduate courses at University of Witwatersrand
4. Lecture in Mining Induced Seismicity and Rockburst for the Peruvian Institute of Mining Engineers
5. Registered as a technical paper reviewer with the SAIMM

Following is a list of recent work experience related to underground mines.

Experience record	
Name of project	**Prefeasibility investigation for Booysendal Platinum Mine**
Year	2008
Location	South Africa
Client	Northam Platinum
Main project features	Geotechnical design for pre-feasibility study.
Positions held	Principal
Name of project	**Assessment of the stability of block cave production Level at PMC**
Year	2012
Location	South Africa
Client	Palabora Mining Company
Main project features	Underground inspection and proposal for rehabilitation
Positions held	Principal
Name of project	**Design and review of primary underground mine infrastructure for Kalagadi Manganese Mine**
Year	2013 to date
Location	South Africa
Client	Kalagadi Manganese
Main project features	Geotechnical data collection and description. Stable excavation and support layout design.
Positions held	Principal
Name of project	**Geotechnical quantification of the mining areas for the No.16 and No.19 Shaft Projects of Impala Platinum.**
Year	2012-2013
Location	South Africa
Client	Impala Platinum

Experience record	
Main project features	Core logging, sample testing, data analyses and presentation.
Positions held	Principal
Name of project	**Investigation into the optimal location of a raise bored ventilation shaft for Impala Platinum Mine.**
Year	2013-2014
Location	South Africa
Client	Impala Platinum
Main project features	Core logging, sample testing, data analyses, presentation, and assessment.
Positions held	Principal
Name of project	**Feasibility Level design for the Jeanette Gold Mining Project**
Year	2014
Location	South Africa
Client	Taung Gold
Main project features	Detailed rock engineering assessment and design for mechanised underground gold mine. The focus being on the successful negotiation of a weak shale layer in the hangingwall of the orebody.
Positions held	Principal
Name of project	**Design and Stability assessment of primary service excavations for the new Synclinorium Shaft**
Year	2013 to 2019
Location	Zambia
Client	Mopani Copper Mines
Main project features	Geotechnical data collection, interpretation and stable excavation design. Design of optimum support layouts and methods for various large excavations and chambers. Including regular site inspections to ensure compliance.
Positions held	Principal
Name of project	**Study of suspected rock burst activity at Trojan Nickle Mine**
Year	2014
Location	Zimbabwe
Client	Bindura Nickel Corporation
Main project features	Underground site investigation, numerical modelling and recommendations for ameliorating strategies.
Positions held	Principal
Name of project	**Assessment of the proposed mining method and layout for the deep extension of Mindola Shaft, Nkana Section.**
Year	2014
Location	Zambia
Client	Mopani Copper Mines
Main project features	Numerical modelling and rock engineering assessment of possible rock mass response to the establishment of a VCR mining method with inter level sill pillars with post pillar extraction, using SLC.
Positions held	Principal
Name of project	**Review of deep mining strategies at Impala Platinum Mines**
Year	2015
Location	South Africa
Client	Impala Platinum
Main project features	Review of the current mine strategies and the implementation of these strategies at No.16 Shaft
Positions held	Principal

Experience record	
Name of project	**Assessment of rock burst incidences at Mufulira Mine**
Year	2015
Location	Zambia
Client	Mopani Copper Mines
Main project features	Underground investigation into rock busts damage, with associated study of revised mine plans and layout. This included a detailed 3D numerical modelling study.
Positions held	Principal
Name of project	**Assessment of the potential for extracting the 59-60 water pillar at Mufulira mine**
Year	2015
Location	Zambia
Client	Mopani Copper Mines
Main project features	The numerical modelling assessment of the proposed extraction of the 59-60 Water Pillar and the likely influence mining will have on adjacent access ways.
Positions held	Principal
Name of project	**Preliminary numerical assessment of the effect of Sub-level Caving mining the Synclinorium orebody on the lower and upper aquafers.**
Year	2014
Location	Zambia
Client	Mopani Copper Mines
Main project features	The numerical modelling assessment of the extraction of the Synclinorium ore body and the effect that the use of the Sub-level Caving mining method will have on the hangingwall aquafers. The study was done for the purpose of deciding whether backfill should be included as an option for the mine design plan.
Positions held	Principal
Name of project	**Design of rock mass deformation monitoring program.**
Year	2014
Location	Zambia
Client	Mopani Copper Mines
Main project features	Following the design of the new 6900 crusher chamber for the Synclinorium project, a rock mass deformation monitoring and instrumentation program was proposed and was accepted by Mine Management.
Positions held	Principal
Name of project	**Review of the Mopani Copper mine strategic mine plan.**
Year	2014
Location	Zambia
Client	Mopani Copper Mines
Main project features	The strategic mine plan that was compiled for deep shafts at Mopani copper mine (SOB, Synclinorium, Mindola, and Mufulira) was numerically modelled and assess with a view of pointing out any rock engineering related issues that may exist. Our team also actively participated in the compilation of the strategic plan over a one-year basis by providing appropriate mine design criteria.
Positions held	Principal
Name of project	**Review of the Kamoto underground mining layout**
Year	2014
Location	DRC
Client	Katanga Copper Mining
Main project features	A 3D numerical model was constructed to assess the stress distribution around the current mine layout. The model is being used to assess the stability of current mine access excavation and proposed future access routes.
Positions held	Principal

Experience record	
Name of project	**External review of hazard quantification for flooding the Blyvooruitzicht Gold mine**
Year	2015
Location	South Africa
Client	AnglogoldAshanti
Main project features	Numerical modelling and seismic data analyses to quantify the hazard associated with flooding the deep operations of Blyvooruitzicht was reviewed and expert opinion was given.
Positions held	Principal
Name of project	**REVIEW OF ROCK ENGINEERING-RELATED STRATEGIES, LAYOUTS, DESIGNS, STANDARDS AND PROCEDURES RELATING TO THE 4TH GENERATION SHAFTS**
Year	2015
Location	South Africa
Client	Impala Platinum
Main project features	The devised strategies for the safe extraction of ore reserves that are currently being accessed by the 4th generation shafts were assessed and compared to industry best practise. Findings and recommendations were presented to Senior executive.
Positions held	Principal
Name of project	**Risk Assessment on single access to Margaret Shaft pumping operations**
Year	2015
Location	South Africa
Client	Margaret Water Company
Main project features	Participation in high level issue-based risk assessment to quantify the risk associated with single access to the pumping infrastructure at Margaret shaft
Positions held	Principal Rock Engineer
Name of project	**Analyses of stress exposure of vital excavations planned for the new Mufulira Deeps expansion**
Year	2015
Location	Zambia
Client	Mopani Copper Mines
Main project features	Performing numerical modelling of large chambers, which forms part of the vital shaft infrastructure planned for the Mufulira Deeps expansion project
Positions held	Principal Rock Engineer
Name of project	**Review of Support Strategies of South Deep Gold Mine**
Year	2015
Location	South Africa
Client	Goldfields
Main project features	A detailed quantification of rock mass properties, stress and seismic activity to assess the support requirements for primary access ways to stopes.
Positions held	Principal Rock Engineer
Name of project	**Audit of Rock Engineering Practises at Zimplats Operations**
Year	2016
Location	Zimbabwe
Client	Implats
Main project features	A detailed assessment was made of all rock engineering practises, designs and strategies employed at the Zimplats operations.
Positions held	Principal Rock Engineer
Name of project	**Review of Khoemacau feasibility study**
Year	2016
Location	Botswana
Client	CSA Global

Experience record	
Main project features	A detailed review of the geotechnical data and design for the Khoemacau underground mining bankable feasibility study.
Positions held	Principal Rock Engineer
Name of project	**Sinking a vertical shaft at the CSA Mine – Second opinion**
Year	2016
Location	Australia
Client	CSA Mine, Glencore
Main project features	Provide a second opinion on geotechnical viability of a vertical shaft in a weak and laminated rockmass with high horizontal stress.
Positions held	Principal Rock Engineer
Name of project	**Re-design of stoping geometry and pillar dimensions at Tau Deeps Gold Mine**
Year	2016
Location	Botswana
Client	Mupane Gold Mining (PTY) Ltd
Main project features	Perform a detailed redesign of stable stope and pillar dimensions based on data collected from underground mapping and core logging.
Positions held	Principal Rock Engineer
Name of project	**Vital service excavation design and numerical assessment for Mufulira Deeps Project**
Year	2017
Location	Zambia
Client	Mopani Copper Mines, Glencore
Main project features	Evaluate the proposed layout and design of the silos and pumping infrastructure excavations for the new Mufulira deeps shaft.
Positions held	Principal Rock Engineer
Name of project	**Review of the Lubambe Copper mine extension feasibility study.**
Year	2017
Location	Zambia
Client	EMR Capital, Australia
Main project features	Assess and review the geotechnical section of the feasibility study for the extension of the underground operations at Lubambe Copper mine. Provide opinion of the adequacy of the input data and relevance of the design provided.
Positions held	Principal Rock Engineer
Name of project	**Lecture on seismicity and rock burst in underground mines**
Year	2017
Location	Lima, Peru
Client	New Concept Mining (Peru) under auspices of the National Institute for Mining Engineers of Peru
Main project features	Conduct mine visits to interact with Geotechnical personnel in regards Seismicity and rock burst and their effects on underground excavations. Present a one-day lecture to industry experts from across South America on mining induced seismicity and rock burst and their effects on the design of excavations layouts and support.
Positions held	Principal Rock Engineer
Name of project	**Review of Geotechnical Design at Red Eagle Mine, Colombia**
Year	2017
Location	Medellin, Colombia
Client	Stracon Gym International through JPMC International Ltd.
Main project features	Conduct a detailed review of the bankable feasibility and current operations, with the aim of identifying areas where improvements can be made to current mining method. The review included the consideration of the viability of the Cut and Fill mining method in a weak and sheared orebody.

Experience record	
Positions held	Principal Rock Engineer
Name of project	**Assessment of early extraction of available ground in the Synclinorium block**
Year	2017
Location	Zambia
Client	Mopani Copper Mines
Main project features	Conduct an investigation into the early application of Sub-level Cave mining in the Synclinorium block. Establish whether caving will occur at the planned mining spans and how this will interact with the Lower and Upper Dolomite water compartments. This study required the application of both stability number and numerical modelling.
Positions held	Principal Rock Engineer
Name of project	**Study to advise mining method selection in the Synclinorium Orebody.**
Year	2018
Location	Zambia
Client	Mopani Copper Mines
Main project features	Conduct a detailed numerical modelling assessment to compare the Cut and Fill, VCR and SLC mining methods, with a view of selecting the most appropriate mining method.
Positions held	Principal Rock Engineer
Name of project	**Third party investigation of Masekhane shaft rockburst accident.**
Year	2018
Location	South Africa
Client	SibanyeStilwater
Main project features	Perform an independent investigation of a serious rockburst accident and advise senior management on possible causes of the rockburst. Advise client's legal counsel and act as expert witness in DMR enquiry.
Positions held	Principal Rock Engineer
Name of project	**Mponeng Carbon Leader Project**
Year	2018
Location	South Africa
Client	AngloGold Ashanti
Main project features	Review of the technical investigation in which footwall vs hangingwall access to the ore body was investigated.
Positions held	Principal Rock Engineer
Name of project	**Investigation into large rock fall incidents at the Styldrift Platinum Mine**
Year	2019
Location	South Africa
Client	Royal Bafokeng Holdings
Main project features	Conduct an investigation into the possible mechanisms and causes of recent large collapses of hangingwall the mechanised Board and Pillar section of the Mine. The investigation included the consideration of the role and influence of weak Lamprophyre Dykes on the stability of excavations.
Positions held	Principal Rock Engineer
Name of project	**Jwaneng Post Cut 9 Pre-feasibility study**
Year	2019
Location	Botswana
Client	Hatch
Main project features	Provide oversight, review and expert input for the geotechnical tasks pertaining to the Jwaneng Post Cut 9 pre-feasibility study.
Positions held	Principal Rock Engineer
Name of project	**Review of Kamoa Kakula Bord and Pillar Pre-feasibility study**

Experience record	
Year	2019
Location	DRC
Client	Ivanhoe Mines
Main project features	Study the data collection and interpretation as well as the mine design of the Bord and Pillar section of the Planned Kamoa Kakula Copper Mine in the DRC. Advise Management team on shortcomings and deficiencies in the geotechnical component of the study. Propose alternative and improved design methodologies.
Positions held	Principal Rock Engineer
Name of project	**Khoemacau Copper mine – Executable mine design**
Year	2018-2019
Location	Botswana
Client	Cupric Canyon
Main project features	Provide oversight and expert input into the design of the new underground mine at Zone 5. Work included the design of layout of access excavations and the design of stoping operations, considering different mining method options. The work also required the design of three large boxcut excavations to facilitate portal access for declines.
Positions held	Principal Rock Engineer
Name of project	**Ivanplats No.1 Shaft 950m Level station stability**
Year	2019
Location	South Africa
Client	Ivanplats Pty Ltd
Main project features	Review of the investigation and support recommendations aimed at the stabilisation of prominent geological discontinuities, intersected at the 950mL Station excavation
Positions held	Principal Rock Engineer
Name of project	**Investigation into suspected fall of ground accident at Black Mountain Mine**
Year	2020
Location	South Africa
Client	Vedanta
Main project features	Conduct an investigation of a suspected fall of ground accident. The owners of the mine required an independent opinion on whether an accident that occurred, without any eyewitnesses, could have been due to a collapse of the hangingwall.
Positions held	Principal Rock Engineer
Name of project	**EPL3 Life of Mine Study**
Year	2020
Location	South Africa
Client	SibanyeStillwater Platinum
Main project features	Conduct a complete geotechnical scoping study for the design of the deep extension of the EPL3 Shaft. The deeper extension is planned to be a mechanised bord and pillar operation, downdip from the existing conventional stoping operation.
Positions held	Principal Rock Engineer
Name of project	**Zimplats Geotechnical Review**
Year	2020
Location	Zimbabwe
Client	Zimplats
Main project features	External Review of Rock Engineering- Related Strategies, Layouts, Designs, Standards and Procedures Relating to Zimplats Operations. Included mine workings inspections and interviews with broad range of management structure
Name of project	**Geotechnical Engineering Considerations and Designs for Lily Mine**
Year	2020
Location	South Africa

Experience record	
Client	ARQOMANZI (PTY) LIMITED
Main project features	Conducted a desktop study for the re-development and mining at of the Lily Gold Mine. The world included Access development and layout, stable stope dimension design and stable pillar design.
Year	2020
Name of project	**Mbamba Kalenda Copper Project PFS Study**
Year	2020
Client	African Mining Consultants
Main project features	Perform a pre-feasibility level study for a longitudinal and transverse open stoping mine. Investigation included stable stope design, mine access and development strategy and excavation support design.
Positions held	Principal Rock Engineer
Name of project	**Kamoa Copper Mine**
Year	2021-2022
Location	DRC
Client	Ivanhoe Mines
Main project features	Conduct detailed design of proposed mining layout and sequence to evaluate regional stability, secondary drift extraction stability and backfill requirements.
Positions held	Principal Rock Engineer
Name of project	**Zimplats Pillar reclamation Project**
Year	2022
Location	Zimbabwe
Client	Zimplats
Main project features	Conduct detailed review of the design for pillar reclamation from historic bord and pillar operations and conduct a detailed assessment of the impact of reclamation and associated risk.
Positions held	Principal Rock Engineer
Name of project	**Copperton Mine**
Year	2022
Location	South Africa (Northern Cape)
Client	Orion Minerals
Main project features	Conduct a review of the Design contained in the feasibility study. Identify Risks and Opportunities, conduct a GAP analyses, with detail regarding further work to be conducted.
Positions held	Principal Rock Engineer
Name of project	**Kipushi Zinc Mine**
Year	2022
Location	DRC
Client	Ivanhoe Mines
Main project features	Conduct a review of the FS Design Study. Conduct detailed assessment of Mining Sequence and layout for purposes of execution. Design support requirements for primary access ways.
Positions held	Principal Rock Engineer
Name of project	**Styldrift IPCOS4**
Year	2023
Location	South Africa
Client	Royal Bafokeng Platinum
Main project features	Conduct a review of the FS Design Study. Conduct detailed assessment of Geotechnical aspects of the design of Mechanised XLP mining as well as a modified Hybrid Mining Method. Conduct a GAP analyses and fatal flaw assessment.
Positions held	Principal Rock Engineer
Name of project	**Impala Rustenburg Operations**

Experience record	
Year	2023
Location	South Africa
Client	Impala Platinum
Main project features	Conduct a review of the mine's support design and Codes of Practise, with special reference to No. 20 Shaft
Positions held	Principal Rock Engineer
Name of project	**South Deep Gold Mine**
Year	2023
Location	South Africa
Client	South Deep Gold Mine
Main project features	Conduct an in-depth independent review of the mines support design and standard practises.
Positions held	Principal Rock Engineer
Name of project	**Zondereinde Platinum Mine**
Year	2023
Location	South Africa
Client	Northam Platinum
Main project features	Conduct a review of the design of a Decline protection pillar. Do numerical modelling to quantify the stress regime over the working life of the vital mine access declines.
Positions held	Principal Rock Engineer
Name of project	**Zondereinde Platinum Mine**
Year	2023
Location	South Africa
Client	DRA Global
Main project features	Design and recommend the holding down bolts for shaft steel work, and services in the new No.3 Raise Bore Shaft
Positions held	Principal Rock Engineer

Following details on papers and presentations made to significant Conferences and Symposia.

Title	Authors	Conference/Symposium
1. Simulating the mechanisms of cave mining.	JD Bosman DA Arnold	Numerical modelling techniques in geotechnical engineering.
2. Strata Control Developments on Hartebeestfontein Gold Mine.	DA Arnold JD Bosman	The Human Element in Rock Engineering.
3. Realistic Simulation of Cave Mining using Distinct Element Techniques.	R Johnson JD Bosman	Discontinuous Deformation Analyses Symposium (California)
4. The Extraction of a Faulted Shaft Pillar.	JD Bosman SJP Retief DF Weyers	First Southern African Rock Engineering Symposium (Retracted on advise of legal council)
5. A viscoplastic approach to the modelling of time-dependent rock behaviour at Hartebeestfontein Gold Mine.	DF Malan JD Bosman	First Southern African Rock Engineering Symposium
6. Preparation for Mining the No.2A Sub-Shaft Pillar at the Hartebeestfontein Division of Avgold.	IN Sinclair JD Bosman	AMM Shaft Pillar Extraction Seminar.
7. Bracket Pillar Design – a case study	JD Bosman	Second Southern African Rock Engineering Symposium

Title	Authors	Conference/Symposium
8. Time-dependent tunnel deformation at Hartebeestfontein Mine	JD Bosman, DF Malan & K Drescher	International Tunneling Congress
9. A process for the management of seismic risk at Hartebeestfontein Gold Mine	JD Bosman, AV Visser	5^{th} International Symposium on Rockburst and Seismicity in Mines
10. Dynamic failure of pillar remnants – Case Studies	JD Bosman, G van Aswegen	Tenth ISRM Congress
11. Evaluating hangingwall beam stability using discontinuum modeling	JD Bosman	Facing the challenges (SANIRE 2006)
12. Practical experience with the use of thin sprayed liners at two rivers platinum mine	AP Esterhuizen, JD Bosman	Shotcrete for Africa Conference
13. Slope design at Kabolela Mine – DRC (Presentation only)	JD Bosman	SANIRE 2012 Symposium
14. Stope support design practise - The quest for wisdom. (Presentation only)	JD Bosman	Keynote Address – SANIRE 2013 Symposium
15. Correlation of point load index with uniaxial compressive strength for bushveld complex rocks	LJ Gardner, JD Bosman	Southern African Rock Engineering Symposium 2014
16. Mechanical Properties of Western Bushveld Complex rocks – South Africa	LJ Gardner, JD Bosman	ISRM Congress 2015
17. Verification of catch berm effectiveness through the application of 3D fall body dynamics	JD Bosman, G Kotze	International symposium on slope stability in Open pit mining and civil engineering Slope stability
18. Towards expediting large scale slope design using a re-worked design chart as derived from limit equilibrium methods	G Kotze, JD Bosman	International symposium on slope stability in Open pit mining and civil engineering Slope stability
19. The relationship between the magnitude of input energy per impulse and cumulative absorbed energy capacity of a rock bolt.	JD Bosman, M Cawood, A Berghorst	Third International Conference on Rock Dynamics and Applications (RocDyn-3)

Certification

I, the undersigned, certify that to the best of my knowledge and belief, this data correctly describes me, my qualifications, and my experience.

Jacobus Delarey Bosman

Date: 17^{th} October 2022