

UNIVERSITY OF THE WITWATERSRAND

PROJECT REPORT

**Assessing Preconditioning
Effectiveness Using Ground
Penetrating Radar Mapping**

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A project report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, October 2018

DECLARATION

I **Zwelinzima Enoch Thebethe** declare that this project report is my own, unaided work. I have read the University Policy on Plagiarism and hereby confirm that no Plagiarism exists in this report. I also confirm that there is no copying nor is there any copyright infringement. I willingly submit to any investigation in this regard by the School of Mining Engineering and I undertake to abide by the decision of any such investigation.

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16 October 2018

ABSTRACT

AngloGold Ashanti's Mponeng Gold Mine, is considered a deep level mine, with stope panels having an inherent risk of face bursts, due to the high face stress conditions encountered. As a face burst control measure, face perpendicular preconditioning of stope faces has been successfully implemented over the last 15 years.

The initial preconditioning assessment done on the mine, was conducted at now considered shallow levels, with the mine having gone deeper. With the operation mining deeper faces and the change in stress levels, it was therefore appropriate to assess whether the current preconditioning standard is still effective.

During the initial preconditioning technique development project, one of the successful assessment tools used was Ground Penetrating Radar (GPR) profiling. The tool can be applied to determine the effectiveness of preconditioning by determining the extent and intensity of fracturing ahead of the panel face. The project therefore used GPR profiling.

Following GPR profiling of 10 preconditioned sites on the mine, and analyses of the results obtained, the following conclusions were made:

- The mine's fracture depth averages 5.0m which is above the 3.5m value shown on the GPR scan done during the initial preconditioning assessment project.
- The Mponeng mine preconditioning standard is adequate to achieve the required fracture depth for effective preconditioning, therefore no need to amend the preconditioning hole length and spacing as used on the mine.
- The type of footwall does affect the depth of fracturing obtained, with the shale footwall panels achieving deeper fracturing than the quartzite footwall panels.
- Depth of fracturing has been shown to increase with increase in Energy Release Rate (ERR) values for the quartzite footwall sites. Therefore deeper fracturing ahead of the face can be expected as the stope matures.
- The expected rate of depth of fracture increase with stope maturity is 0.17m/ERR (MJ/m²), for quartzite footwall panels.

- The depth of fracturing for shale footwall sites indicates a decrease in fracture depth with an increase in ERR values. There is however a reduced confidence in this analysis since only 3 data values were used.
- The GPR results were able to show the effect of preconditioning hole burden spacing on the fracturing. The burden spacing of 3.0m as used at Mponeng, is the effective spacing for achieving a continuous fracture profile ahead of the faces.
- There is a general increase in fracture depth when preconditioning hole burden spacing is reduced, however this benefit is insignificant at a range of 6cm increase in fracture depth for 0.5m preconditioning burden reduction. Burden spacing reduction does not significantly increase fracture depth, however it can be used to ensure a high percentage (up to 100%) probability of continuous fracture achievement.
- Where hole spacing is reduced to less than the 3.0m mine standard, the depth of fracturing is increased, and inversely wider preconditioning burden causes the depth of fracturing to be reduced.

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LIST OF ACRONYMS

CSIR: Council for Scientific Industrial Research

EM: Electro Magnetic

ERR: Energy Release Rate

GSSI: Geophysical Survey Systems Incorporated

GAP: Gold And Platinum

GPR: Ground Penetrating Radar

SIMRAC: Safety In Mines Research Advisory Committee

UCS: Uniaxial Compressive Strength

VCR: Ventersdorp Contact Reef

WDLS: Western Deep Levels South

LIST OF DEFINITIONS

The following mining definitions are given as taken from GAP 336 research report (Toper, et al, 1998):

Rockburst

Damage to an underground mining excavation caused by brief violent movement of the rock mass in response to a seismic event.

Faceburst

A type of rockburst caused by the accumulation of strain energy in the fractured rock mass ahead of a mining face, characterized by the violent ejection of material from the face into the excavation.

Preconditioning

A method which makes use of explosives ahead of mining faces to control and limit the amount of damage resulting from face bursts.

Brief definitions of common terms in GPR application as taken from the European GPR Association's Glossary of GPR terms are given below (EuroGPR, 2015):

Antenna

The means or device by which Radar energy is transmitted into (and also received back from) the ground or material

Attenuation (α)

A reduction in GPR signal amplitude caused by energy dissipation in the radiated material (commonly expressed in dB/metre)

Centre Frequency

Middle of the frequency band defined by a device's bandwidth

Conductivity (σ)

Electrical conductivity is the reciprocal of electrical resistivity, and measures a material's ability to conduct an electric current. In general the higher the conductivity the shallower the GPR penetrates. Units are Siemen/m or S/m.

Depth of Penetration

In any medium, the radar wave is attenuated as it progresses due to losses that occur. At radar frequencies in a resistive dielectric earth material (fresh water, granite, quartz sand, etc.), where the losses are low, the depth of penetration can be quite great (>30m).

Dielectric Constant / Dielectric Permittivity (ϵ_r)

Dielectric Permittivity is a property of an electrical insulating material (a dielectric) equal to the ratio of the capacitance of a capacitor filled with the given material to the capacitance of the identical capacitor filled with air. Earth materials are classified generally as conductors, semiconductors and insulators (dielectrics). A dielectric material is a poor conductor of electric current. The relative dielectric constant, ϵ_r for air is 1 and is approximately 81 for fresh water.

Radargram

A graph showing the depth measurements as a vertical cross section of the medium along a horizontal line.

Reflection Coefficient

A reflection coefficient describes the amplitude of a reflected wave relative to that of the incident wave.

Reflector

An object with sufficient ϵ contrast to reflect & refract an EM wave.

1. INTRODUCTION

AngloGold Ashanti's Mponeng Gold Mine, is considered a deep level mine, with its stopes being mined at an average depth of 3500m below surface. These stope panels have an inherent risk of face bursts, due to the high face stress conditions encountered, a cause of their depth below surface. As a face burst control measure, face perpendicular preconditioning of stope faces was implemented in the early 2000's and to date continues to be used (Mahne, 2004).

The historic implementation of pre-conditioning stated above was necessitated by the mine's working stopes moving to deeper ground, the generated multiple strain burst events and subsequent serious injuries. Mahne (2004) stated that, the implementation of preconditioning resulted in a decrease of on shift face bursts and the number of injuries associated with this form of seismicity.

The SIMRAC, utilising the CSIR Mining Division, funded research work, between 1993 and 1998, into the mechanism and implementation of preconditioning in deep level stopes. The research work produced two methodologies of pre-conditioning, namely face perpendicular and face parallel, with the latter having numerous implementation challenges. This research work, which formed the basis for precondition application in South Africa's deep level mines, is documented in the SIMRAC reports GAP 030 and GAP 336 (Lightfoot, et al, 1996 & Topper, et al, 1998).

The SIMRAC issued 'Preconditioning Implementation Guidelines', recommended the use of face perpendicular methodology for preconditioning of stope faces, which Mponeng Gold Mine implemented and continues to apply to date (Mahne, 2004). The effectiveness assessment of preconditioning will therefore be based on the face perpendicular preconditioning methodology as applied on the mine.

The correct understanding of the mechanism of preconditioning is critical in guiding the effectiveness assessment process. Topper, et al (1998) indicated, from the study of the mechanism of preconditioning, that the purpose of a preconditioning blast is not to create

new fractures, since a face stress generated fracture zone ahead of the face pre-exists. The gas and shock energy from the preconditioning blast, within the fracture zone, merely remobilise the blocks by shearing through the asperities that are causing block lock-ups. This facilitated stable sliding of blocks past each other results in strain energy release, thereby reducing the risk of face bursting during the production shift (Jager and Ryder, 1999). The resultant effect of a good preconditioning blast is a stress redistribution away from the working face, thereby reducing the risk of a face burst.

The purpose of preconditioning is to eliminate strain energy lock-ups due to asperities on pre-existing or mining-induced fracturing. The preconditioning blast does not therefore need to generate new fractures, but rather, to provide large quantities of gas at high pressure to open the pre-existing fractures (Tooper, et al, 1998).

The preconditioning guidelines (SIMRAC GAP 336 and 811) indicated that, the monitoring of the effectiveness of preconditioning should be conducted at implementation sites when conditions differ markedly from those investigated during the development of the technique. In the case of Mponeng Mine, initial investigations during GAP projects 030, 336 and 811 were conducted at the upper 87, 94 and 109 levels. Mponeng Mine has since moved even deeper with levels such as 116, 120 and 123 coming on board. It is therefore important that the mine monitors the effectiveness of preconditioning at current working sites and is prepared to change some of the parameters in the standard to suit current conditions. Amendable face perpendicular preconditioning parameters include: hole length, hole diameter and the spacing between adjacent holes (Tooper, et al, 1998 and Tooper, et al, 2003a).

During the preconditioning technique development project (GAP 336), a number of useful assessment tools were utilised to assess the effectiveness of preconditioning. One of the assessment tools used was GPR profiling. Although this assessment tool requires specialist equipment and data interpretation, GPR profiling provides a view into the preconditioned rock ahead of the face (Tooper, et al, 2003a). GPR profiling is the tool to be used for this assessment project.

Processed GPR profiles are able to clearly show the increased intensity, extent and increased separation of fracturing ahead of the face due to the preconditioning blast. The GPR profiles can also be analysed to assess the preconditioning hole burden spacing by looking at the continuity of the fracturing between adjacent holes (Grodner, 2001).

1.1. Research Problem

The frequency of face bursts was drastically reduced with the successful implementation of face perpendicular pre-conditioning on Mponeng Mine in the early 2000's. The preconditioning assessments done on the mine, were conducted from 87 level and down to the then deepest working level of 109. The mine has since moved deeper with levels such as 116, 120 and 123 coming into production. With the operation mining deeper faces and the change in stress levels, it was therefore appropriate to assess whether the current preconditioning standard is still effective.

1.2. Project Objectives and Expected Outcomes

The success of a project is determined by the attainment of project objectives and delivery of the expected outcomes. The project objectives and outcomes as provided for in the project brief are given and attainment is discussed below.

The four objectives of the project are as follows:

- **OBJ1:** To ascertain whether the standards for pre-conditioning of stope faces, as found on Mponeng Mine, are sufficient in achieving the goal of a fractured profile ahead of the stope face,
- **OBJ2:** To assess the influence of certain variables, such as footwall type (quartzite / shale) and stope maturity (face ERR) on the fracture profile,
- **OBJ3:** To compare the results to that of the original GAP projects,
- **OBJ4:** To amend the current pre-conditioning standards, if deemed necessary.

The following should also be noted regarding the project objectives:

- The project will not assess the compliance of mining personnel to the preconditioning mine standards and the effects of sub-standard pre-conditioning, nor was it intended to assess historic trends of face bursting versus actual pre-conditioning compliance.
- The influence of standing time on pre-conditioning is envisaged as a stand-alone project.

The expected outcomes of the project are summarized into the following four outcomes:

- **OUT1:** Do 3.0m wide pre-conditioning burdens provide an uninterrupted fracture profile ahead of the panel face, and if so, what is the effective depth of that fracture profile, this against a 3.0m burden as recommended in GAP 336? What difference is observed in the fracture profile when different burdens are used, i.e. 3.0m, 2.5m, and 2.0m? Should the standard burden of 3.0m remain unchanged, or should it perhaps, be reduced?
- **OUT2:** How does the 2.6m long pre-conditioning drill steel (2.4m effective hole length) influence the fracture profile and effective depth of fracturing, this against the GAP 3.0m hole length? Should the effective hole depth increase, or will reducing the hole burdens provide a sufficiently deep uninterrupted fracture profile?
- **OUT3:** What influence do differing footwall lithologies have on the fracture profile ahead of the panel face? Is there a difference between the fracture profiles when a shale footwall is compared to a quartzite footwall?
- **OUT4:** What influence do differing stope maturities have on the fracture profile ahead of the panel face? Is there a difference between the fracture profiles ahead of a panel on a young stope compared to a mature stope? Maturity will be assessed by numerically modelled face ERR values.

The work done on the project will be able to meet the requirements for OBJ1, OBJ2, OBJ3 and OBJ4. The project work done will also be able to provide solutions for

OUT1, OUT2, OUT 3 and OUT4. It can therefore be summarised that all four project outcomes can be delivered and the project objectives will be met.

1.3. Content of Report

The report will provide information laid out in the following sections, with related subsections:

- **LITERATURE REVIEW**

This section will give a brief summary of the literature consulted in preparing and conducting the assessment. The relevant subtopics related to preconditioning are provided below:

- Preconditioning Mechanism and Guideline
- Preconditioning at Mponeng Gold Mine
- Fracturing Around a Deep Level Stope
- GPR Mapping of Preconditioning Fracture Zone

- **GROUND PENETRATING RADAR (GPR)**

A background study on GPR application was also conducted in preparation for the data collection. Background information related to GPR is provided in this section, with the information discussed in the following subtopics:

- GPR Method and Survey
- Dielectric Constant of the Host Rocks
- GPR Survey Design
- The GPR System

- **METHODOLOGY**

This methodology section will provide brief explanation on how data was collected during the project. The collection of the different data sources and data processing activities are explained under the following subtopics:

- Precon Socket Mapping
- GPR Scan Details
- GPR Data Processing
- Determining Depth of Fracturing
- Precon Burden Spacing Evaluation
- Footwall Type Evaluation
- Stope Face Maturity Evaluation (ERR)

▪ RESULTS

This section will provide the results obtained from each of the ten sites where the GPR scans were conducted. The following information about each site is given:

- General site details such as geology, mining parameters, ERR, and any other issues encountered at the site.
- Preconditioning socket mapping results
- The 7.0m depth GPR scan results
- Indication of depth of fracturing on GPR scans,
- Graphical illustration of the depth of fracturing results, and
- Burden spacing analysis of precon holes on GPR scans

▪ ANALYSIS OF RESULTS

The section will provide analysis of key items required to meet the project objectives and deliver on the project outcomes. The information will be given under the following subsections:

- Depth of fracturing ahead of the face
- The effect of footwall types on the depth of fracturing
- Depth of Fracturing vs Stope Face Maturity (ERR and Sigma 1)
- Preconditioning holes burden spacing

▪ CONCLUSIONS

This section will provide the conclusions from the work detailed in the rest of the report. This section will conclude in response to the set project objectives and the expected outcomes.

- RECOMMENDATIONS FOR FURTHER RESEARCH

Following the conclusion on the work conducted, this section discusses recommendations for any further work to be conducted.

2. LITERATURE REVIEW

A literature review on topics related to preconditioning was conducted in order to provide background information for the effectiveness assessment. The objective of the literature review was to assess technical information which will guide in the achievement of the project objectives. The review is a summary of the relevant technical information, and therefore does not give a historic perspective on preconditioning. The following subtopics were determined to be relevant for the assessment objectives:

- Understanding of the preconditioning mechanism and knowledge of the precondition guidelines.
- How preconditioning has been applied on Mponeng Mine.
- A detailed understanding of pre-existing fracturing, extent of the fracture zone and parameters influencing fracture zone size around a deep level stope.
- Knowledge of what is considered to be the effective depth of fracturing after preconditioning.
- How to conduct a GPR mapping exercise of post preconditioning blast fracture zone and expected outcomes.

2.1. Preconditioning Mechanism

The concept of preconditioning for deep level stopes premises upon the fact that the stope excavation is surrounded by mining-induced fractures. The significance of this to preconditioning is that, the rock immediately ahead of the stope face has already been fractured before the preconditioning and production blasts. The extent of this fracture zone is dependent mainly on the stress levels and rock properties. The actual size of this zone can extend for a few metres ahead of the face, depending on the above parameters (Jager and Ryder, 1999).

In deep level stopes, the fracture zone ahead of the stope face, is still under high levels of stress, since it is still confined. The blocks in this confined fractured zone have to slip past each other for deformation and strain energy release to occur. As the stress load on

the fracture zone ahead of the face increases due to advancing mining faces, so does the need for strain energy to be released. If slip along the fractures is inhibited (lock-ups), strain energy will begin to accumulate to unsustainably high levels. When sufficiently high levels of energy are accumulated immediately ahead of the stope face, then an immediate violent energy release could take place resulting in a face burst (Jager and Ryder, 1999).

The detonation of a preconditioning blast, produces a stress field and gas pressure in the fractured zone ahead of the stope face. This stress field and the gas pressure results in the remobilization of the fracture defined blocks, by releasing the locked-up blocks. This movement of blocks results in stable strain energy release during the blast, therefore preventing the occurrence of a face burst during the production shift (Tooper, et al, 1998).

The release of strain energy in the fracture zone, results in the redistribution of stress deeper into the rock ahead, away from the working face and therefore reducing the risk of a face burst. A theoretical model of the preconditioning mechanism is shown in Figure 1 which indicates the stress redistribution ahead of the working face.

The supplementary effect of the low stress fractured zone immediately ahead of the stope face is that the ground is able to absorb additional energy from other distant seismic events, therefore preventing or reducing the damage caused by such events in the working place (Jager and Ryder, 1999).

The preconditioning tool therefore serves two functions, being:

- To reduce the risk / prevent the occurrence of face bursts, and
- To minimize instope damage caused by any seismic event that occurs in the vicinity of the face.

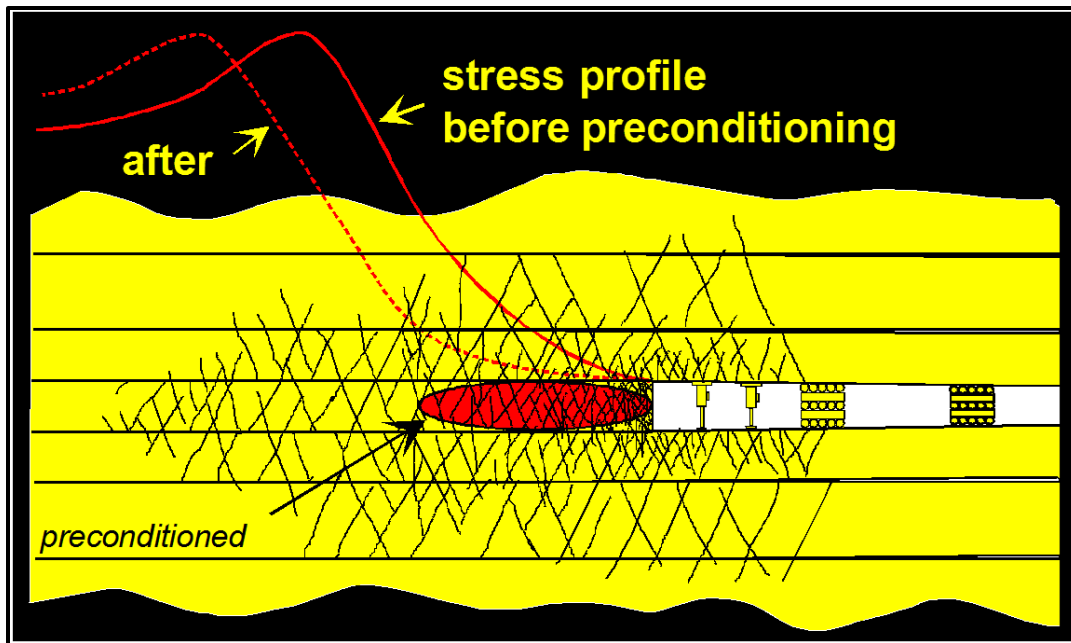


Figure 1: Stress redistribution due to preconditioning (Toper, et al,1998)

2.2. Preconditioning Guideline

At the completion of SIMRAC project GAP 336, Toper, et al (1998) produced as part of the project objectives, content for “Guidelines for the implementation of face-perpendicular preconditioning”. They recommended that these guidelines should be produced in a separate booklet, which was produced in 2003 and forms the basis for preconditioning application in South African Mines. A brief summary of the main items covered in the booklet when implementing face perpendicular preconditioning is given.

Face perpendicular preconditioning is the drilling and blasting of face perpendicular holes, longer than production holes, to form part of the actual production blast cycle. This preconditioning technique was considered to be suitable for normal production faces since it is easily included into the mining cycle (Toper, et al,1998).

This preconditioning technique is recommended with the use of 3.0m long blastholes, with a diameter range of 36 – 40mm, and drilled perpendicular to the stope face. The recommended burden spacing between preconditioning holes is also 3.0m (Toper, et al, 2003a). The layout of the cycle and preconditioning hole position are shown in Figure 2.

The preconditioning holes should be drilled in the mid-height of the stope face when the stoping width is 1.2m or less. When the stoping width is greater than 1.2m then the holes must be drilled 60cm below the hangingwall (Tooper, et al, 2003a).

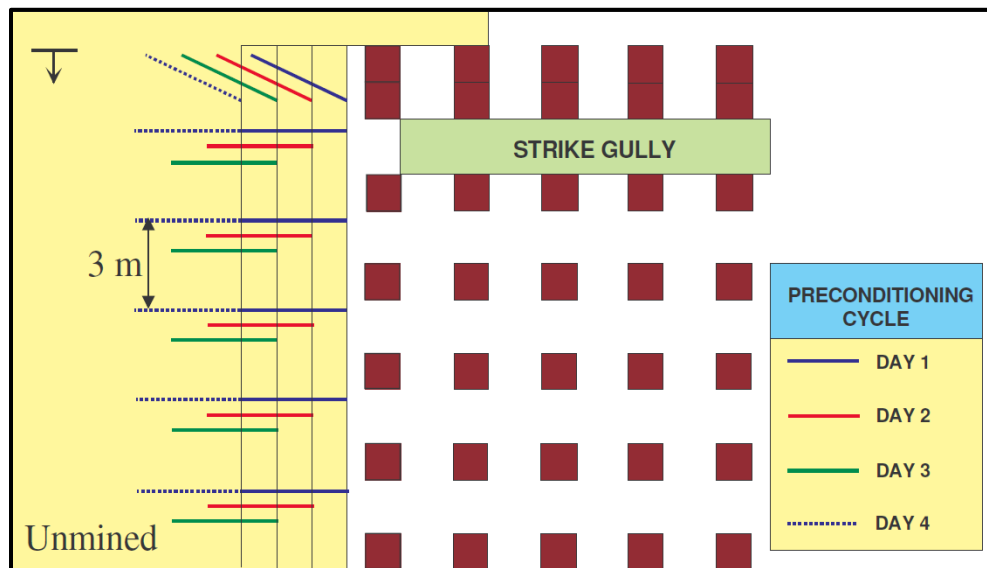


Figure 2: Face perpendicular preconditioning layout (Tooper, et al, 2003b)

For the charging of the preconditioning holes, it is recommended that, the back 2.0m of the hole be charged with explosives and the remaining 1.0m be stemmed as shown in Figure 3. Top-priming of the explosive charge is recommended, to ease primer removal when preconditioning holes misfire. The recommended detonation sequence is for preconditioning holes to be initiated a minimum of 1.0m ahead of the production holes (Tooper, et al, 2003b).

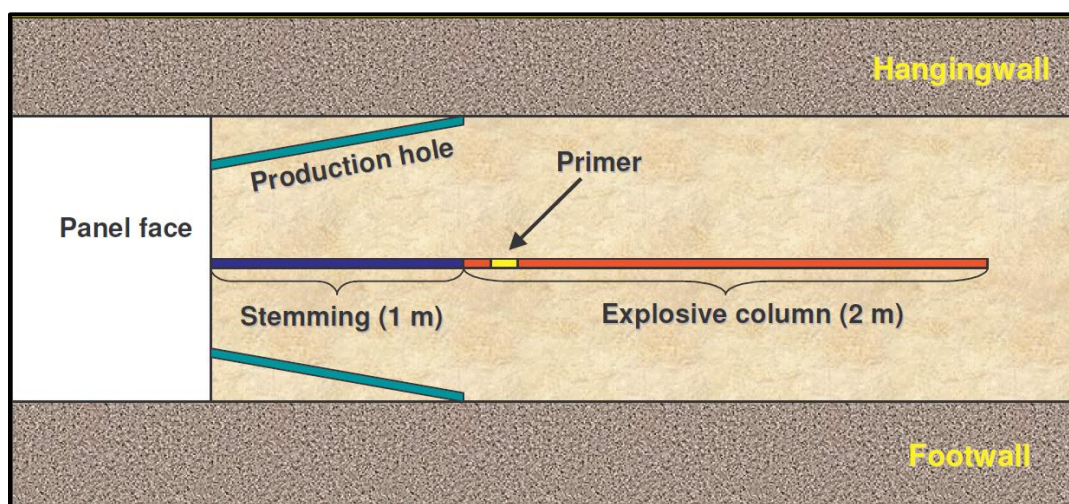


Figure 3: Charging and stemming of preconditioning hole (Tooper, et al, 2003b)

2.3. Preconditioning at Mponeng Gold Mine

Research work on the application of face perpendicular preconditioning on Mponeng Mine, then Western Deep Level South, was conducted by SIMRAC (GAP 030 & 336) at 87-49W longwall stopes, from May 1995 to February 1997. Although the research work proved preconditioning to be effective for face burst control, it was not rolled out throughout the mine due to personnel issues (Lightfoot, et al, 1996 and Tooper, et al, 1998).

It was only in the 2000's that Mponeng Mine started a program of enforcing mine wide use of preconditioning, although not very successful due to personnel issues. It was only in the first quarter of 2003 that a successful campaign was implemented to roll out the use of preconditioning to all mined stope panels (Mahne, 2004).

Following from the SIMRAC research work conducted on the mine, Mponeng Mine's standards for the application of preconditioning were closely in line with the SIMRAC guidelines provided in GAP 336 and 811. Mahne (2004) provided the applied standards on Mponeng Mine, as shown in Figure 4 and Figure 5. Mponeng Mine however used a preconditioning hole length of 2.4m, instead of the recommended 3.0m, as shown in Figure 4. A length of 1.4m was charged with explosives, which is slightly less than the 2/3 rule in the guideline booklet (Mahne, 2004).

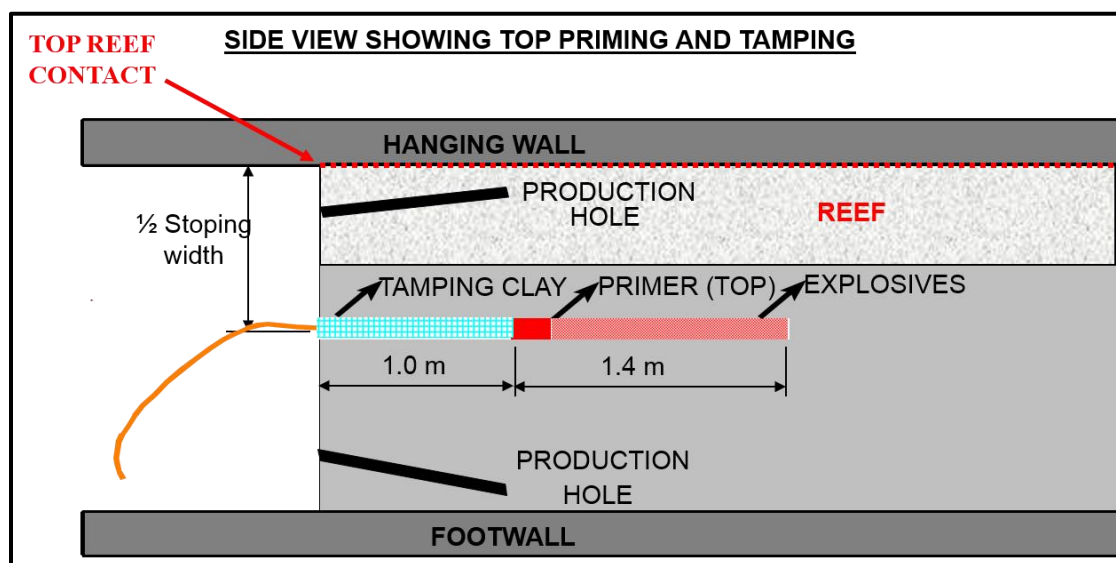


Figure 4: Initial Preconditioning Hole Charging at Mponeng (Mahne, 2004)

Preconditioning hole burden spacing applied on the mine was 3.0m as per guideline and shown in Figure 5. All other parameters were applied as given in the guideline. A poster developed during the preconditioning campaign implemented in the first quarter of 2003 can be seen in Appendix 4.

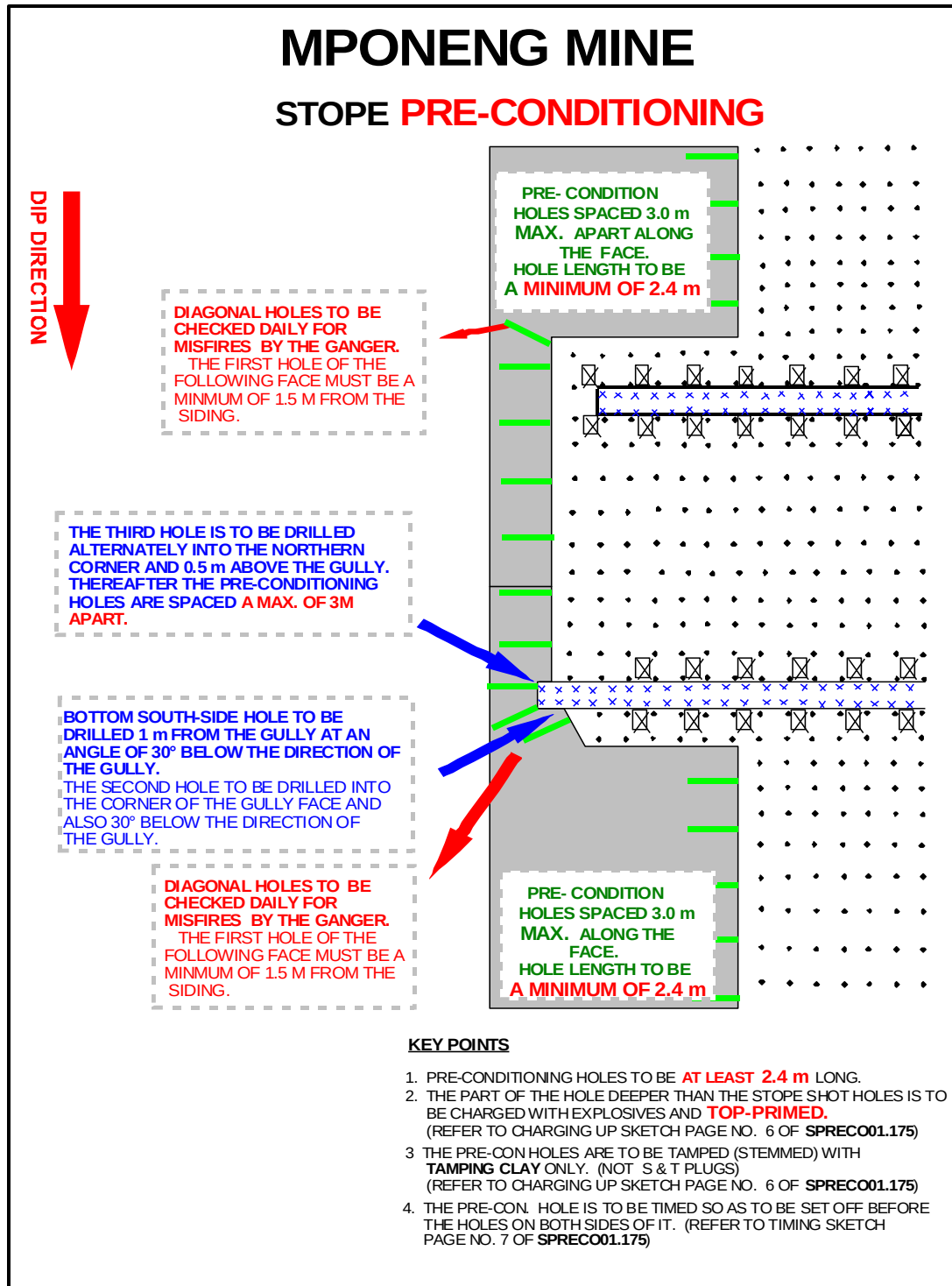


Figure 5: Initial Preconditioning Layout at Mponeng (Mahne, 2004)

Due to the success of the preconditioning over the years, the mine standards have remained unchanged. It was only in 2016 that minor changes to the preconditioning standards were done. Extracts from these standard are shown in Figures 6 and 7.

The preconditioning hole length of 2.4m and the charging therefore has remained unchanged, only charging details were included in the new standard, as observed in Figure 6 below.

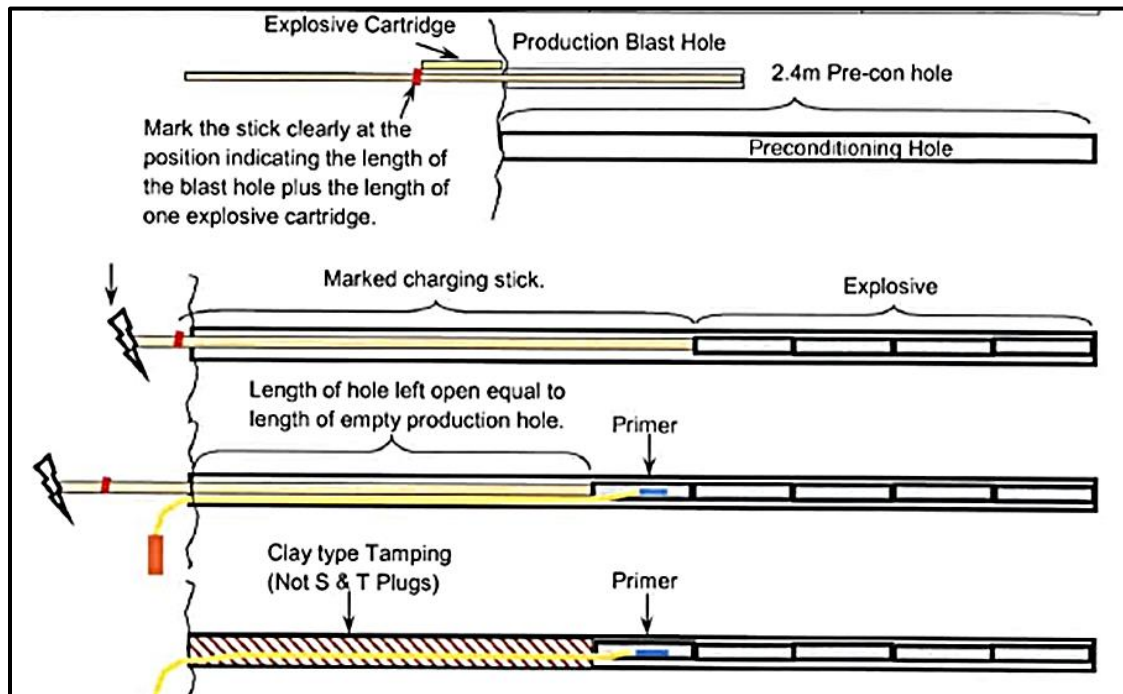


Figure 6: Current Hole Charging Standard (AngloGold Ashanti, 2016a)

The precondition burden spacing was reduced slightly to a range of 2.5m (minimum) and 3.0m (maximum), as shown in Figure 7. All other details on the standard were left unchanged and are in line with the industry guideline (AngloGold Ashanti, 2016b).

The above discussion on the preconditioning standard applied on the mine can be summarised as follows:

- Preconditioning holes are spaced at minimum 2.5m and maximum 3.0m apart
- Preconditioning hole length is minimum 2.4m and 1.4m of the hole must be charged with explosives.

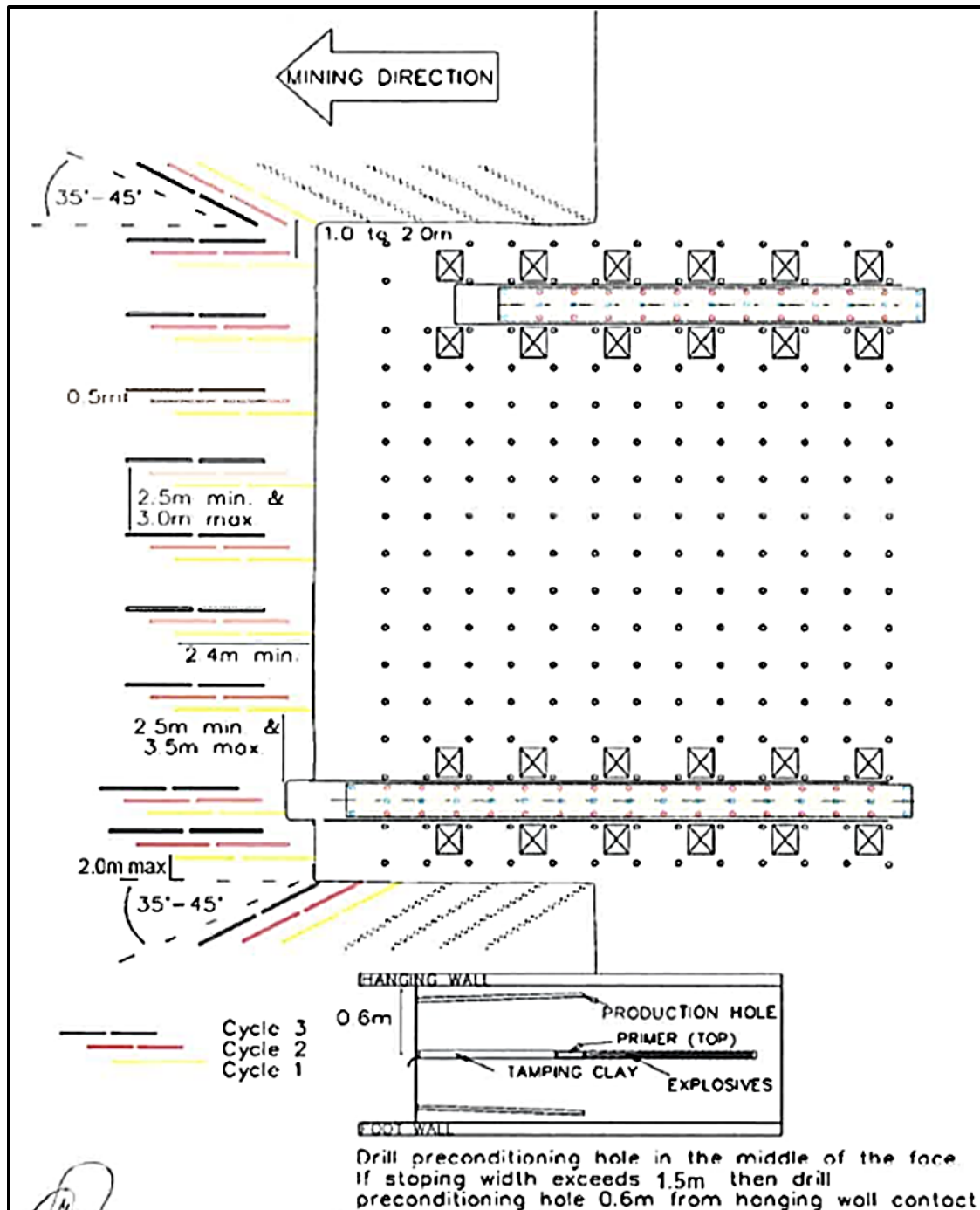


Figure 7: Current Preconditioning Layout Standard (AngloGold Ashanti, 2016b)

2.4. Fracturing Around a Deep Level Stope (No Preconditioning)

The previous section discussing the preconditioning mechanism indicated that the blasted explosives in the preconditioning hole help to remobilize pre-existing fractures ahead of the stope face. It is therefore important to understand the character of this fracture zone, by looking into the type of fractures in the zone, the depth / size of the fracture zone and parameters that influence the size of the fracture zone.

In deep level mines, the stress concentration is highest immediately ahead of the stope face, and it is these stresses that result in dense and characteristic patterns of fracturing as indicated in Figure 8. Mining-induced shear fractures (S), form well ahead of the face and are generally parallel to the face on plan. The figure also indicates the presence of mining-induced extension fractures (E), which form very near the stope face and are also face parallel in plan. The other pre-existing fractures are parting-planes (P) and joints (J) which are not mining-induced (Jager and Ryder, 1999).

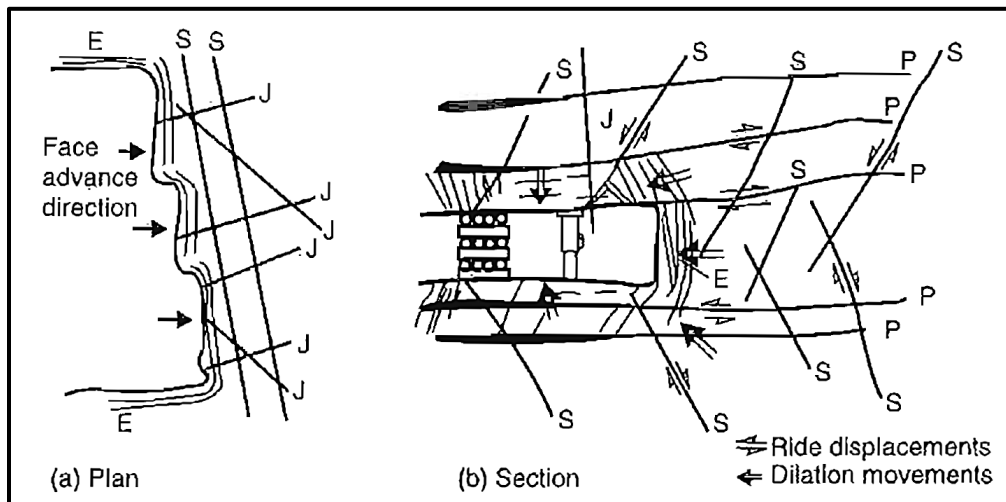


Figure 8: Fracture patterns around a deep level stope (Jager and Ryder, 1999)

Following from work conducted by Adams, et al (1981), Jager and Ryder (1999) improved on the fracture model. According to the new model, the following fractures exist ahead of a stope, as depicted in Figure 9:

- Shear fractures (numbered 1). The handbook indicates that these fractures develop at the edge of the fracture zone, where normal stresses and confining stresses exceed the UCS of the rock.
- Primary Extension fractures (numbered 2a). These fractures are also thought to develop near the edge of the fracture zone and are near vertical. Occurrence at least 2.0m ahead of the face was measured (Adams and Jager, 1980), while Figure 9 suggests a greater distance
- Secondary Extension fractures (numbered 2b). These fractures develop close to the face, between the face and primary extension fractures, assumed to be within 2.0m from the face. They are vertical ahead of the face, but dip around 70° in the hanging- and footwalls.

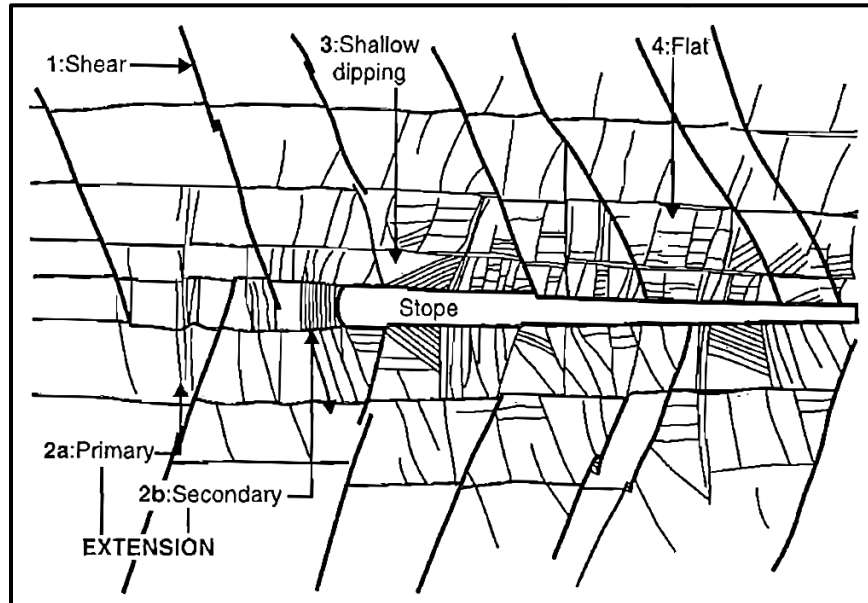


Figure 9: Stress fracturing around a deep stope (Jager and Ryder, 1999)

Another important factor in understanding the influence of stope fracturing for preconditioning, is the deformation of the fracture zone, which indicates the condition of the above discussed fractures. Jager and Ryder (1999) provide a model for the deformation of the fracture zone, as given in Figure 10.

The process of dilation shown in Figure 10, indicates that the extension fractures ahead of the face can open up by a cumulative amount of 30 – 50mm. Shear fractures can

similarly open up by 10mm and also shear for a distance of 2 – 5mm. (Jager and Ryder, 1999). The preconditioning blast therefore assists in speeding up a naturally occurring process immediately after the blast.

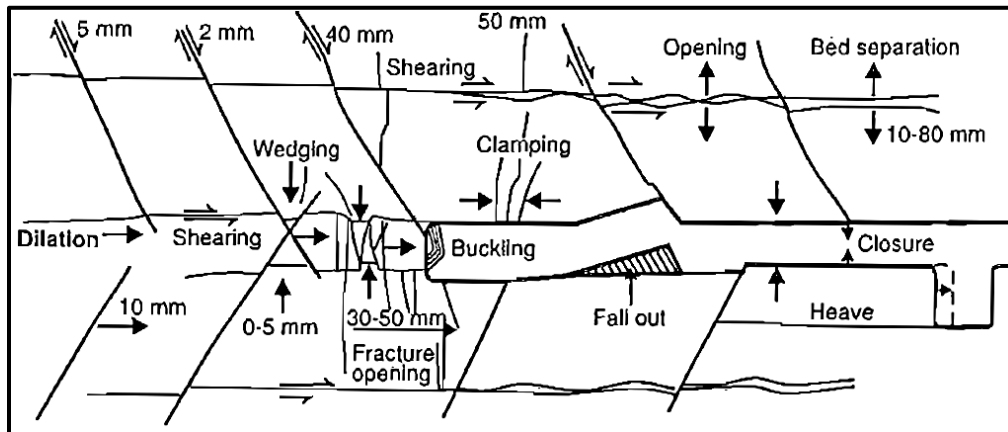


Figure 10: Deformation of fracture zone (Jager and Ryder, 1999)

Determination of the extent or size of the fracture zone around a deep level stope, was conducted by Adams and Jager (1980). In their work, they drilled perpendicular boreholes into mining faces, observed the boreholes with a petroscope to determine the position of fracturing, as the faces were advancing. The results of observations for a panel with an ERR value of 17MJ/m^2 are shown in Figure 11. The end of the borehole is indicated as E.O.H., with the advancing face positions also shown on the dates measured.

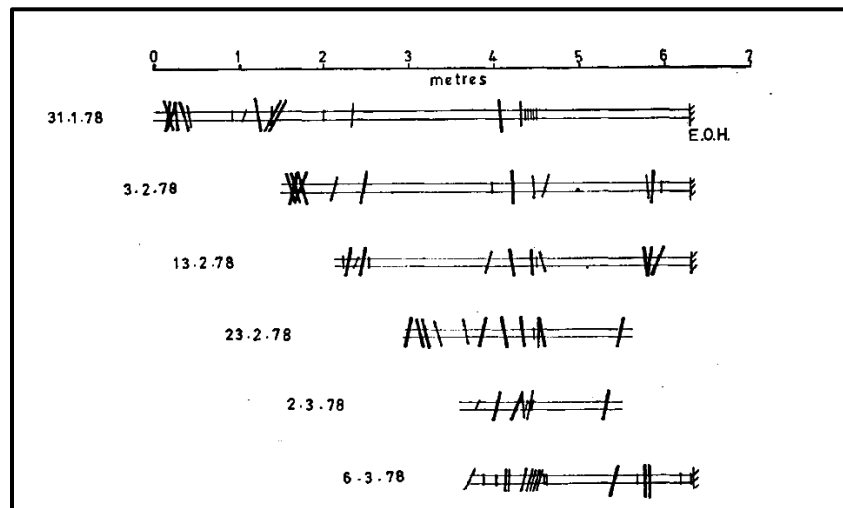


Figure 11: Plan views of petroscope observations in panel with ERR of 17MJ/m^2 (Adams and Jager, 1980)

The results indicated in Figure 11 are similar to other boreholes drilled at similar ERR figures, and indicate the following (Adams and Jager, 1980):

- Identifiable areas of fracturing are separated by areas of solid rock within the fracture zone,
- The fracture zone extends forward by a distance of 1.0m, as the face advances, forming new fractures,
- Additional fractures develop within the previously solid areas of the fracture zone as the stope face advances, and
- The maximum depth of the fracture zone varies between 3.0 and 4.0m.

Additional indication of the expected depth of the fracture zone ahead of the stope face, was given in the handbook by Jager and Ryder (1999). Figure 12 from the handbook indicates the extent of the fracture zone and the stresses ahead of a stope face. The depth of the stope face depicted below is between 2500m and 3500 below surface, which was determined from the virgin stress levels indicated on the diagram. The depth of the fracture zone from Figure 12 is about 5.0m.

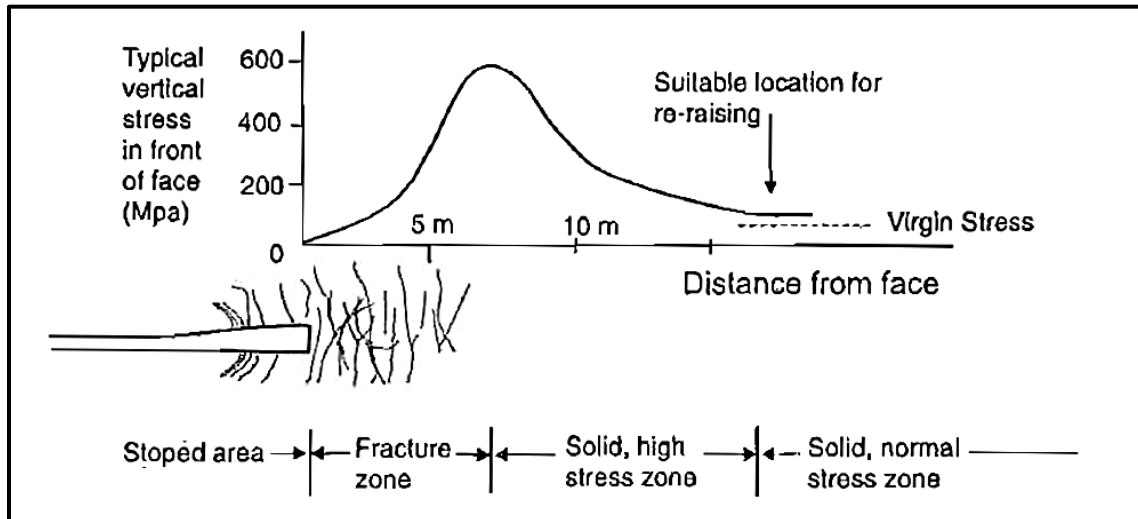


Figure 12: Fracture zone and stresses ahead of a deep face (Jager and Ryder, 1999)

From the work done by Adams and Jager (1980) and Jager and Ryder (1999), it is shown that the depth of the fracture zone ahead of a typical, well planned deep level stope face varies from 3.0 – 5.0m.

Both publications also indicate that the size of this fracture zone can increase up to 7.0m in highly stressed stope faces. This was shown by comparing the depth of the fracture zone to ERR values, since ERR is directly related to the major stress on the face.

Adams and Jager (1980) were able to show this by plotting borehole mapping at increasing ERR values from different panels. Figure 13, clearly shows that the extent of fracturing increases for increasing ERR values.

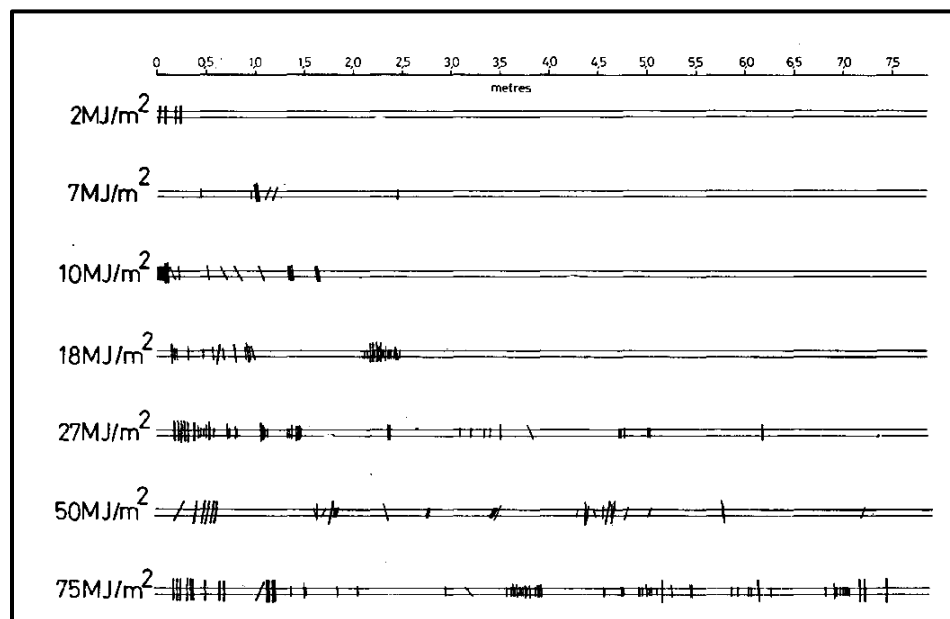


Figure 13: Depth of fracture zone at different ERR values ((Adams and Jager,1980)

Jager and Ryder (1999) also briefly discuss and confirm the relationship between fracture zone depth and ERR, as initially indicated by Adams and Jager (1980). They however make the following further indications, as shown in Figure 14:

- ERR correlates with face stresses, with an increase in face stresses leading to an increase in the ERR values.
- Fracture depth and height increase with increasing ERR values.
- Fracture dilation increases with increasing ERR values.

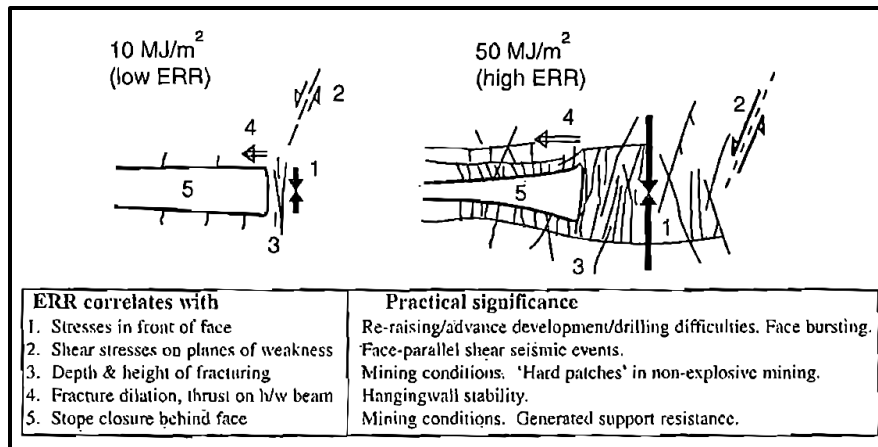


Figure 14: Effect of ERR on mining conditions (Jager and Ryder, 1999)

2.5. GPR Mapping of Preconditioning Fracture Zone

During the first preconditioning project GAP 030, the first experiment of using GPR to assess the fracturing from preconditioning blasts was undertaken at Blyvooruitzicht Gold Mine, on 14 December 1993. The purpose of the experiment was to determine the effective burden spacing between face perpendicular preconditioning holes. A face perpendicular hole 3.0m long was drilled and blasted. A GPR scan was conducted before and after the preconditioning blast. The scans indicated an intensification of the radar signal for the post preconditioning blast as expected and on detailed analyses of the scan it was indicated that the effective burden spacing is 3.0m, instead of the previously thought 1.5m (Lightfoot, et al, 1996).

The continuation project GAP 336, did detailed optimisation of the face perpendicular preconditioning technique which started at the end of August 1996 at Mponeng (WDLs). One tool that was used as part of the optimisation exercise was GPR. The GPR tool was successful in indicating the extent of reactivated fractures ahead of the face by the preconditioning blast (Tooper, et al, 1998).

Figure 15 indicates GPR scans which were taken on a stope face, before and after a preconditioning blast. The scan on the left is from an un-preconditioned face, while the scan on the right is post the preconditioning blast. There is an intensity of fracturing and the fractures extend further in the preconditioned GPR scan (Tooper, et al, 1998).

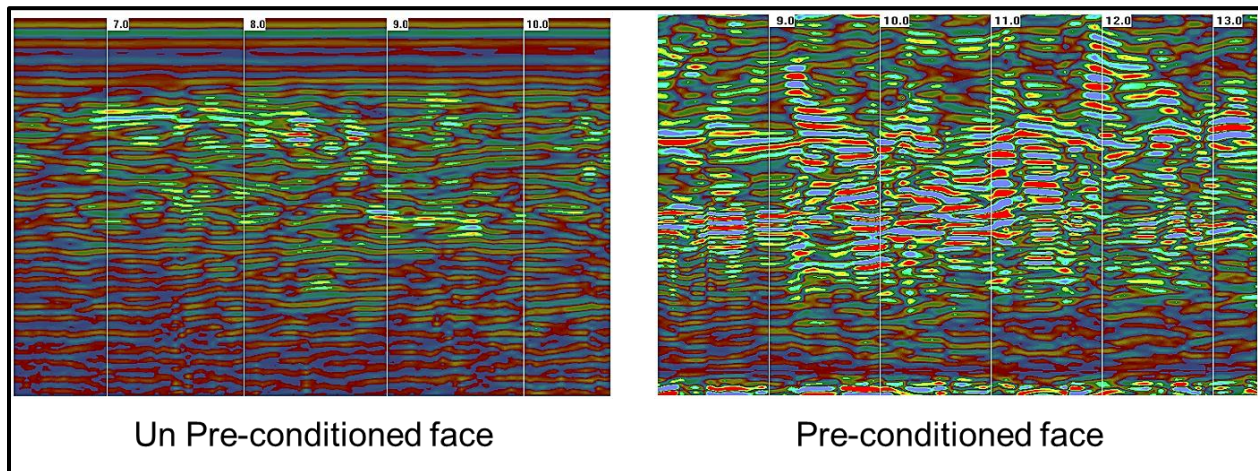


Figure 15: GPR scans for un-preconditioned and preconditioned faces (Mahne, 2004)

An example of the optimisation results achieved from using GPR are shown in Figure 16. The figure shows a GPR scan with the preconditioning hole sockets superimposed. From these results it could be determined that the 7.0m spacing between the preconditioned holes did not achieve the objective of a continuous fracture pattern ahead of the stope face (Tooper, et al,1998) .

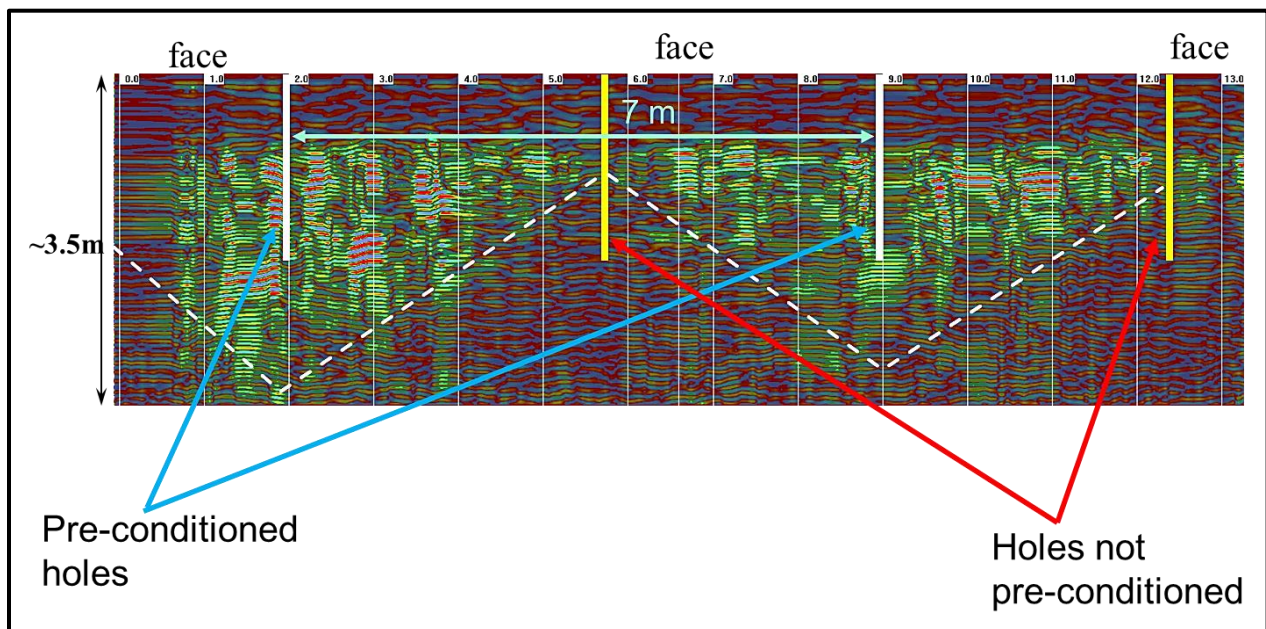


Figure 16: GPR scan indicating over spaced preconditioning holes (Mahne, 2004)

The GPR scan shown in Figure 16, clearly shows the extent and intensity of the fracturing around the preconditioning blast. Grodner (2001) concluded from the radargrams that the stronger electromagnetic reflections seen in the GPR indicated a greater intensity of fracturing and dilation of individual fractures associated with the preconditioning blast. The GPR scan does not only show the increase in number of fractures, it also shows the shape of the fracture envelope. The influence of each precondition hole could be defined from the GPR scan. The GPR scan also shows that, where preconditioning holes were not drilled, the fracturing does not extend deeper into the rock. Therefore an indication that preconditioning extends the fractures deeper into the rock ahead of the preconditioning hole socket.

It was subsequently determined from these results that 4.0m is the maximum spacing between two holes to achieve a continuous fracture pattern. In order to be cautious, a spacing of 3.0m was decided upon (Tooper, et al, 1998). The expected fracture pattern and extent of fracturing for a 3.0m spacing between preconditioning holes is shown in Figure 17.

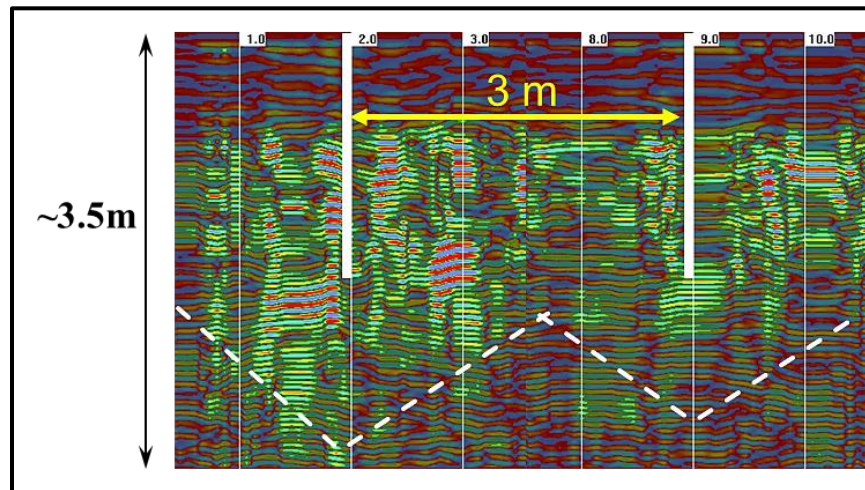


Figure 17: GPR scan of expected fracturing for a 3.0m burden spacing (Mahne, 2004)

The above results were obtained using a SIR-2M radar system developed by GSSI, with a 500MHz antenna attached to the system. The GPR system was moved along the face as shown in Figure 18. Distance intervals along the scan line were taken at 1.0m as observed in Figures 15 – 17 (Grodner, 2001).



Figure 18: The GPR antenna being dragged along the face to collect data (Grodner, 2001)

Full details regarding the data collection parameters and processing of the data are not given in the preconditioning related literature. The only data collection parameter given is the depth of data collection. Different depth scans were conducted with the deepest scans taken at 8.0m into the solid (Grodner, 2001).

3. GROUND PENETRATING RADAR (GPR)

Literature reviewed concerning GPR mapping of preconditioned faces from the SIMRAC GAP 030 and 336 projects did not provide any technical details on GPR mapping survey design and the collection of GPR data. Only the final results were provided, and therefore for this section to accompany the GPR results to be provided was deemed necessary. This section and subsections are intended to explain how GPR works, the determination of technical input parameters, survey design and the choice of a GPR system.

3.1. GPR Method and Survey

Ground Penetration Radar is an electromagnetic method which operates at a frequency range of 1 to 1000MHz. At these frequencies the electromagnetic field propagates as a wave through the rock (Dentith & Mudge, 2014).

Electromagnetic energy pulses are sent from the antenna by the transmitter through the rock and arrive at the receiver (also inside the antenna) by wave reflection on a rock/material with different electrical properties such as an open fracture in the fracture mapping exercise, see illustration in Figure 19.

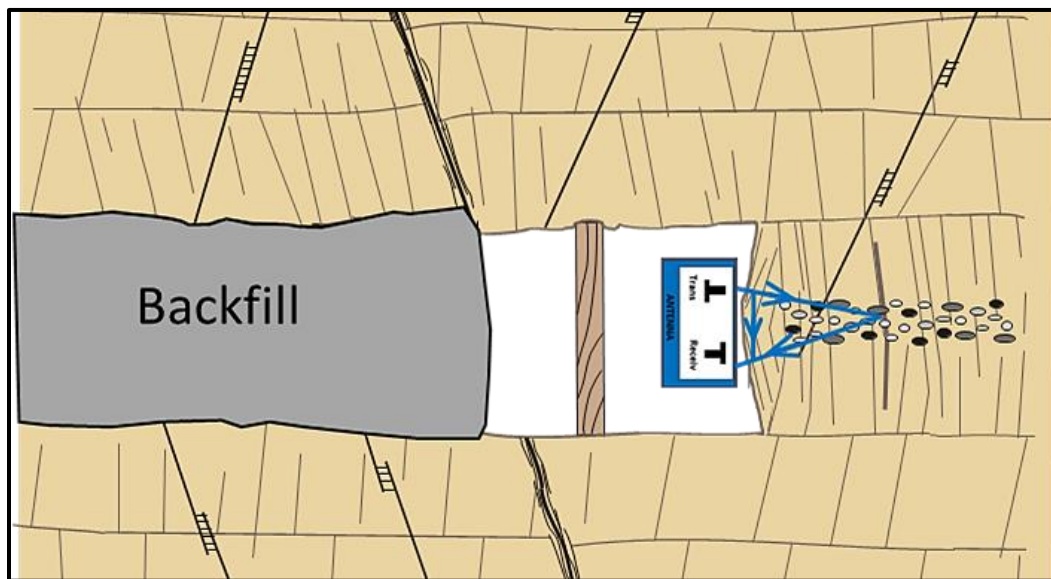


Figure 19: Schematic of GPR Stope Face Fracture Application. Adapted from Dentith and Mudge (2014)

It should be noted that the different material in the fracture is the air gap through which the electromagnetic field has to propagate (Dentith & Mudge, 2014). In GPR stope mapping of fractures ahead of the face, the antenna is placed against the face and the signal is sent into the rock ahead of the face as illustrated in Figure 19.

The most common configuration of a GPR survey is the reflection profiling mode, where the antenna direction is parallel to a survey line. The antenna is moved at near constant velocity along the face which is the survey line, and the number of samples taken along the survey line affects the lateral resolution of the survey, see Figure 20.

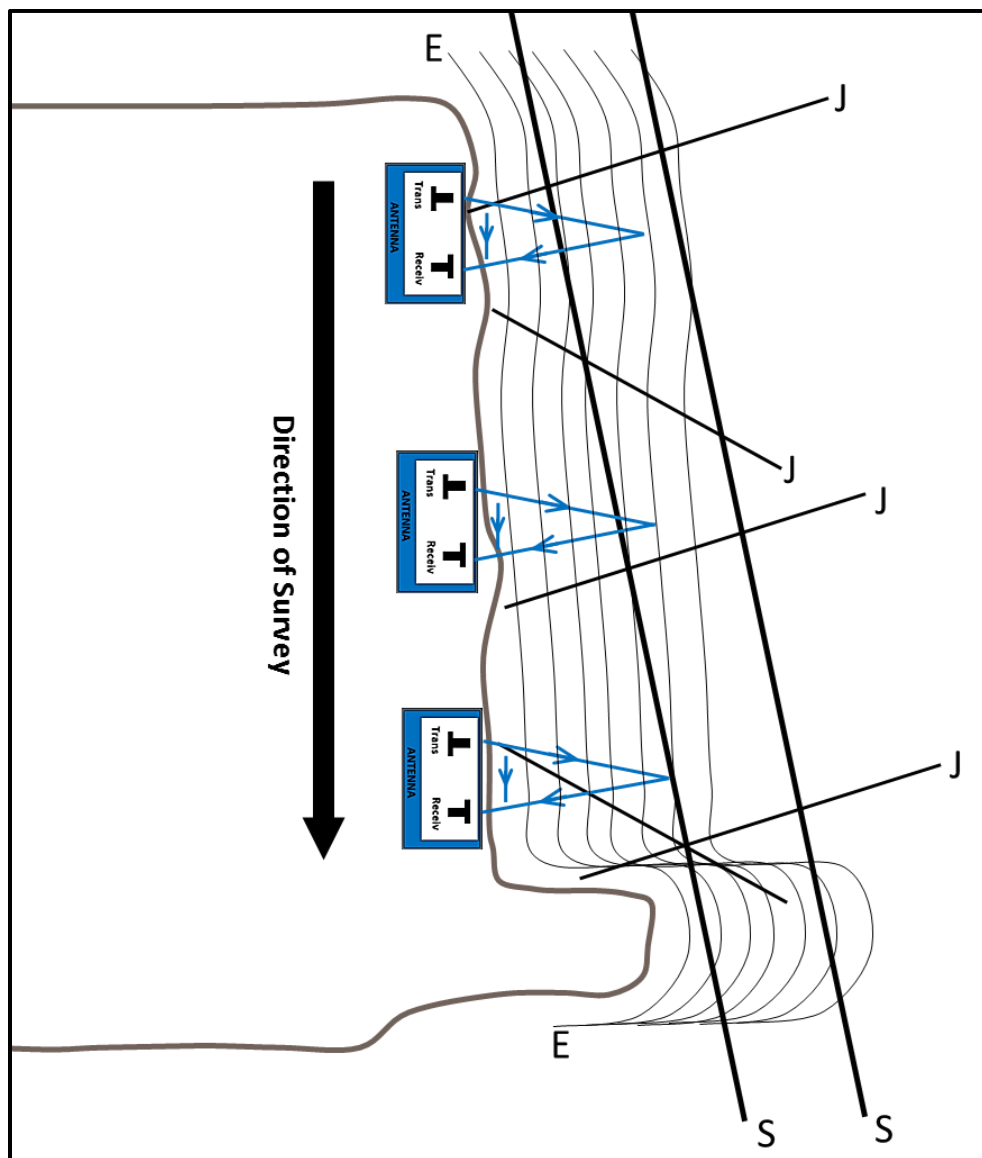


Figure 20: Schematic of GPR Stope Panel Fracture Profiling. Adapted from Dentith and Mudge (2014)

To complete the whole stope face survey, electromagnetic pulses are transmitted as discrete pulses of electromagnetic radiation, and the responses of the open fractures are recorded. The method operates on a reflection-mode, where the pulses are reflected by the electrical property contrast in the open fracture, and a record of the time difference in the reflected pulses is kept.

The depth to the signal reflectors (open fractures) indicated in Figure 20 depends on the propagation velocity of the pulse through the host rock. The signal propagation velocity and other electrical properties of the host rock and open fracture are determined in laboratory tests, and those related to this project are given in section 3.2 (Dentith & Mudge, 2014).

3.2. Electrical Properties of the Host Rock and Open Fracture

The VCR reef at Mponeng Mine is a well-defined quartz-pebble conglomerate with an average thickness of 85cm. The VCR also commonly contains internal quartzite bands. Different footwall rocks are exposed beneath the VCR across the mine, which are generalised into quartzite and shale types. The Booysens shale footwall is located in the east of the mine, while towards the west side of the mine, the footwall transforms from a Kimberley formation quartzite to a Denny's quartzite. The hanging wall rock immediately above the VCR reef is Ventersdorp Lava (Viljoen, 2003).

Since preconditioning holes are generally drilled within the VCR reef, the host rock of interest will be the VCR reef (a quartz-pebble conglomerate) and the target will be the air gap in the open fracture.

The electrical property measurement work for VCR related rocks published by Du Pisani and Vogt (2003) provides the dielectric constant (permittivity) values for quartzite, VCR and lava. This work has been widely used for other radar related research in S.A. and will therefore be used for the host rock properties. It should be noted that although the measurements were done at 64MHz, the dielectric constant (permittivity) behaves relatively constant over the GPR antenna frequency range of 25 – 1000MHz. The dielectric constant values from this work are given in Table 1.

The dielectric constant for air as given in general GPR literature is provided in Table 1 as given by Dentith & Mudge (2014).

Table 1: Dielectric Constants Values for Host Rocks and Target (Du Pisani and Vogt, 2003)

Material	Dielectric Constant
VCR (Host Rock)	7.0
Quartzite (Host Rock)	7.0
Lava	10
Air (Target Material)	1.0

3.3. Radar Wave Propagation in Rocks and Survey Design

Important parameters in the design of GPR surveys are the velocity and attenuation of the electromagnetic waves in the rock medium. These parameters are dependent on the conductivity and dielectric properties of the host rock and they vary with the signal frequency outside the radar window. Figure 21 indicates the radar window where the attenuation (a) and velocity (b) are independent of the wave frequency. This is the plateau where the GPR system operates between 1MHz and 1000MHz (Dentith & Mudge, 2014).

Figure 21 indicates that to operate a GPR between 100MHz to 1000MHz the host rock conductivity must be about or less than 0.1S/m, based on the plateau (Dentith & Mudge, 2014).

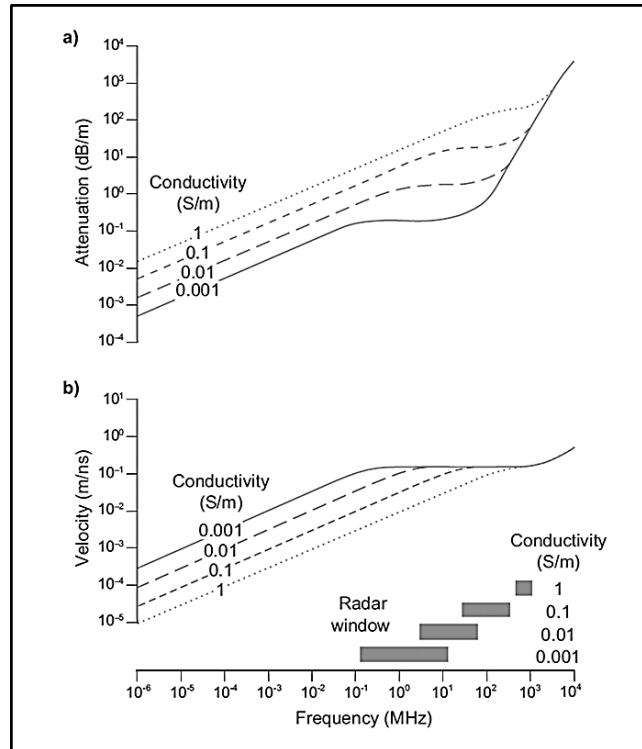


Figure 21: Attenuation and Velocity Dependence on Frequency (Dentith and Mudge, 2014)

According to Dentith and Mudge (2014) when operating within the Radar window, the most important parameter to radar wave response is the dielectric constant of the host and target (open fracture). It is therefore important that the radar window for a rock type and the correct values of dielectric constant are known.

The theoretical calculation of radar wave propagation parameters relevant to radar survey design are discussed in the bullet points below as explained by Dentith & Mudge (2014) and Sensors & Software Inc. (1992):

- **Wave Propagation Velocity**

Within the radar window in geological materials such as rocks, Electromagnetic (EM) wave velocity (v in m/s) is calculated by the equation below. This velocity is dependent on the dielectric constant (ϵ_r) of the material.

$$v = \frac{c}{\sqrt{\epsilon_r}}$$

Equation 1

c is the speed of light ($\approx 3 \times 10^8$ m/s).

For GPR applications, the velocity is generally shown in metres per nanosecond (m/ns) where $1 \text{ ns} = 10^{-9} \text{ s}$.

Since the dielectric constant of the VCR host rock is given as 7.0 in subsection 3.2, the calculated electromagnetic wave velocity can be estimated as **113mm/ns** within the VCR.

▪ Resolution Size

For the GPR system, it is the wavelength of the pulse signal that determines the horizontal and vertical resolution. The wavelength of the signal is therefore determined by the antenna choice, since all GPR antennas have a predesigned central frequency (Sensors & Software Inc.,1992).

Sensors & Software Inc. (1992) cited by Dentith & Mudge (2014) gives the following formula as a rule of thumb for selecting the appropriate central frequency (f in MHz) of the antenna:

$$f = \frac{150}{x\sqrt{\epsilon_r}}$$

Equation 2

x is the desired spatial resolution (m).

The spatial resolution gives the minimum width or size of a detectable target. This formula can therefore be reversed to calculate the minimum size detectable using an antenna with a particular central frequency.

The typically used antenna for underground mapping is a 400Mhz antenna, and if this frequency is used to calculate the resolution with equation 2, the resultant resolution is 13cm. This resolution indicates that the individual fractures will not be identifiable from the radar results, since the opening of the fractures is less than 13cm in most fractures.

▪ Depth of Penetration and Antenna Selection

The penetration depth of EM waves into conductive materials is determined from the attenuation of the signal with depth, which is a function of conductivity, dielectric properties and frequency (Sensors & Software Inc.,1992).

In order to select an antenna for the anticipated depth of mapping, Du Pisani and Vogt (2003) cite a nomogram from Noon et al. (1998) which is indicated in Figure 22.

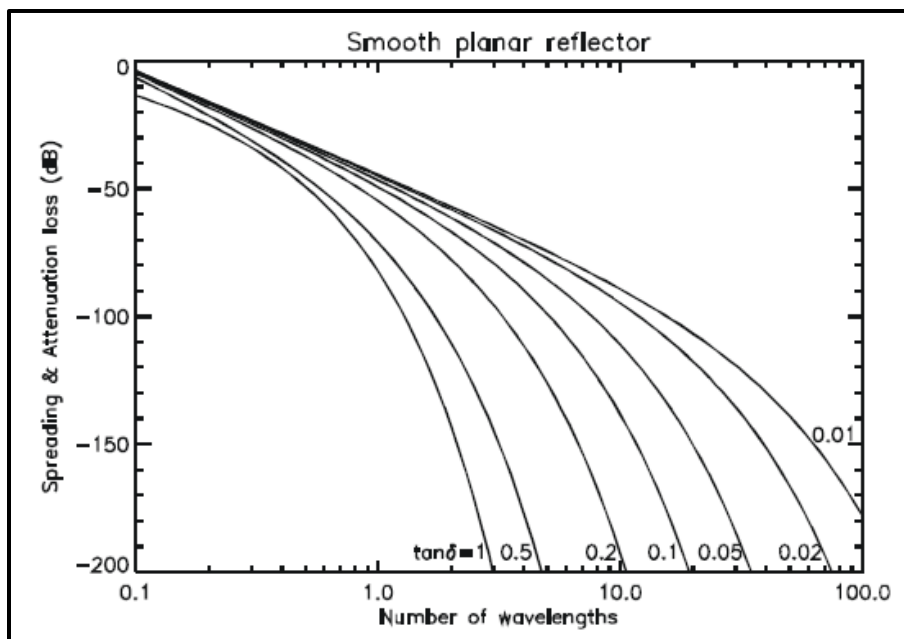


Figure 22: Radar performance prediction for a smooth planar target (Noon et al., 1998 as cited in Du Pisani and Vogt, 2003).

Figure 22 shows the radar system performance on the y-axis and typical modern GPR systems have a signal loss of 120dB to 150dB. The loss tangent of VCR is 0.04 as given by Du Pisani and Vogt (2003) and therefore an estimated curve of 0.04 from Figure 22 can be used to estimate performance. If the radar system is assumed to have a performance of 150dB, then a penetration of about 30 wavelengths can be achieved into the rock.

Wavelength is normally taken as twice the resolution determined above. Therefore the wavelength for the 400MHz antenna will be 26cm, or 0.26m. The penetration as given from Figure 22 is 30 wavelengths, or 7.8m.

The expected depth of fracturing is at most 7.0m from the literature review of fracturing ahead of the face, and therefore GPR mapping into the rock will be to a depth of 7.0m. An antenna with a central frequency of 400MHz is therefore adequate for the purpose of mapping fractures.

▪ Power Reflectivity Index

In order to determine whether a target will generate a response detectable by the antenna, the following factors must be considered:

- Is there enough contrast in the host and target dielectric constant?
- Is the target physically adequate (size) to reflect a detectable amount of energy?

Sensors & Software Inc. (1992) provides the following formula for estimating the Power Reflectivity (Pr):

$$Pr = \left| \frac{\sqrt{\epsilon_{host}} - \sqrt{\epsilon_{target}}}{\sqrt{\epsilon_{host}} + \sqrt{\epsilon_{target}}} \right|^2 \quad \text{Equation 3}$$

ϵ_{host} is the dielectric constant of the host rock and ϵ_{target} is the dielectric constant of the target material.

There are two rules of thumb for predicting success based on the above two considerations (Sensors & Software Inc.,1992):

- The Power Reflectivity (Pr) should be at least 0.01 and above
- The ratio of target depth to smallest lateral dimension should not exceed 10:1

The power reflectivity calculated from the dielectric constant of host rock (7.0) and target air gap (1.0) is 0.2, which exceeds the rule of thumb of 0.01. The target will provide adequate reflection of the radar signal.

The on deep dimensions of the extension and shear fractures are large in size and are longer than 1.0m. When the fractures are this long, they will be identifiable since they are within the 10:1 ratio.

3.4. GPR System Chosen

This subsection provides the details of the GPR system chosen for mapping of the fractures ahead of the face. Consideration was given to the parameters calculated in subsection 3.3 in selecting the system. The Geophysical Survey Systems Incorporated's (GSSI) GPR system was used in the GPR evaluation during SIMRAC project GAP 336, and therefore a system from the same manufacturer was chosen.

A basic modern day GPR system consists of a digital control unit, an antenna, cable to connect the control unit to the antenna, and finally the post processing software. The details of the three main components as chosen and hired from Open Ground Resources, will be discussed under the bullets below:

- **Digital Control unit**

The digital unit chosen for the collection of GPR survey data is the GSSI SIR System-3000 Control Unit. A picture of the unit is shown in Figure 23. The SIR 3000 unit is the basic part of the GSSI GPR system and can be connected to all the antennas in their range.

The SIR-3000 is a lightweight, portable, single channel ground penetrating radar system. The major external features of the control unit are the keypad, colour SVGA video screen, connector panel, battery slot, and indicator lights. The video screen allows the user to view data in real time or in playback mode. The system is battery powered by a 10.8V

Lithium-Ion rechargeable battery, which can provide a survey time of up to 3 hours. A large, protruding 19-pin connector at the back of the unit is for connection to the antenna via a control copper cable (GSSI, 2011).

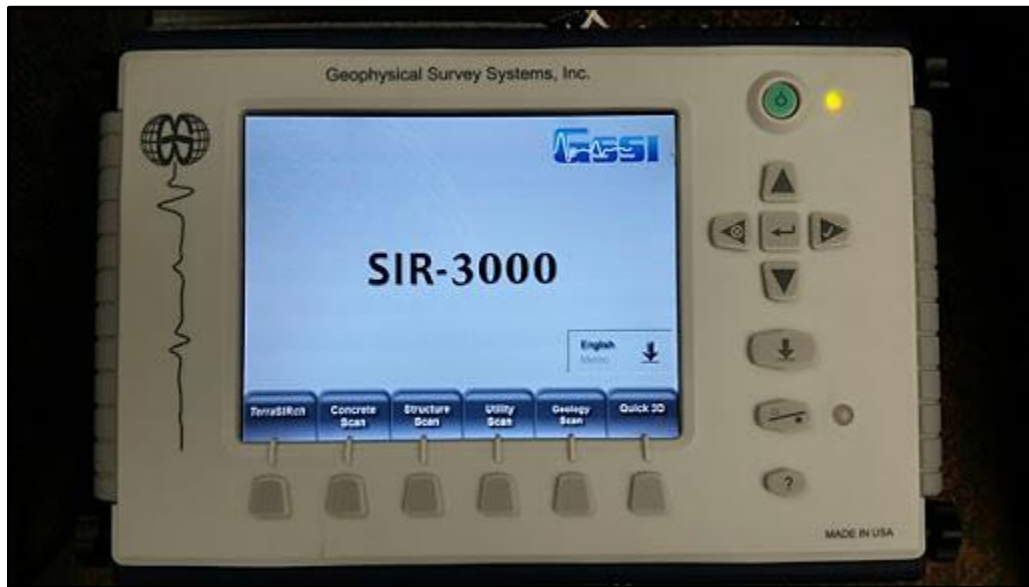


Figure 23: The GSSI SIR System-3000 Control Unit

- **Antenna**

As indicated in subsection 3.3, a 400MHz central frequency antenna is adequate for the mapping of fractures ahead of the face. The GSSI 400MHz antenna, model 50400S, is shown in Figure 24, as chosen for the project.

The Model 50400S is a “smart” antenna. This antenna has a special chip in it that identifies the antenna to the SIR-system control unit so that the controller unit will be able to automatically upload the correct default settings (GSSI, 2015).

The antenna weighs 6.4kg and has dimensions of 30x30x17 cm, which makes it manageable for use in low width stopes (GSSI, 2015).



Figure 24: GSSI 400MHz Antenna

▪ **Post Processing Software**

The post processing of collected GPR data on the GSSI system is done using the RADAN 7 software. This software is used to process the radar files from the data logger, which are transferred to a PC via a memory card installed in the control unit.

RADAN 7 software was designed to process, view, and document data collected with GPR systems from GSSI. A screen view of the RADAN 7 module is shown in Figure 25.

The software is capable of performing the following functions (GSSI, 2012):

- Display multiple screens of radar data as line scan, wiggle trace, and/or oscilloscope.
- Manipulate colour table and colour transform parameters to enhance data display.
- Edit file headers and distance markers.
- Process individual files in Process Lists.
- Process multiple files using Project Processing.
- Modify or restore data gains.
- Correct position (shift data scans along the time axis).
- Provide horizontal scaling and distance normalization.
- Incorporate topographic changes with top surface normalization.
- Display the frequency spectrum of data.

- Apply Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) filtering
- Spatial Filtering (2 Dimensional/F-K filter).
- Perform migration.
- Perform Predictive Deconvolution.
- Perform Envelope processing functions (Hilbert Transform).
- Velocity analysis.
- Local Peak Interpretation.
- Interactive Interpretation.
- Print to all Windows supported printers.

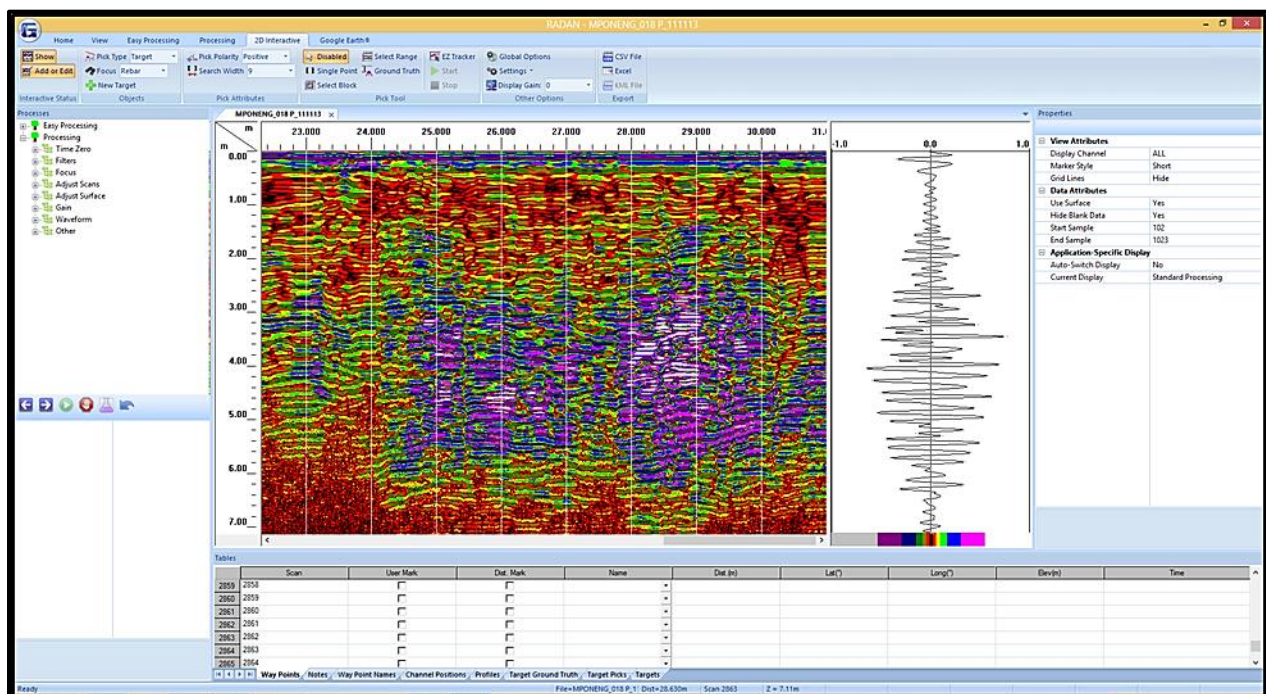


Figure 25: Screen view of RADAN 7 Software

4. METHODOLOGY

This section will briefly describe the methodology used to conduct the GPR survey underground, the post processing of the GPR data and the techniques used for results analysis, in order to meet the project objectives.

4.1. Panel and Preconditioning Hole Socket Mapping

In order to establish reference points for the subsequent analyses of the GPR survey results, it was important to conduct mapping exercises of the stope panels to be surveyed. The following mapping exercises were conducted:

- The face shapes and panel positions relative to panels above and below were recorded.
- Geological mapping of the panel to establish the reef position, channel width, stoping width, footwall type and presence of major geological disturbances, was conducted.
- Preconditioning hole socket mapping was conducted, to establish the position and depth of previous blast preconditioning hole sockets.

The results of the mapping exercises were then put together into face plots in order to establish reference points for the GPR survey results.

4.2. GPR Scan Collection and Data Post Processing

The GPR scans were obtained using the GSSI system with a 400MHz central frequency antenna. The panel faces were marked at 1.0m intervals with distance markers along the scan line. The 0.0m markers were at the top of the panels and progressive markers were established down dip, until the bottom position for the GPR survey was reached. The scan lines were run along the line of the Precon sockets as found in each stope face. A dielectric constant of 7.0 was used for the host rock parameters and scans to a depth of 2.0m and 7.0m were conducted over the scan lines.

Since the GPR surveys were conducted using the continuous time survey method, the data collected underground had to be processed to ensure that it indicated the correct location of the data relative to the face. The following processing was done to the raw data using the RADAN7 software to obtain the final GPR survey results:

- Cut out the scans collected by the system before the 0.00m marker and after the last marker.
- Distance normalization on a 1.0m spacing per marker was conducted on the cut scans, to ensure that collected scans are placed at the correct position.
- A manual time zero movement for surface position was done to ensure that the correct face position is established.
- A Finite Impulse Response (FIR) signal filter was applied, with a low pass of 725MHz and a high pass of 225MHz, to remove noise signals.

The GPR scan results were then superimposed on the panel precon socket mapping discussed in subsection 4.1.

4.3. GPR Scan Results Display

The GPR survey results are shown using “colour table 1” in RADAN7, which is shown in Figure 26 and briefly explained to ensure understanding of the results.

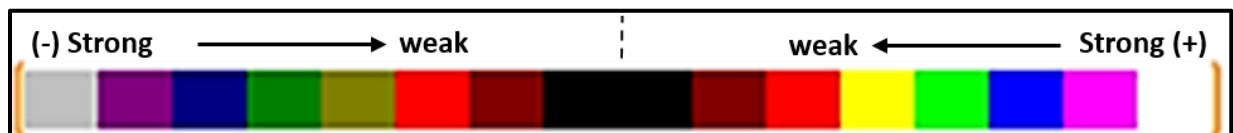


Figure 26: Colour Table 1 in RADAN7

In RADAN7 colour tables are used to code the amplitude of each scan (i.e., the recorded radar signal). In Figure 26, the grey colour on the far left side of the spectrum represents the stronger negative amplitudes. As the colours move to the right, this represents the amplitude getting weaker (or closer to 0) and the middle (black) of the spectrum is the area of weak amplitude. As the colours go further right from the middle, this represents a stronger positive amplitude up to the white colour.

Since the scans are done to identify areas of wide open fracturing in the rock mass ahead, it is expected that wide open fracturing will be identifiable by strong signal reflection which corresponds to high positive or negative amplitude pulses.

- White, grey, purple and blue in colour Table 1 correspond to the high amplitude pulses; therefore, when they appear on the radar record, it means that there is a strong reflection and therefore wide open fracturing exists.
- Green and yellow colours are indicative of middle level pulse amplitudes and therefore correspond with normal gap fracturing in the rock.
- The red, maroon and black colours indicate low amplitude reflections. Therefore, a large region with these colours on the radar record is indicative of a uniform structure with little to no fracturing or no openings in the fractures.

It should also be noted that there is a signal reduction closer to the subsurface and also due to the resolution on the 7.0m depth scan. Lower reflectivity closer to the subsurface (<2.0m) does not necessarily indicate less open fracturing. The subsurface results should be analysed with the deeper signals in mind.

4.4. Determining Depth of Fracturing

Evaluation of the GPR survey results based on the colour scheme discussed in subsection 4.3 was used to determine the extent of fracturing by visual observation. A solid trace line indicating the extent of fracturing was then drawn on the survey results.

The RADAN 7 software has a functionality for 2D interaction in order to assist with radar results interpretation. This functionality was used to determine the exact values of depth of fracturing. In order to extract the depth values from RADAN 7, target markers were placed at a 0.5m interval along the extent of fracturing, as shown in an example on Figure 27. The markers are pink dots on the scan, highlighted with white circles for clarity.

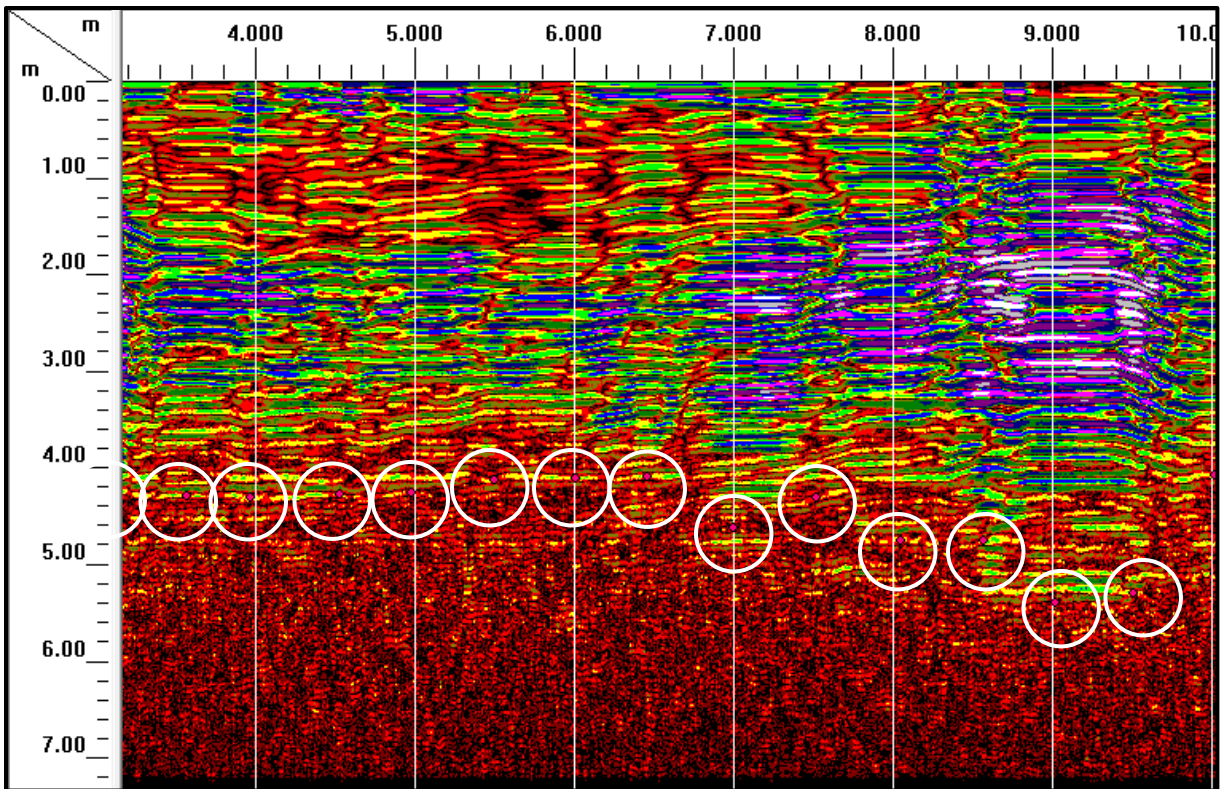


Figure 27: Example of depth marker placement

Comma-Separated Values (CSV) files containing the depth values were then exported from RADAN 7 into excel spread sheets where graphs of the depth against scan distance were developed. The average depth values for entire panels were also added to the above discussed graphs.

4.5. Precon Burden Spacing Evaluation

The question to be resolved as per the objectives was to determine whether preconditioning hole spacing affected the depth of fracturing achieved by the preconditioning blast. It was also necessary to determine how hole spacing affected the continuity of the fracturing between the holes.

In order to determine a technical response for the objectives above, the following was done to collect data to be used in a statistical analyses:

- The depths of fracturing at the preconditioning hole socket positions were determined as observed on the GPR scans.

- It was observed that the depth of fracturing decreased between a set of preconditioning holes. The depth of fracturing at the midpoint between a set of holes was also determined and taken to represent the decrease between the holes.
- The average fracturing depth between a set of holes was also determined by taking the depth of fracturing for the two adjacent preconditioning sockets and the depth of fracturing at midpoint, to determine the average depth of fracturing between the holes.
- The continuity of the fracturing between adjacent precondition holes was also assessed.
- Bar graphs indicating the average depth of fracturing between holes against hole spacing were then created, to easily indicate the effect of hole spacing on fracture depth.
- Graph plots indicating the continuity or lack thereof of fracturing between adjacent holes against the hole spacing were also created.

The data sheet, as indicated in Table 2, was developed and populated for the collected data, for further statistical analyses.

Table 2: Hole spacing analysis data sheet

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracture Profile (Y/N)
1						
2		1 - 2				
3		2 - 3				
4		3 - 4				
Average						

4.6. Footwall Type Evaluation

To determine the effect of footwall types on the depth of fracturing, a graph of the average fracture depths for all the sites was plotted against the footwall type as collected during the mapping exercise. The average of the fracturing per footwall type was also determined and plotted on the graphs.

4.7. Stope Face Maturity Evaluation (ERR)

Stope maturity as a term was deemed difficult to determine with a technical value. It was therefore decided that stope maturity will be evaluated with the use of the ERR value of each site, since ERR values increase as the mining spans increase and are therefore indicative of the stope maturity. The ERR values were obtained from routine elastic modelling done by the mine's rock engineering department. These values were obtained from Kleynhans (2018) and were used as given.

A graph of average fracture depths from each site against the ERR values for the sites was developed.

5. RESULTS

This section provides the results obtained from the 10 project sites. The details of each site will be given in the following ten subsections.

The subsections of results will provide information under the following subheadings:

- Site details and conditions
- The 7.0m depth GPR scan results
- Indication of depth of fracturing, and
- Burden spacing analysis of precon holes

It should be noted that all the face scan results are indicative of the precon fracturing ahead of the face following a blast. All scans were taken within 24 hours after the blast.

5.1. SITE 1: 123-42-W4

The results to be given in this subsection are for the first preconditioning project site at 123-42-W4 panel which was scanned on 13 October 2017.

5.1.1. Site Details and Conditions

During the panel visit the following panel details and issues were encountered:

- The total panel length was 38m, however only the top 16m of the panel was scanned since the bottom portion was not made safe to work in.
- The panel was reported to be in the process of swinging the face and therefore it seems only the bottom portion was blasted, as suggested by the bottom not yet having jacks installed and made safe.
- The face seemed to have experienced some face ejection. Loose slabs were present on the face, and in the area between the face and the jacks, this made the scanning process difficult.
- The panel had an average stoping width of 1.3m and was on reef, despite it being carried in a thin channel and rolling at places.

- Quartzite footwall type was encountered in this panel.
- The ERR value was given as 14MJ/m².
- General stope maturity can be observed on the panel plan indicated in Figure 28.



Figure 28: Plan of 123-42 Raiseline

5.1.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 29. The following key analyses can be viewed from the figure:

- High impulse signals are observed at the positions of the previous day's preconditioning sockets. This can be observed at the positions of socket 1, 2 and 3.
- The signal intensity between socket 1 and 2 at a spacing of 4.9m is low compared to that observed between socket 3 and 4 at a spacing of 4.1m. The spacing between the previous day's preconditioning sockets influences the level of fracturing between the precon holes.

- The wider the hole spacing, the lower the fracturing and hard patches are observed.
- The depth of the fracturing is highest between socket 3 and 4 at a spacing of 4.1m, reduces between socket 2 and 3 at a spacing of 4.6m, and is the lowest between socket 1 and 2 at a spacing of 4.9m.
- The depth of fracturing decreases as the hole spacing is increases.

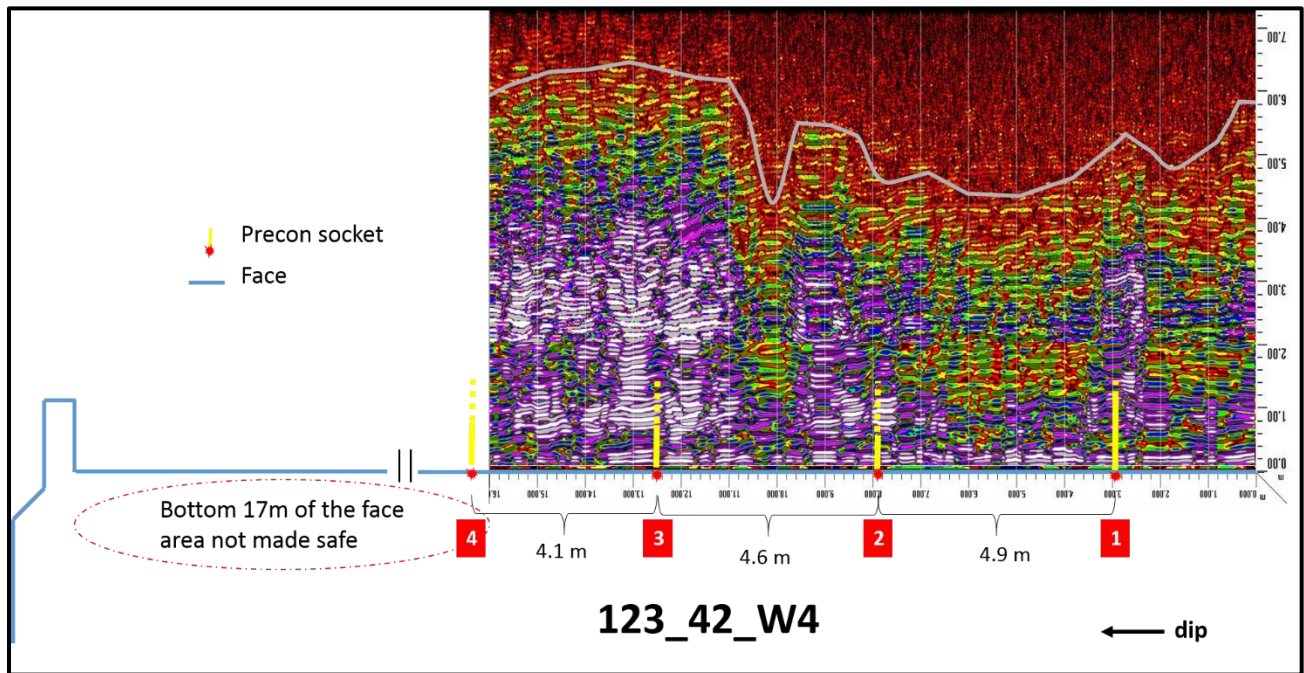


Figure 29: 123-42-W4 GPR Results @ 7.0m Depth

5.1.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 29 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 30 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 5.0m. A minimum of 4.1m was observed at the 10.0m distance marker, and a maximum of 6.6m at the 12.5m distance marker. The full marker data for all 10 sites are provided in Appendix 1.

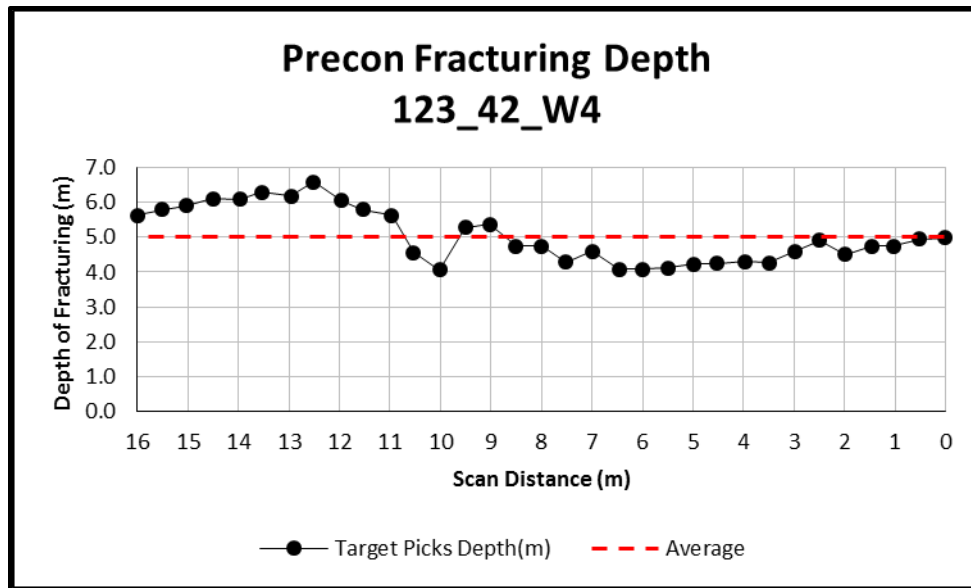


Figure 30: 123-42-W4 Depth of Fracturing

5.1.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the results data from Figure 29 are summarised in Table 3. Detailed data for all 10 sites is shown in Appendix 2.

Table 3: Spacing Evaluation Data for 123-42-W4

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracture Profile (Y/N)
A1	1 - 2	4.9	4.7	N
A2	2 - 3	4.6	5.3	N
A3	3 - 4	4.1	6.4	Y

Figure 31 was developed from the data in table 3 and it shows that fracture depth decreases as the hole spacing is increased. The equation of the linear regression line for the site is also given in Figure 31.

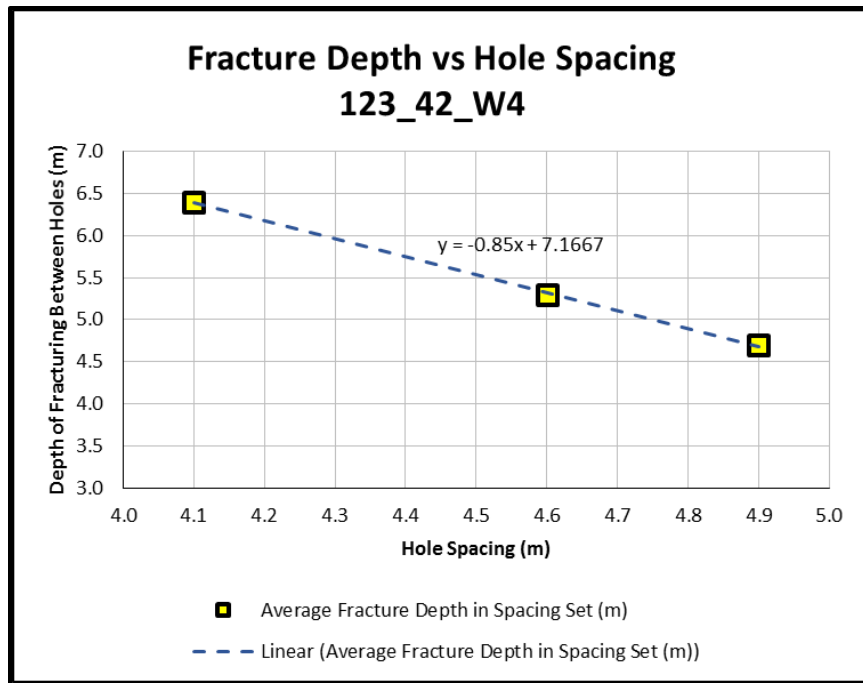


Figure 31: 123-42-W4 Fracture Depth vs Hole Spacing

Figure 32 is a graphical representation of the results observed in Figure 29 relating to the continuity of fracturing between adjacent preconditioning holes. The observed data was summarised in Table 3. This figure indicates that a continuous fracture profile was achieved between socket 3 and 4 spaced at the 4.1m, which is represented by data set id A3. A non-continuous fracture profile was observed for data set id A1 (socket 1 and 2) and A2 (socket 2 and 3), which have hole spacings of 4.9m and 4.6m respectively.

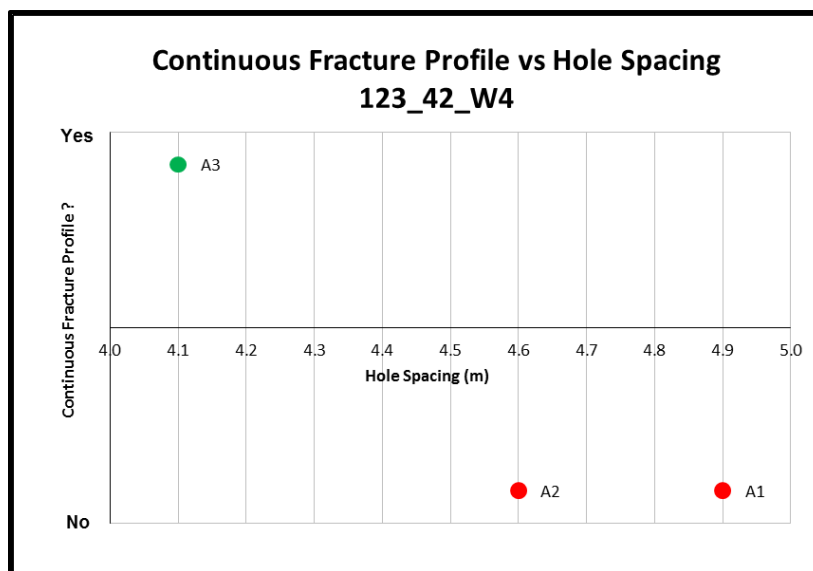


Figure 32: 123-42-W4 Continuous Fracture Profile vs Hole Spacing

5.2. SITE 2: 116-34-E7

The results for the second project site at 116-34-E7 panel which was scanned on 02 November 2017 are given in this subsection.

5.2.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 27.5m and 27.0m was scanned starting from the top of the panel and scanning down to the gully.
- The panel had an average stopping width of 1.3m, was on reef and had a quartzite footwall.
- The ERR value was given as 9MJ/m².
- The 2.0m depth scan was not conducted since the team was pulled out of the panel due to a shaft emergency (only 7.0m depth scan conducted).
- General panel maturity can be observed on the stope plan indicated in Figure 33.

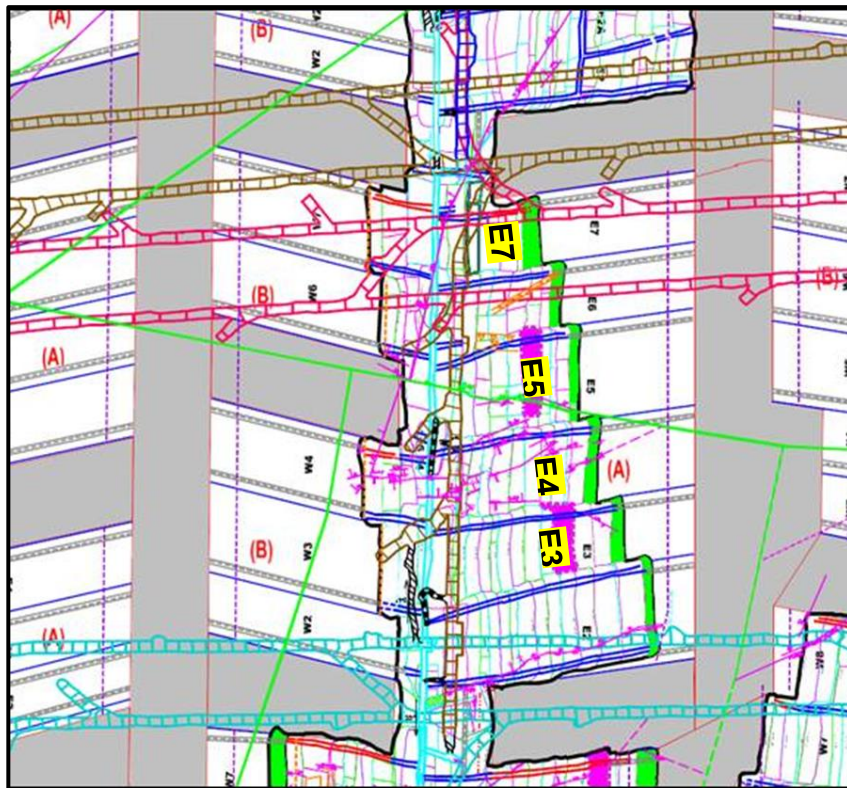


Figure 33: Plan of 116-34 Raiseline

5.2.2. GPR Results

The following key analyses can be viewed from the GPR results in Figure 34:

- Due to the absence of the 2.0m depth scan, the expected intensity around the previous day's preconditioning sockets cannot be observed. The use of the 7.0m depth scan will only be for determining the depth of fracturing and continuity of fracturing.
- There is a continuous high intensity signal from socket 1 to socket 4, where the spacing between the holes is from 2.8m (min) to 3.5m (max).
- There is a break in the high intensity signal between socket 4 and 5, where a hole spacing of 4.0m was encountered.
- A continuous high intensity signal is again observed from socket 5 to socket 9, where the hole spacing is from 1.8m (min) to 4.5m (max).
- The depth of estimated fracturing is similar for the entire scan, no large variations being observable at different hole spacings.

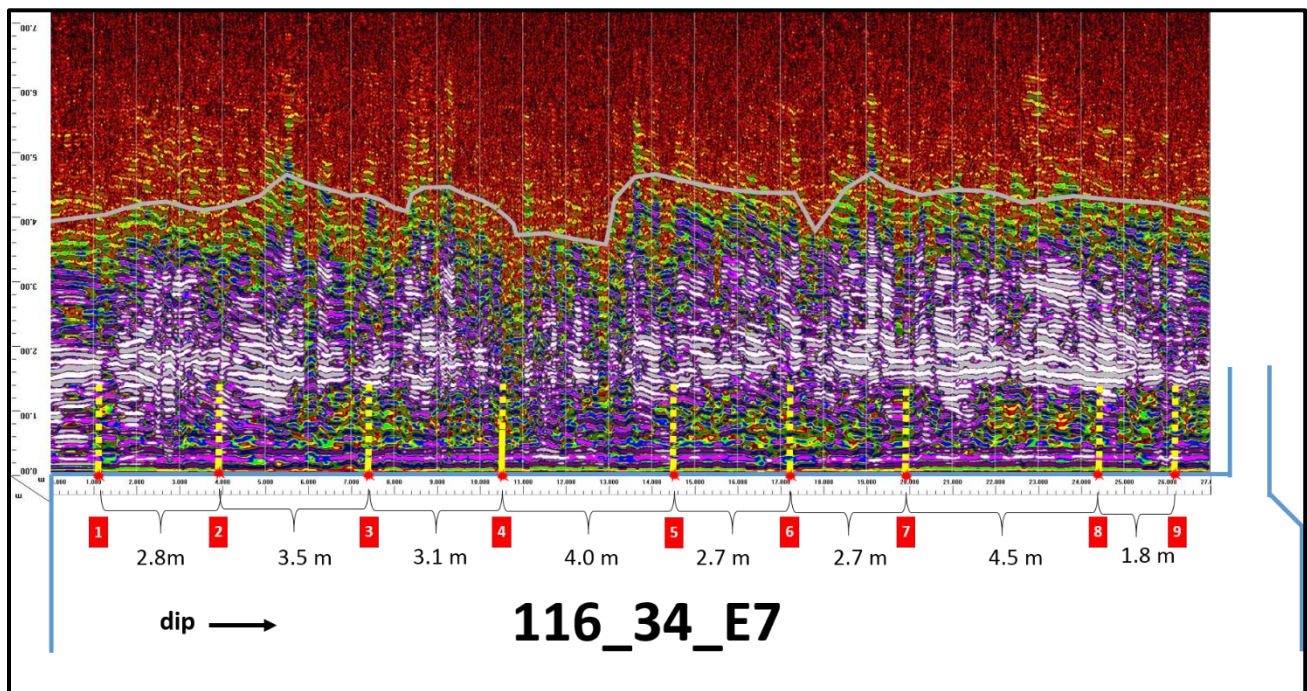


Figure 34: 116-34-E7 GPR Results @ 7.0m Depth

5.2.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 34 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 35 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 4.5m. A minimum of 3.7m was observed at the 13.0m distance marker, and a maximum of 5.3m at the 5.5m distance marker.

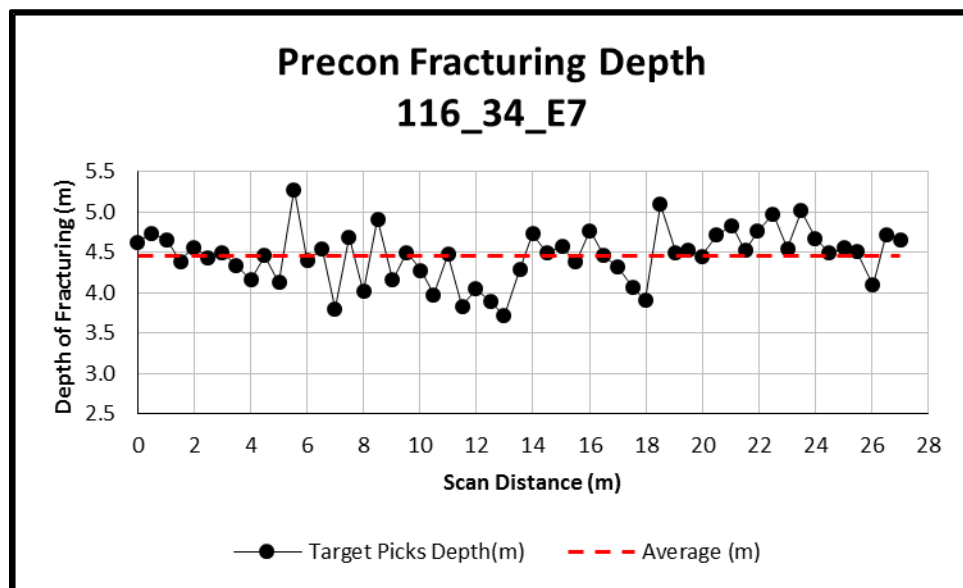


Figure 35: 116-34-E7 Depth of Fracturing

5.2.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the results data from Figure 34 are summarised in Table 4.

The data indicates a close fracture depth range, from 4.0m to 4.4m, for all the spacing sets. There is only one spacing set, with set id B4, which indicates a non-continuous fracture profile.

Table 4: Spacing Evaluation Data for 116-34-E7

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
B1	1 - 2	2.8	4.0	Y
B2	2 - 3	3.5	4.4	Y
B3	3 - 4	3.1	4.4	Y
B4	4 - 5	4.0	4.1	N
B5	5 - 6	2.7	4.4	Y
B6	6 - 7	2.7	4.4	Y
B7	7 - 8	4.5	4.4	Y
B8	8 - 9	1.8	4.2	Y

Figure 36 was developed from the data in Table 4 and it shows a relatively constant fracture depth for all the spacing sets. The equation of the linear regression line for the site is also given in Figure 36, and it shows a fractional positive gradient, which is indicative of a fractional depth of fracture increase with hole spacing increase.

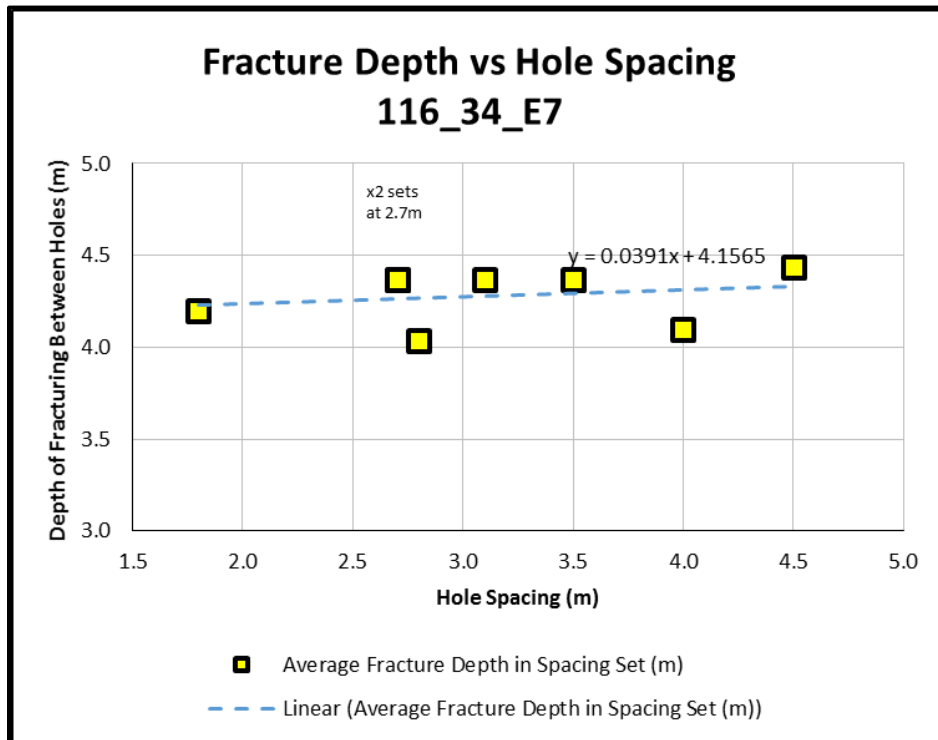


Figure 36: 116-34-E7 Fracture Depth vs Hole Spacing

Figure 37 is a graphical representation of the results observed in Figure 34, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 4. This figure indicates that continuous fracture profiles were achieved for the entire panel, with the exception of data set id B4 between sockets 4 and 5 spaced at 4.0m.

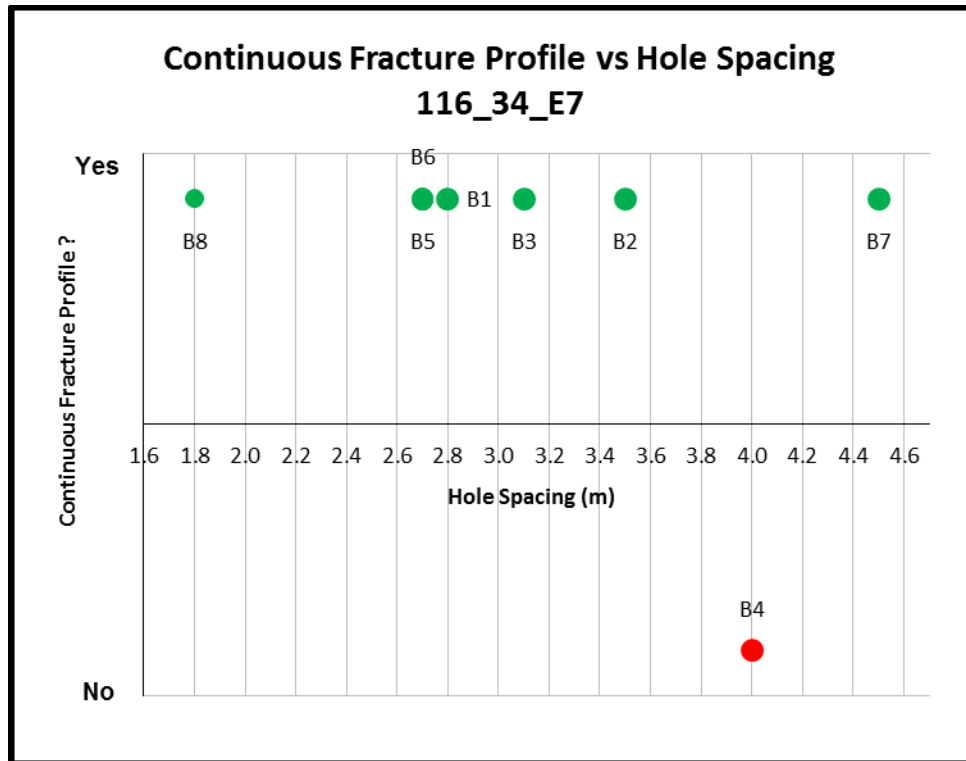


Figure 37: 116-34-E7 Continuous Fracture Profile vs Hole Spacing

5.3. SITE 3: 116-34-E4

The results given in this subsection are for the third project site at 116-34-E4 panel which was scanned on 27 November 2017.

5.3.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 33.5m and 33.0m was scanned starting from the top of the panel down to the gully.
- The panel had an average stoping width of 1.58m and was on reef, with wide reef and stoping width cut to leave reef in the footwall.
- Quartzite footwall type was encountered in this panel.
- The ERR value was given as 11MJ/m².
- General panel maturity can be observed on the stope plan indicated in Figure 33.

5.3.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 38. The following key analyses can be viewed from the figure:

- High impulse signals are observed at the positions of most of the previous day's preconditioning sockets, which can be observed at the positions of socket 1, 2, 3, 4, 5, 6, 8, 9, 10, 11 and 12. Socket 7 indicates an exception.
- At the position of socket 7, there is a low level signal intensity around the mapped preconditioning socket. The depth of fracturing also reduces directly ahead of this socket hole. Both observations are indicative of a poor blast by this hole.
- There is a continuous high intensity signal from socket 1 to socket 12, where the spacing between the holes is from 1.7m (min) to 3.7m (max). The signal ahead of socket 7 and 9 is not in the white and grey range, however it is in the purple range which is adequately high to be considered as continuous fracturing.

- The depth of estimated fracturing is similar for the entire scan, except for a large drop noted ahead of socket 7.

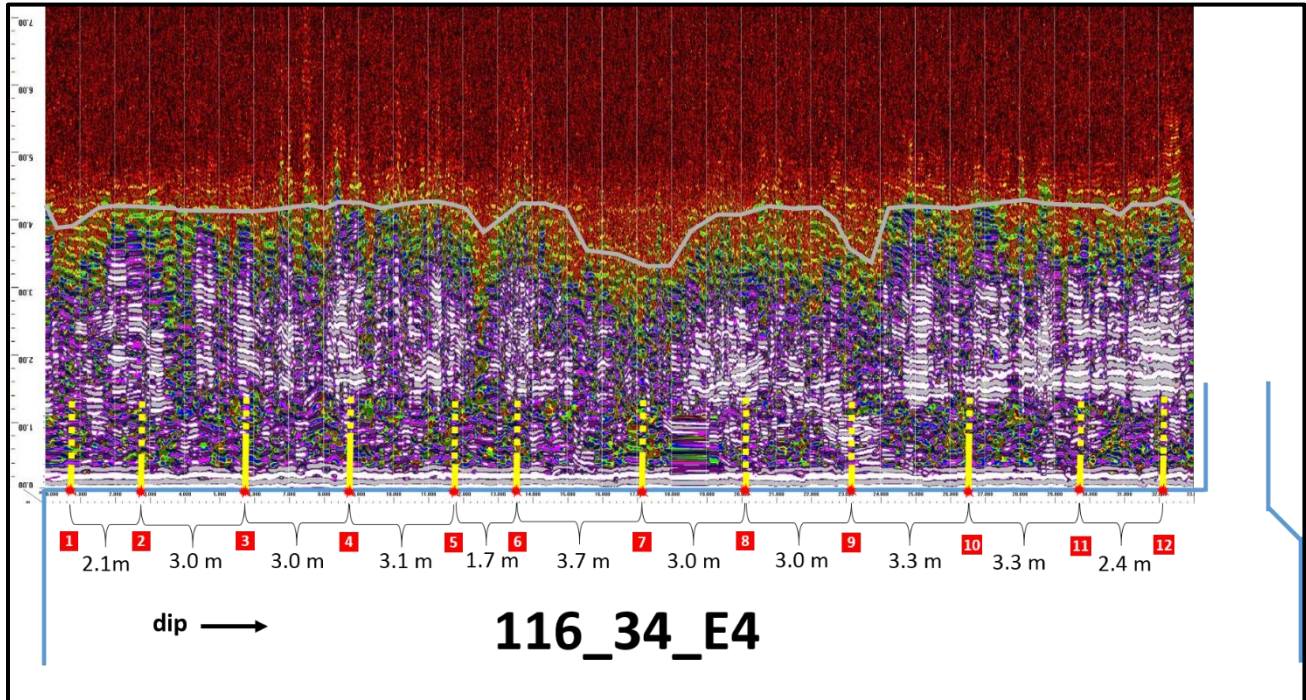


Figure 38: 116-34-E4 GPR Results @ 7.0m Depth

5.3.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 38 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 39 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 4.1m. A minimum of 3.2m was observed at the 18.0m distance marker, and a maximum of 4.6m at the 32.5m and 11.0m distance markers.

The calculated average depth of fracturing is representative of the fracturing observed along the full length of the panel, since the values have a low variance. The drop in fracture depth from distance marker 15.0m to 19.0m is due to the poor blast at socket 7. This 4.0m distance is also indicative of the effective radius of each hole.

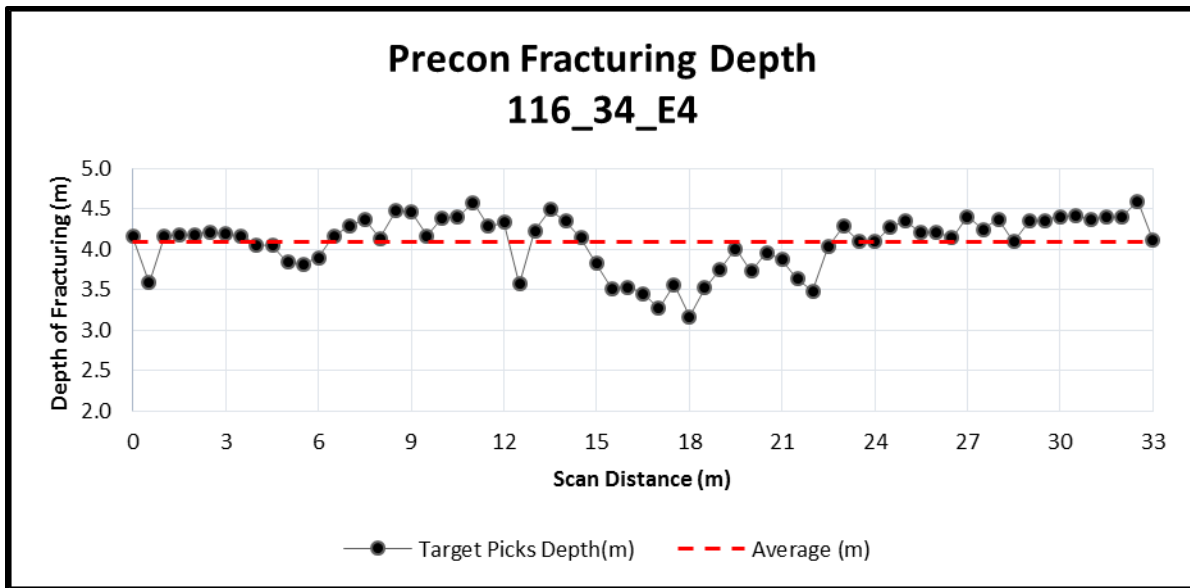


Figure 39: 116-34-E4 Depth of Fracturing

5.3.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the data from Figure 38 are summarised in Table 5.

Table 5: Spacing Evaluation Data for 116-34-E4

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
C1	1 - 2	2.1	4.3	Y
C2	2 - 3	3.0	4.1	Y
C3	3 - 4	3.0	4.4	Y
C4	4 - 5	3.1	4.4	Y
C5	5 - 6	1.7	4.0	Y
C6	6 - 7	3.7	3.6	Y
C7	7 - 8	3.0	3.6	Y
C8	8 - 9	3.0	3.9	Y
C9	9 - 10	3.3	4.2	Y
C10	10 - 11	3.3	4.2	Y
C11	11 - 12	2.4	4.4	Y

The data in Table 5 indicates a 0.8m fracture depth range, from 3.6m to 4.4m, for all the spacing sets. All spacing sets indicate continuous fracture profiles.

Figure 40 was developed from the data in Table 5 and it shows a reduction in fracture depth as the hole spacing is increased. The equation of the linear regression line for the site is also given in Figure 40, and it shows a fractional negative gradient, which is indicative of a fractional depth of fracture reduction with hole spacing increase.

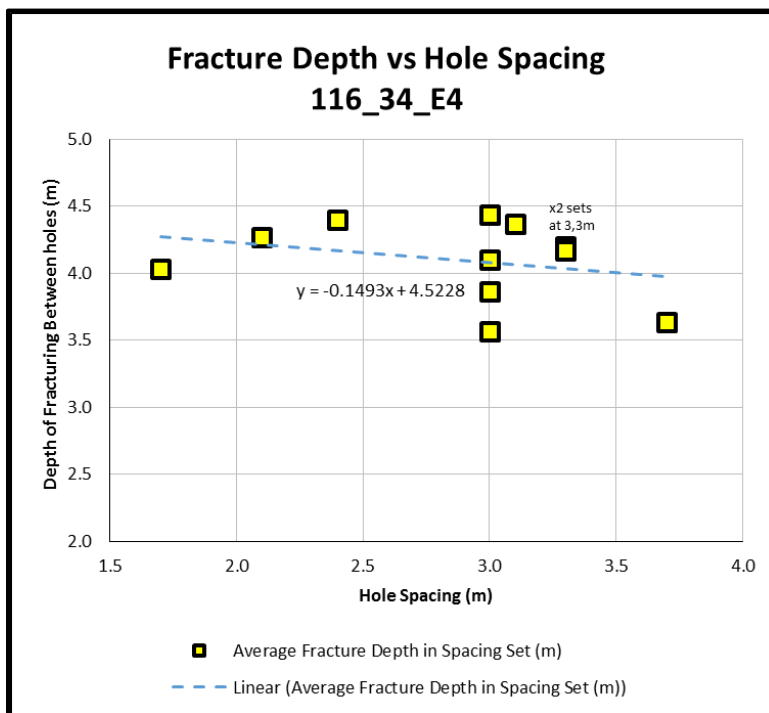


Figure 40: 116-34-E4 Fracture Depth vs Hole Spacing

Figure 41 is a graphical representation of the results observed in Figure 38, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 5. This figure indicates that continuous fracture profiles were observed for all hole spacing sets mapped in the panel. The spacing ranged from 1.7m to 3.7m.

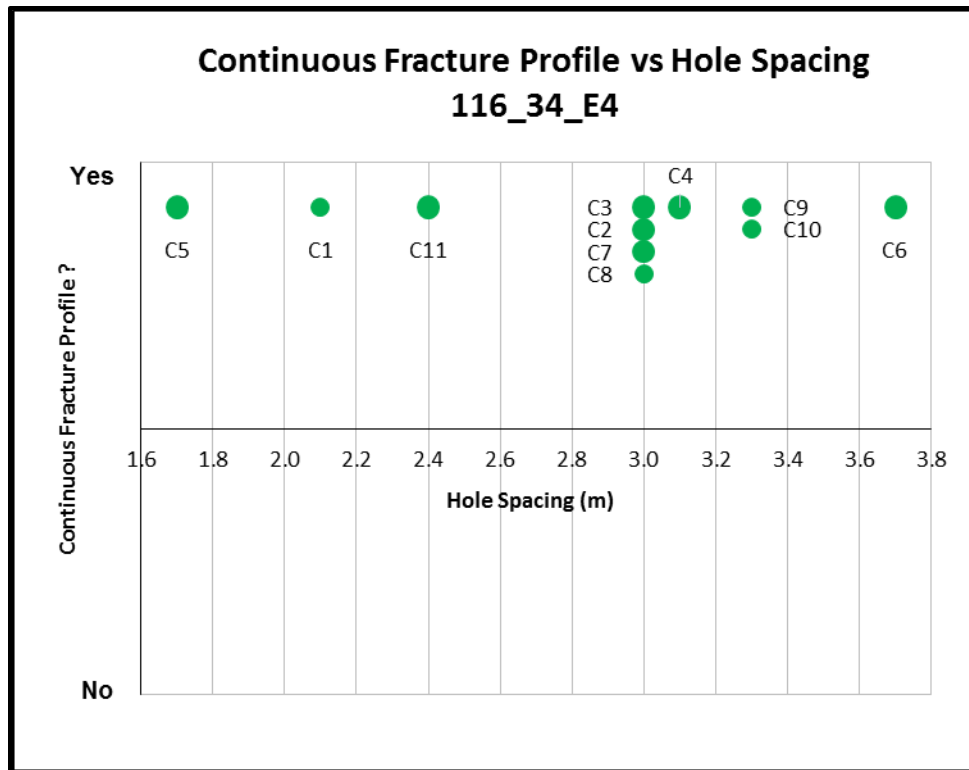


Figure 41: 116-34-E4 Continuous Fracture Profile vs Hole Spacing

5.4. SITE 4: 116-34-E3

The results for the fourth project site at 116-34-E3 panel which was scanned on 28 November 2017 are given in this subsection.

5.4.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 26.0m and the whole panel face was scanned starting from the top of the panel and scanning down to the gully.
- The panel had an average stoping width of 1.5m and was on reef, with wide reef and stoping width cut to leave reef in the footwall.
- Quartzite footwall type was encountered in this panel.
- The ERR value was given as 13MJ/m².
- General panel maturity can be observed on the stope plan shown in Figure 33.

5.4.2. GPR Results

The following key analyses can be viewed from the 7.0m depth GPR scan results shown in Figure 42:

- No precon holes were observed in the bottom 4.0m of the face.
- High impulse signals are observed at the positions of most of the previous day's preconditioning sockets, as can be observed at the positions of socket 2, 3, 4, 5, 6 and 7. Weak signal intensity can be observed around sockets 1 and 8.
- At the position of socket 1, there is no signal intensity around the mapped preconditioning socket and ahead of the socket. The depth of fracturing also reduces directly ahead of this socket hole. Both observations are indicative of a poor blast at this hole and an increased hole spacing due to the hole angle.
- At the position of socket 8, there is a high signal intensity around the mapped preconditioning socket, however the signal is reduced directly ahead of the socket.

The depth of fracturing also starts to reduce directly ahead of this socket hole. These observations indicate that the blast was adequate, but there was poor hole interaction since there are no precon sockets down dip of the hole for a distance of 4.0m.

- There is a continuous high intensity signal from socket 2 to socket 8, where the spacing between the holes is from 2.7m (min) to 3.3m (max). The signal in the gaps between socket 2-3, 3-4 and 4-5 is not continuously in the white, grey and purple range, however patches in the purple range can be observed in these sections, which is adequately to be considered as continuous fracturing.
- The depth of estimated fracturing is around the 5.0m mark for the entire scan, except for a large drop noted in the last 4.0m of the panel, where no preconditioning sockets were observed.

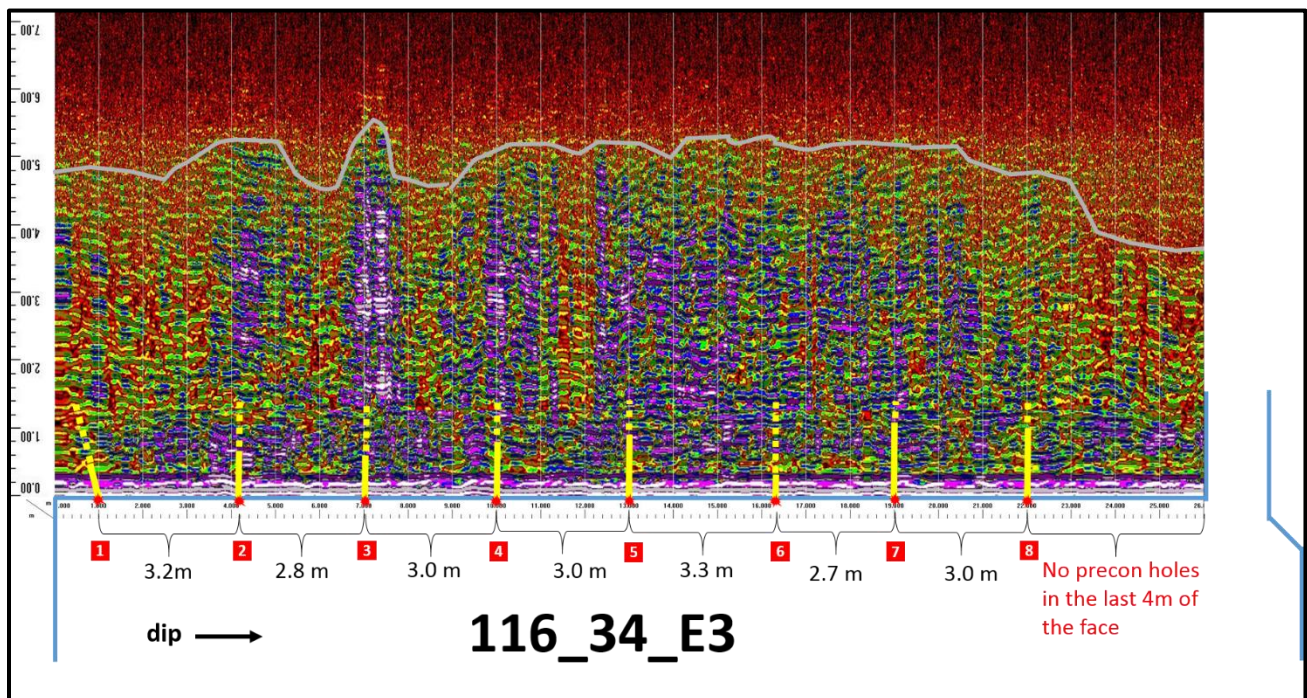


Figure 42: 116-34-E3 GPR Results @ 7.0m Depth

5.4.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 42 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 43 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 5.1m. A minimum of 3.8m was observed at the 26.0m distance marker, and a maximum of 5.7m at the 7.0m distance marker.

The calculated average depth of fracturing is representative of the fracturing observed along the full length of the panel, since the values have a low variance. The Drop in fracture depth from distance marker 23.0m to 26.0m is due to the absence of preconditioning holes in the last 4.0m of the face. This observation indicates that the first preconditioning holes must be within 3.0m as indicated in the mine standard.

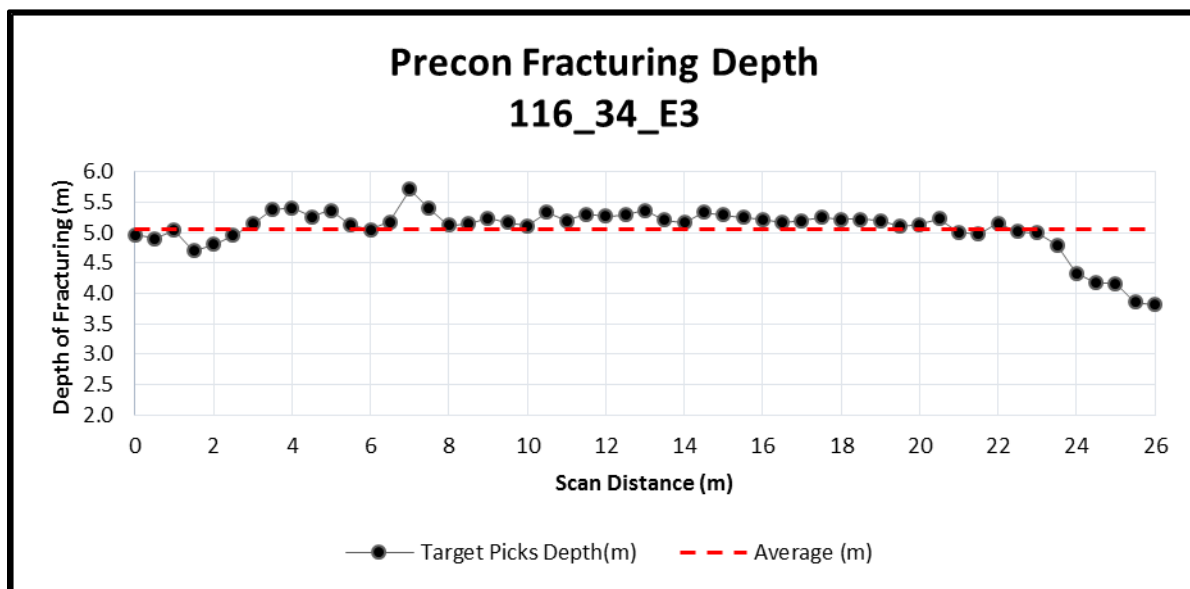


Figure 43: 116-34-E3 Depth of Fracturing

5.4.4. Burden Spacing

To evaluate the effect of burden spacing using statistical analyses, the results data from Figure 42 are summarised in Table 6.

Table 6: Spacing Evaluation Data for 116-34-E3

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
D1	1 - 2	3.2	5.1	N
D2	2 - 3	2.8	5.4	Y
D3	3 - 4	3.0	5.4	Y
D4	4 - 5	3.0	5.4	Y
D5	5 - 6	3.3	5.4	Y
D6	6 - 7	2.7	5.4	Y
D7	7 - 8	3.0	5.3	Y

The data in Table 6 indicates a 0.3m fracture depth range, from 5.1m to 5.4m, for all the spacing sets. The majority of spacing sets indicate continuous fracture profiles, except for set id D1, which indicates a non-continuous fracture profile between the holes.

Figure 44 was developed from the data in Table 6 and it shows a general reduction in fracture depth as the hole spacing is increased. It should however be noted that 5 out of the 7 data sets have an average fracture depth of 5.4m. The equation of the linear regression line for the site is also given in Figure 44, and it shows a fractional negative gradient, which is indicative of a small depth of fracture reduction with hole spacing increase.

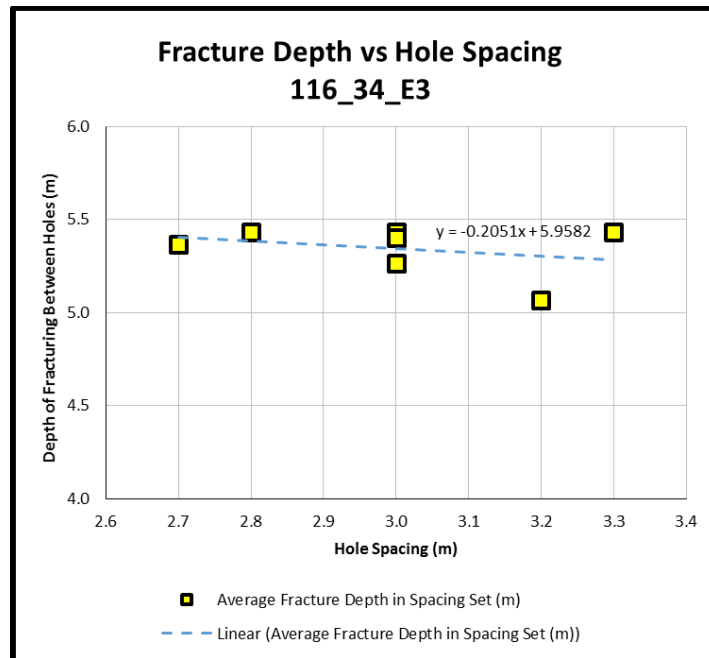


Figure 44: 116-34-E3 Fracture Depth vs Hole Spacing

Figure 45 is a graphical representation of the results observed in Figure 42, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 6. This figure indicates that continuous fracture profiles were observed for 85% of hole spacing sets mapped in the panel, with the exception of set id D1 which indicates that a non-continuous fracture profile was observed. The panel had a spacing ranged from 2.7m to 3.3m.

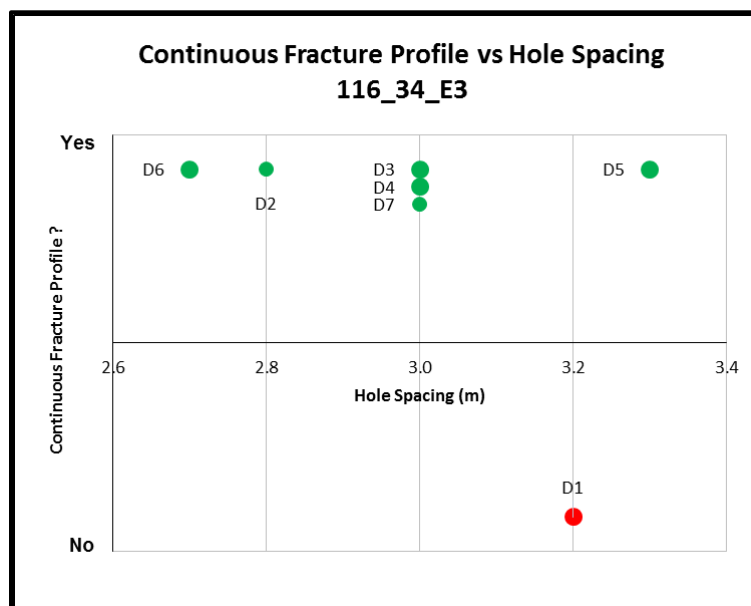


Figure 45: 116-34-E3 Continuous Fracture Profile vs Hole Spacing

5.5. SITE 5: 113-34-E5

The results to be given in this subsection are for the fifth project site at 113-34-E5 panel which was scanned on 30 November 2017.

5.5.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 31.0m and 30.0m of the face was scanned starting from the top of the panel and scanning down to the gully.
- The panel had an average stoping width of 1.2m and was on reef, with 10cm thin reef and exposing about 1.0m of quartzite footwall on the face.
- Quartzite footwall type was encountered in this panel.
- The ERR value was given as 14MJ/m².
- General panel maturity can be observed on the stope plan indicated in Figure 46.

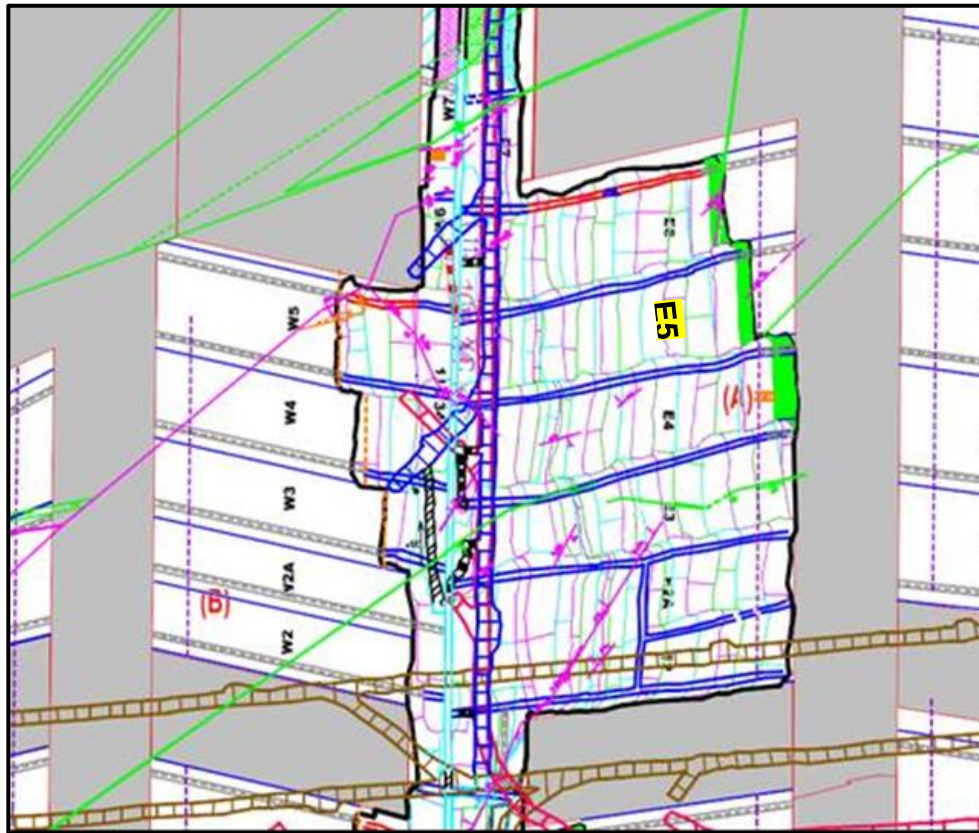


Figure 46: Plan of 113-34 Raiseline

5.5.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 47.

The following key analyses can be viewed from the figure:

- High impulse signals are observed around the positions and ahead of 5 out of 9 previous day's preconditioning holes, as can be observed at the positions of holes 5, 6, 7, 8 and 9.
- At the positions of holes 3 and 4, a high intensity signal is observed around the precondition hole, but the intense signal does not extend ahead of the holes. The depth of fracturing also reduces directly ahead of these preconditioning holes. These observations are an indication of poor hole spacing leading to ineffective preconditioning blasts.
- At hole positions 1 and 2, there is no high intensity signal around the hole position, however the high intensity signal is evident ahead of these positions.
- There is a continuous high intensity signal from hole 5 to socket 9, where the spacing between the holes is from 2.3m (min) to 3.6m (max), which is indicative of a continuous fracture profile.
- The area between holes 2 and 5 shows a discontinuous high intensity signal, due to the hole over spacing where the spacing between the holes is from 3.8m (min) to 6.3m (max), which is indicative of a non-continuous fracture profile.
- The high intensity signal continuity between holes 1 and 2 is also indicative of a continuous fracture profile, with a hole spacing of 2.8m.
- The depth of fracturing ahead of the top 5.0m and the bottom 11.0m of the panel, where the hole spacing is generally within the mine standard of 3.0m, is estimated to be 5.8m. This is the portion which is indicative of the panel fracture depth if all holes were spaced within mine standard.
- The estimated depth of fracturing in the middle 14.0m of the panel where the preconditioning holes were hugely over spaced is 4.0m.

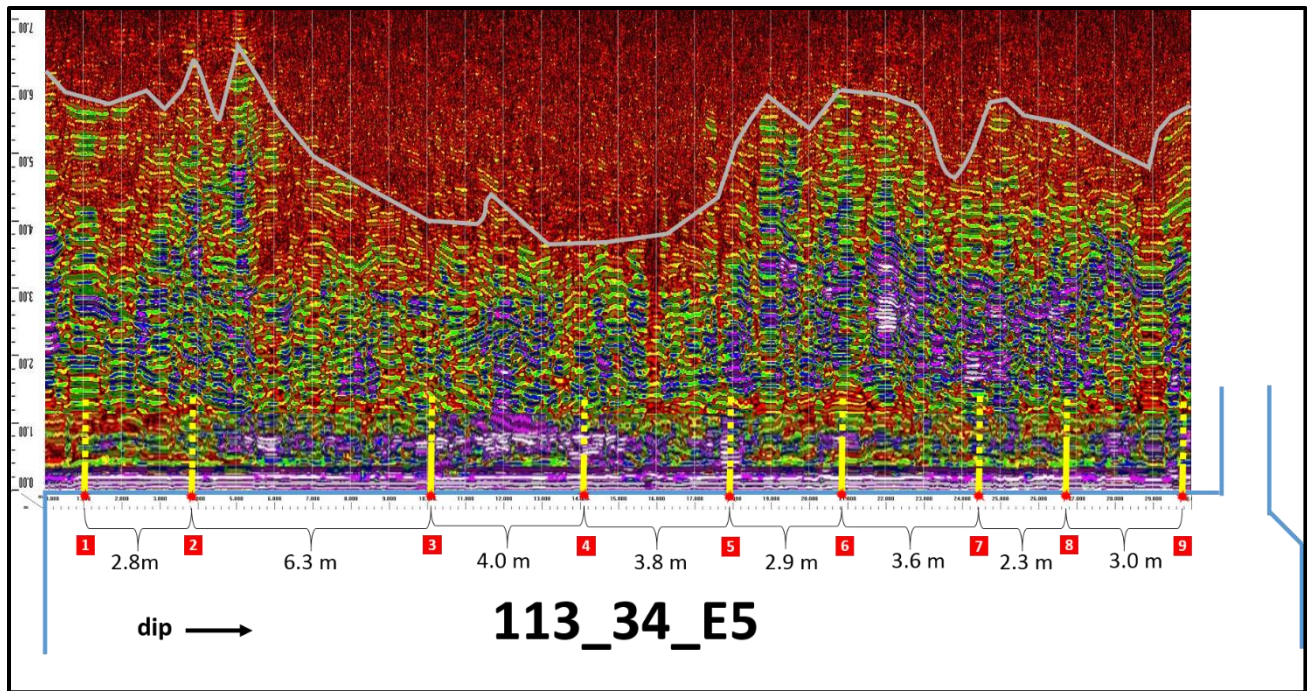


Figure 47: 113-34-E5 GPR Results @ 7.0m Depth

5.5.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 47 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 48 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 5.0m. A minimum of 3.7m was observed between the 13.5m and 16.0m distance markers, and a maximum of 6.7m at the 5.0m distance marker.

The calculated average depth of fracturing is not representative of the fracturing observed along the full length of the panel, since the values have a high variance. The reduction in fracture depth from distance marker 5.0m to 16.0m is due to the substandard over spacing of preconditioning holes in this area of the face. The calculated average depth of fracturing for the areas where the hole spacing is generally within standard (between 0.0 – 5.0 and 16.0 – 30.0) is 5.4m.

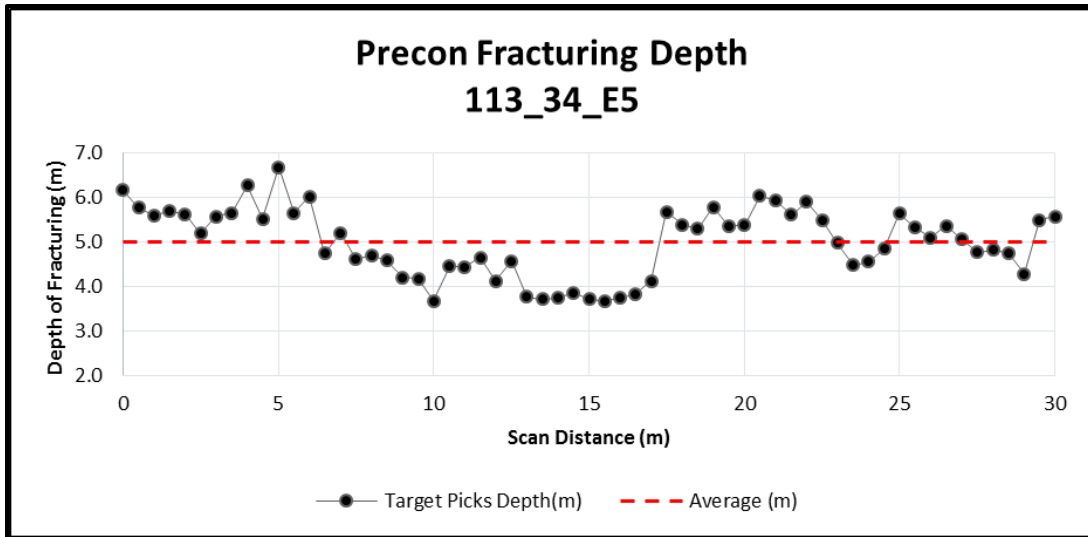


Figure 48: 113-34-E5 Depth of Fracturing

5.5.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the results data from Figure 47 are summarised in Table 7.

Table 7: Spacing Evaluation Data for 113-34-E5

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
E1	1 - 2	2.8	6.2	Y
E2	2 - 3	6.3	5.1	N
E3	3 - 4	4.0	3.9	N
E4	4 - 5	3.8	4.4	N
E5	5 - 6	2.9	5.8	Y
E6	6 - 7	3.6	5.5	Y
E7	7 - 8	2.3	5.4	Y
E8	8 - 9	3.0	5.3	Y

The data in table 7 indicates a 2.3m fracture depth range, from 3.9m to 6.2m, for all the spacing sets. Majority (5 out of 8) of spacing sets indicate continuous fracture profiles, except for set id E2, E3 and E4 which indicate a non-continuous fracture profile between the holes.

Figure 49 was developed from the data in Table 7 and it shows a general reduction in fracture depth as the hole spacing is increased. It should be noted that 6 out of the 8 data sets have an average fracture depth above 5.0m. The other 2 sets have an average fracture depth around 4.0m and as observable in Figure 49 are outlier data points. The equation of the linear regression line for the site is also given in Figure 49, and it shows a negative gradient, which is indicative of a depth of fracture reduction with hole spacing increase.

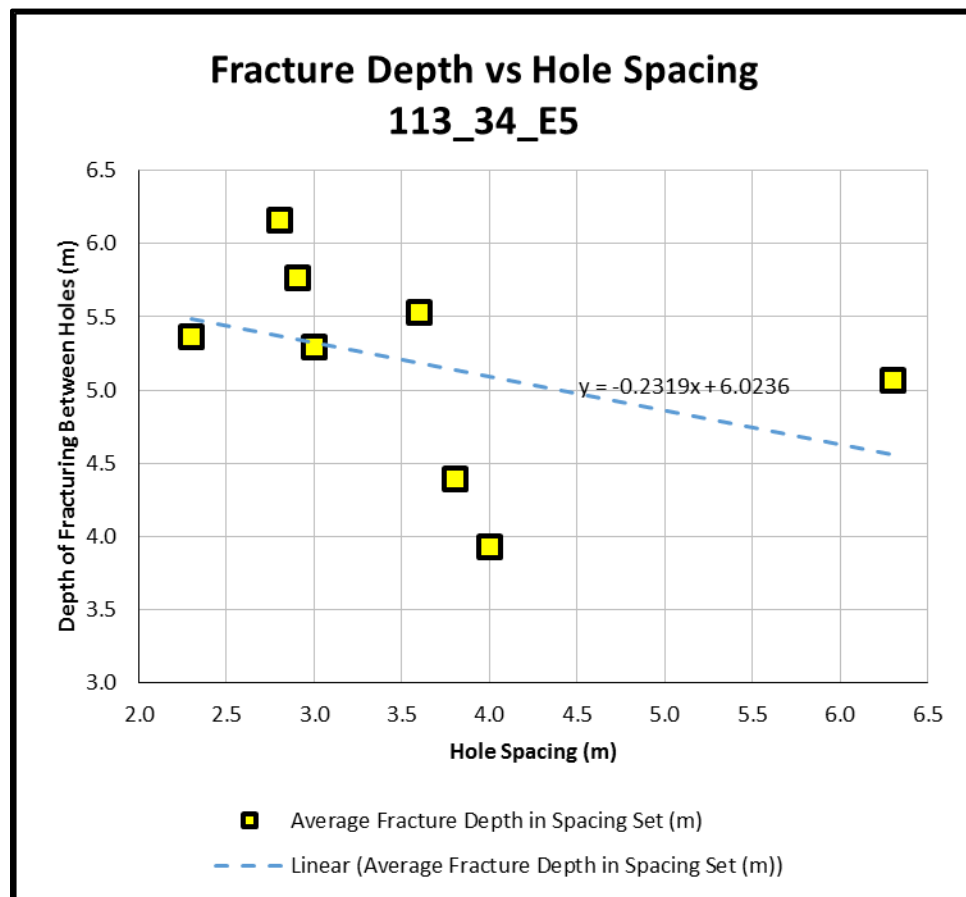


Figure 49: 113-34-E5 Fracture Depth vs Hole Spacing

Figure 50 is a graphical representation of the results observed in Figure 47, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 7. This figure indicates that continuous fracture profiles were observed for 63% of hole spacing sets mapped in the panel, with the exception of sets id E2, E3 and E4 which indicate that a non-continuous fracture profile was observed. The panel had a spacing that ranged from 2.3m to 6.3m.

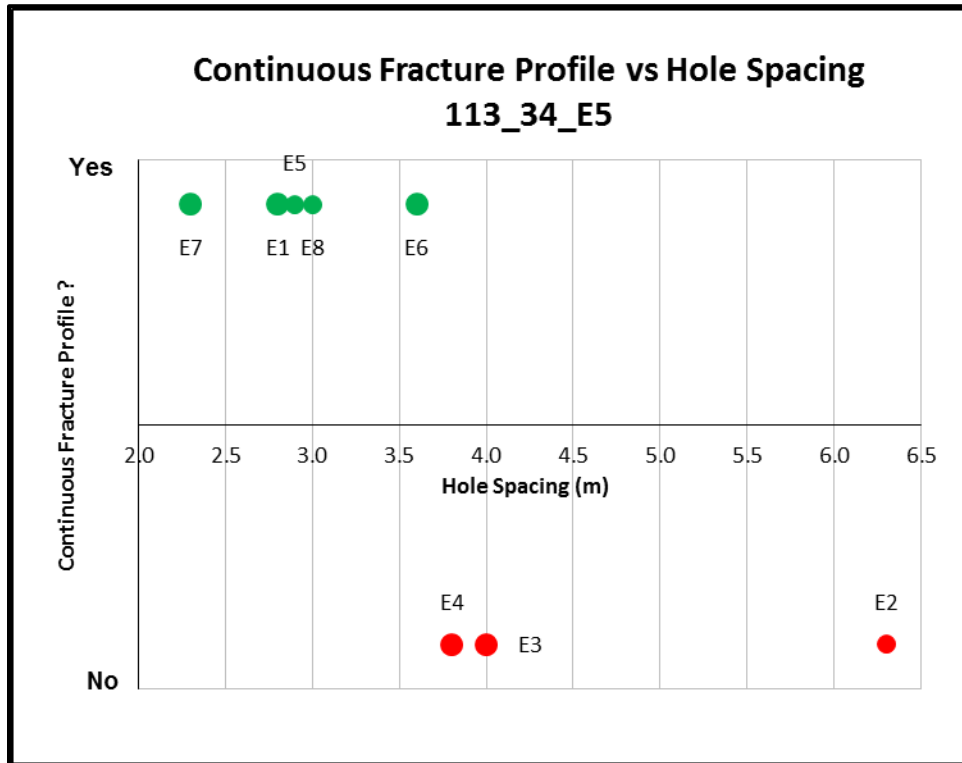


Figure 50: 113-34-E5 Continuous Fracture Profile vs Hole Spacing

5.6. SITE 6: 113-35-W2

The results for the sixth project site at 113-35-W2 panel which was scanned on 01 December 2017 are given in this subsection.

5.6.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 32.0m and 30.0m of the face was scanned starting from the top of the panel and down to the gully.
- The panel had an average stopping width of 1.2m and was on reef, with 30cm thin reef.
- Quartzite footwall type was encountered in this panel.
- The ERR value was given as 14MJ/m².
- General stope maturity can be observed on the panel plan indicated in Figure 51.



Figure 51: Plan of 113-35 Raiseline

5.6.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 52.

The following key analyses can be viewed from the figure:

- High impulse signals are observable around the positions and ahead of all the previous day's preconditioning holes.
- There is a continuous high intensity signal from hole 1 to hole 10, where the spacing between the holes is from 2.1m (min) to 4.4m (max), which is indicative of a continuous fracture profile.
- These results are indicative of a good preconditioning blast, with a good hole spacing compliance.
- The depth of fracturing ahead of the whole panel is estimated to be 5.0m. This estimation is a good indicator for the panel since the values do not have a large variance.

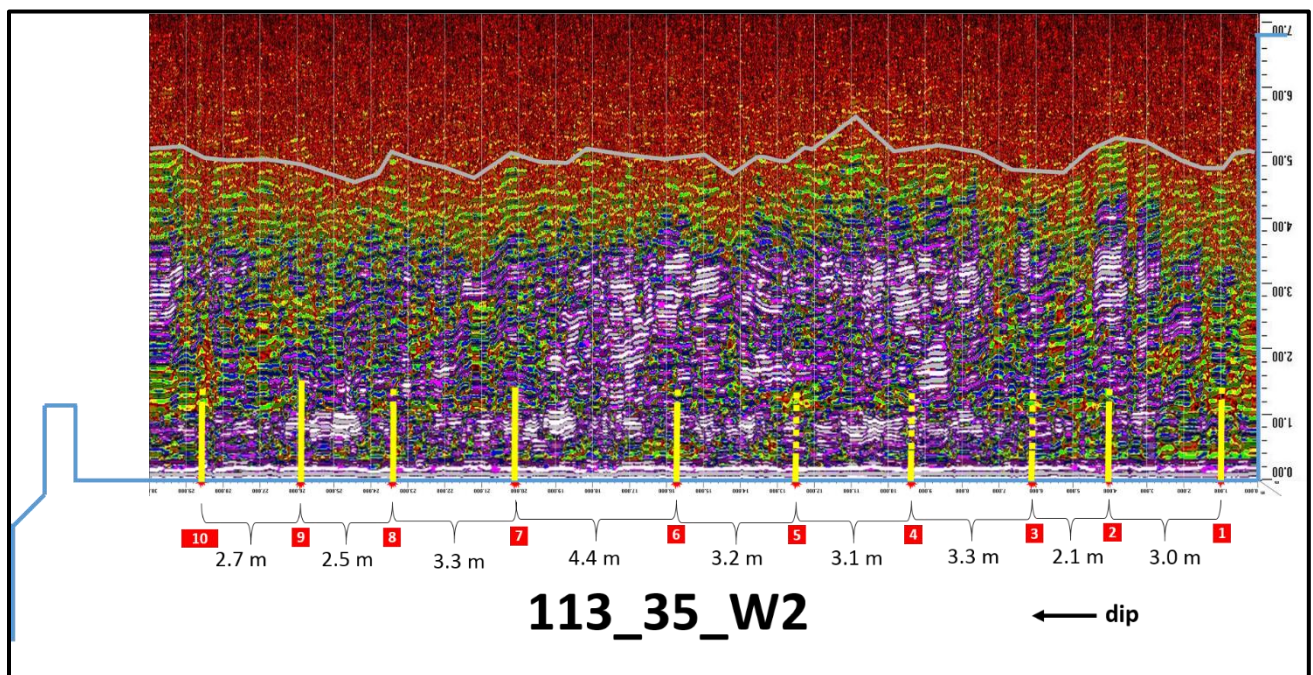


Figure 52: 113-35-W2 GPR Results @ 7.0m Depth

5.6.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 52 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 53 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 4.9m. Minima of 4.4m were observed at the 21.5m and 25.5m distance markers, and a maximum of 5.6m between the 10.0m and 11.0m distance markers.

The calculated average depth of fracturing is representative of the fracturing observed along the full length of the panel.

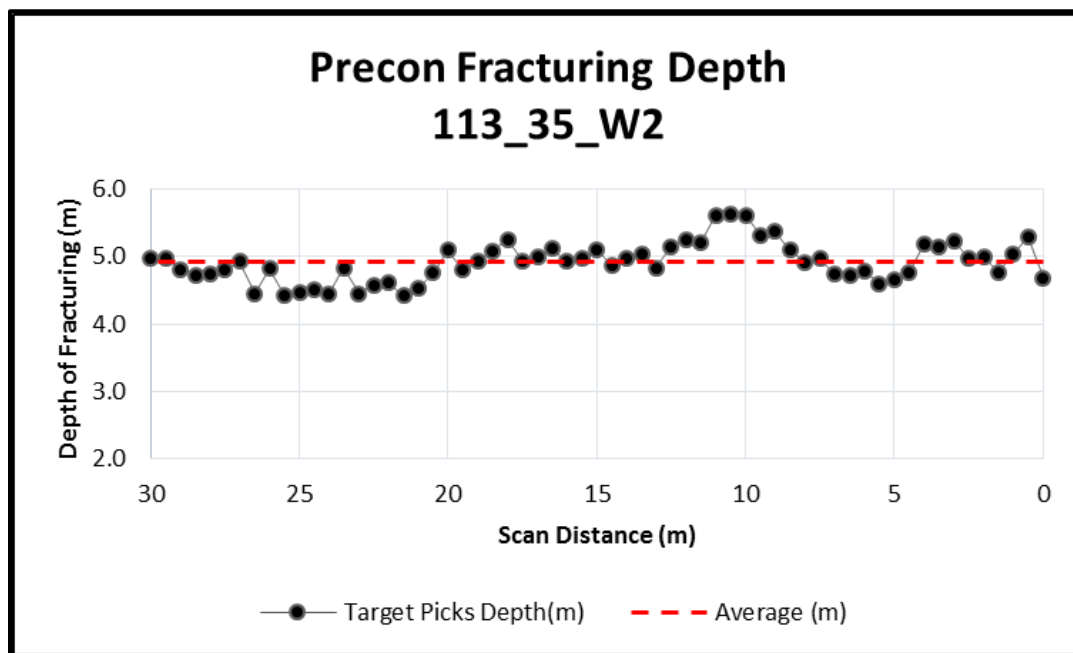


Figure 53: 113-35-W2 Depth of Fracturing

5.6.4. Burden Spacing

To evaluate the effect of burden spacing using statistical analyses, the results data from Figure 52 are summarised in Table 8.

Table 8: Spacing Evaluation Data for 113-35-W2

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
F1	1 - 2	3.0	5.1	Y
F2	2 - 3	2.1	5.1	Y
F3	3 - 4	3.3	5.1	Y
F4	4 - 5	3.1	5.3	Y
F5	5 - 6	3.2	5.1	Y
F6	6 - 7	4.4	5.0	Y
F7	7 - 8	3.3	4.9	Y
F8	8 - 9	2.5	4.9	Y
F9	9 - 10	2.7	5.1	Y

The data in Table 8 indicates a 0.4m fracture depth range, from 4.9m to 5.3m, for all the spacing sets. All the spacing sets indicate continuous fracture profiles.

Figure 54 was developed from the data in Table 8 and it shows a fractional reduction in fracture depth as the hole spacing is increased. It should also be noted that 7 out of the 9 data sets have an average fracture depth above 5.0m. The other 2 sets have an average fracture depth of 4.9m. The equation of the linear regression line for the site is also given in Figure 54, and it shows a fractional negative gradient, which is indicative of a minimal depth of fracture reduction with hole spacing increase.

Figure 55 is a graphical representation of the results observed in Figure 52, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 8.

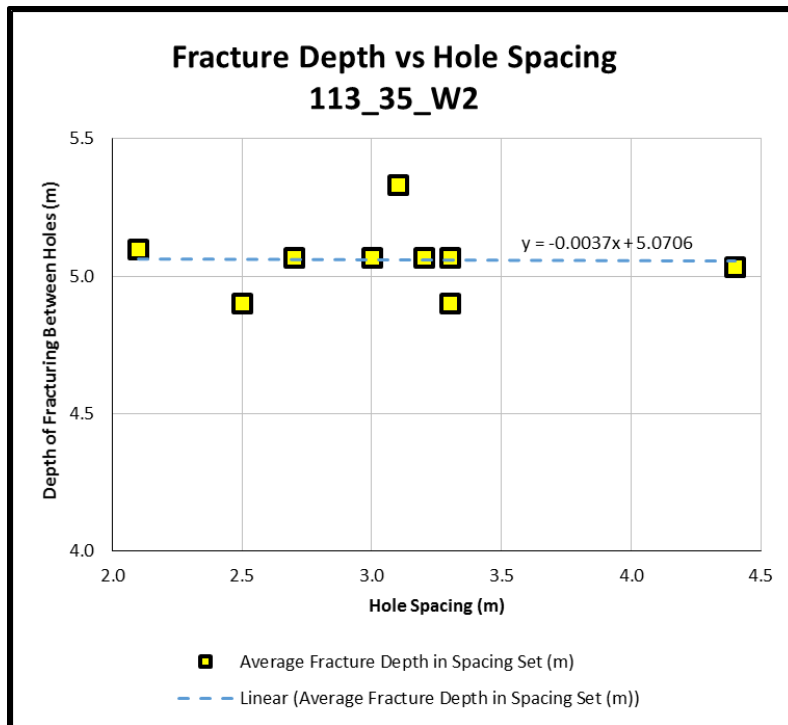


Figure 54: 113-35-W2 Fracture Depth vs Hole Spacing

Figure 55 indicates that continuous fracture profiles were observed for all hole spacing sets mapped in the panel, with a spacing range from 2.1m to 4.4m.

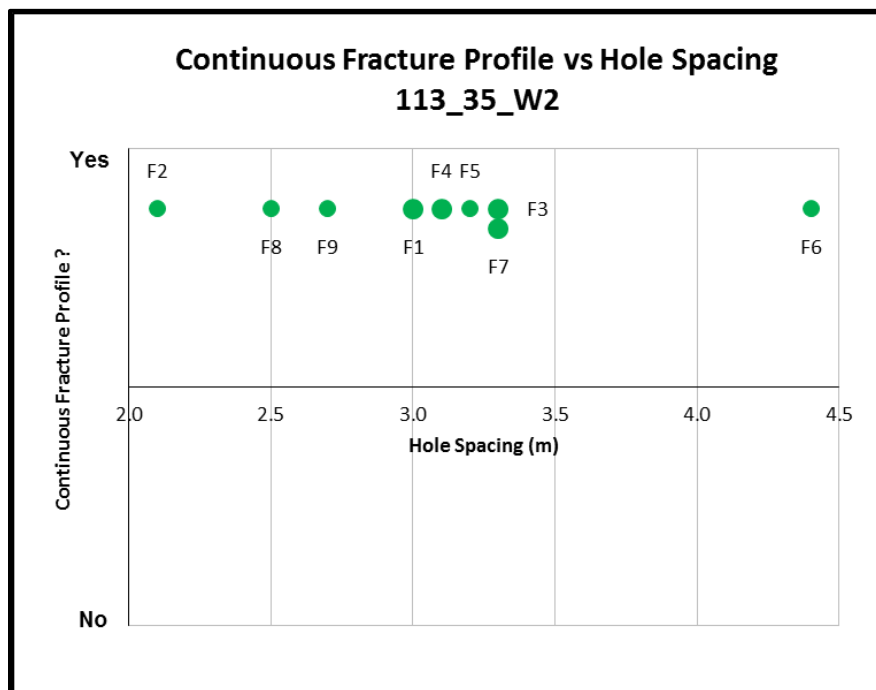


Figure 55: 113-35-W2 Continuous Fracture Profile vs Hole Spacing

5.7. SITE 7: 113-66-W2

The results to be given in this subsection are for the seventh project site at 113-66-W2 panel which was scanned on 04 December 2017.

5.7.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 37.3m and 36.0m of the face was scanned starting from the top of the panel and down to the gully.
- Shale footwall type was encountered in this panel.
- The ERR value was given as 5MJ/m².
- General stope maturity can be observed on the panel plan indicated in Figure 56.



Figure 56: Plan of 113-66 Raiseline

5.7.2. GPR Results

The following key analyses can be viewed from the 7.0m depth GPR scan results shown in Figure 57:

- High impulse signals are observed around the positions and ahead of 11 out of 12 previous day's preconditioning holes, with the exception of hole 4.
- At the position of hole 4, a high intensity signal is observed around the precondition hole, but the intense signal does not extend ahead of the hole. The depth of fracturing also reduces directly ahead of this preconditioning hole. These observations are an indication of poor hole spacing leading to ineffective preconditioning blasts, since the hole spacing exceeds the mine standard on either side.
- There is a continuous high intensity signal from holes 1 to 3, where the spacing between the holes is from 2.7m (min) to 4.0m (max), which is indicative of a continuous fracture profile.
- The area between holes 3 and 5 shows a discontinuous high intensity signal, due to the hole over spacing where the spacing between the holes is from 3.3m (min) to 4.1m (max), which is indicative of a non-continuous fracture profile.
- The high intensity signal continuity between holes 5 to 12 is also indicative of a continuous fracture profile, where the spacing between the holes is from 2.0m (min) to 3.4m (max).
- The depth of fracturing ahead of the bottom 19.0m of the panel, where the hole spacing is generally within the mine standard of 3.0m, except 1 hole out of 7, is estimated to be 6.2m. This is the portion which is indicative of the panel fracture depth if all holes were spaced within mine standard.
- The top 17.0m of the panel shows a reduced depth of fracture, since the hole spacing is mostly above the mine standard of 3.0m, with 4 out of 5 being substandard. The reduced estimated depth of fracture for this portion is 4.6m.

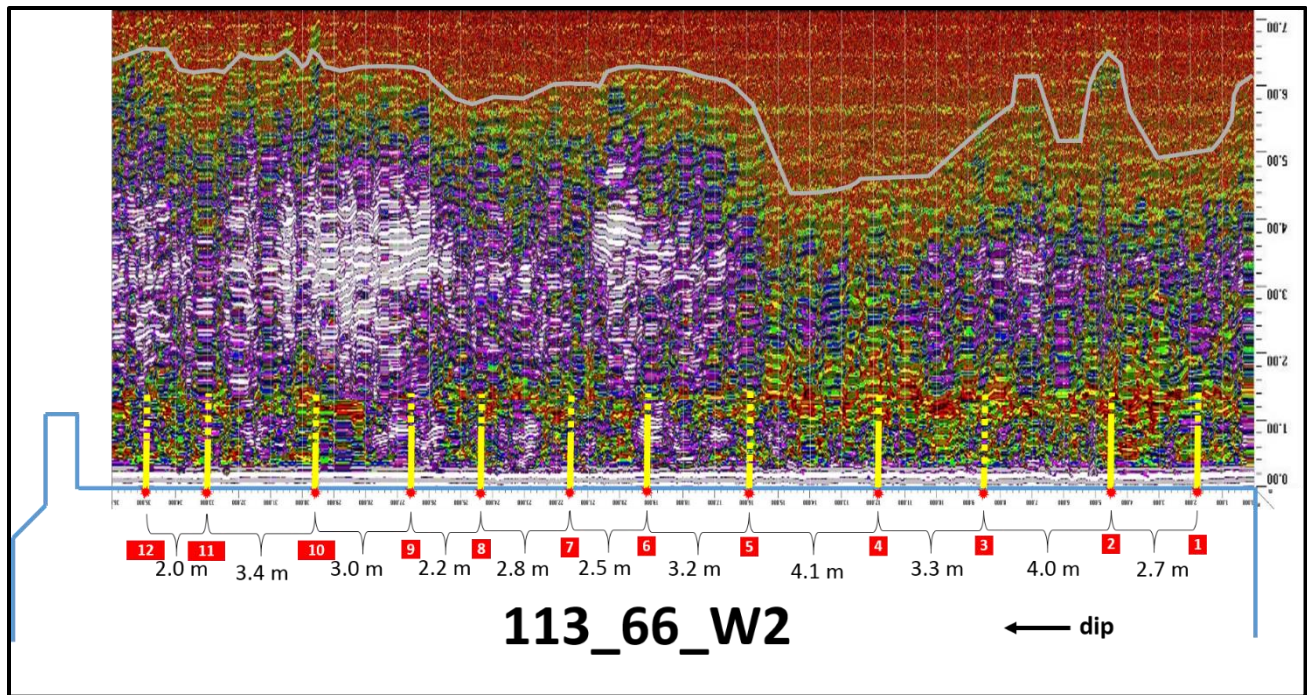


Figure 57: 113-66-W2 GPR Results @ 7.0m Depth

5.7.3. Depth of Fracturing

The depth of fracturing is also indicated in figure 57 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 58 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 5.5m. A minimum of 4.3m was observed at 12.5m and 14.0m distance markers, and maxima of 7.0m at 34.4m and 35.0m distance markers.

The calculated average depth of fracturing is not representative of the fracturing observed along the full length of the panel, since the values have a high variance. The reduction in fracture depth from distance marker 0.0m to 16.0m is due to the substandard over spacing of preconditioning holes in this area of the face. The calculated average depth of fracturing for the areas where the hole spacing is generally within standard (between 16.0 – 36.0) is 6.0m.

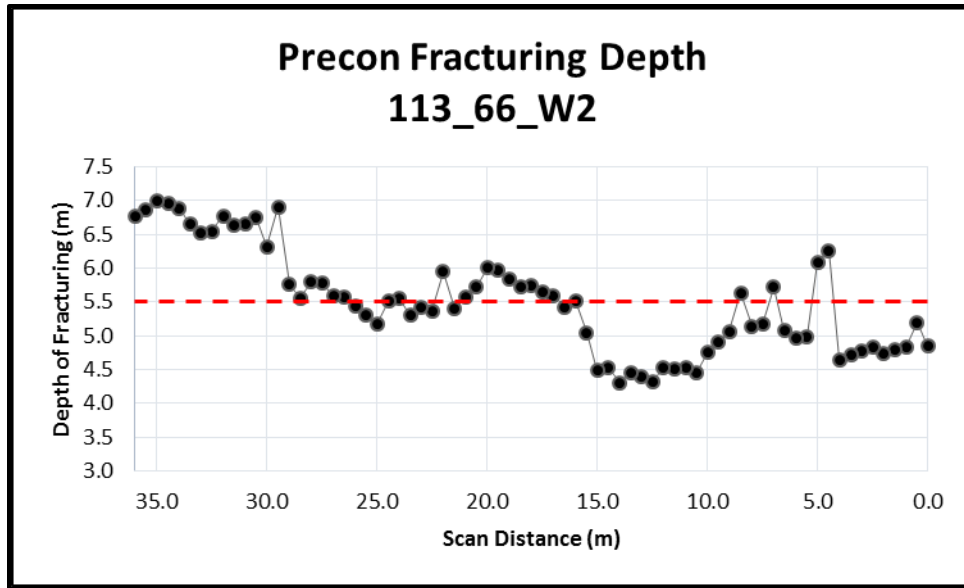


Figure 58: 113-66-W2 Depth of Fracturing

5.7.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the results data from Figure 57 are summarised in Table 9.

Table 9: Spacing Evaluation Data for 113-66-W2

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
G1	1 - 2	2.7	5.0	Y
G2	2 - 3	4.0	5.5	Y
G3	3 - 4	3.3	4.7	Y
G4	4 - 5	4.1	4.5	N
G5	5 - 6	3.2	5.6	Y
G6	6 - 7	2.5	6.0	Y
G7	7 - 8	2.8	5.6	Y
G8	8 - 9	2.2	5.6	Y
G9	9 - 10	3.0	6.3	Y
G10	10 - 11	3.4	6.6	Y
G11	11 - 12	2.0	6.5	Y

The data in Table 9 indicates a 2.1m fracture depth range, from 4.5m to 6.6m, for all the spacing sets. The majority (10 out of 11) of spacing sets indicate continuous fracture profiles, except for set id G4 which indicates a non-continuous fracture profile between holes 4 and 5.

Figure 59 developed from the data in Table 9 shows a general reduction in fracture depth as the hole spacing is increased. The equation of the linear regression line for the site is also given in Figure 59, and it shows a negative gradient, which is indicative of a depth of fracture reduction with hole spacing increase.

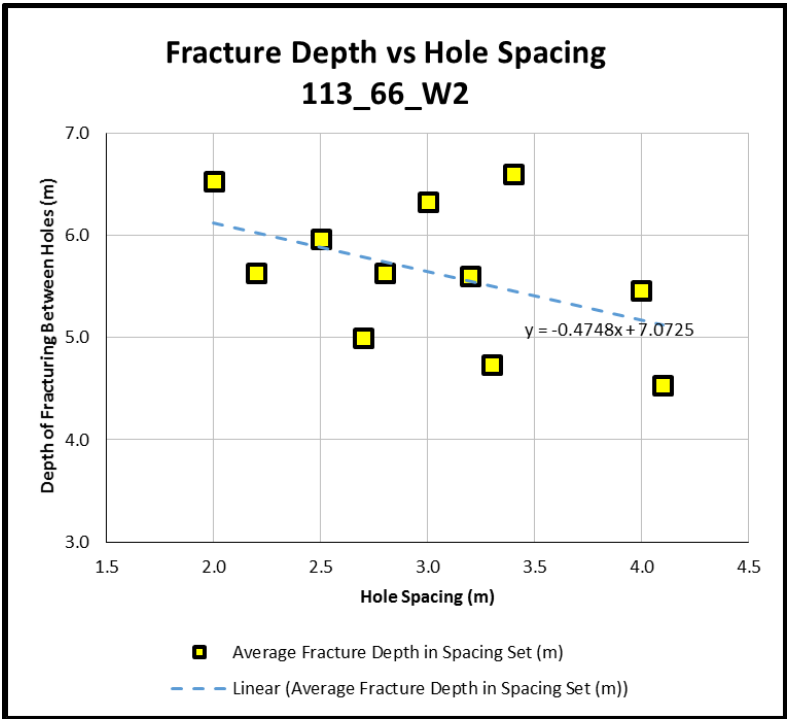


Figure 59: 113-66-W2 Fracture Depth vs Hole Spacing

Figure 60 is a graphical representation of the results observed in Figure 57, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 9. This figure indicates that continuous fracture profiles were observed for 91% of hole spacing sets mapped in the panel, with the exception of set id G4 which indicates that a non-continuous fracture profile was observed. The panel had a hole spacing ranged from 2.0m to 4.1m.

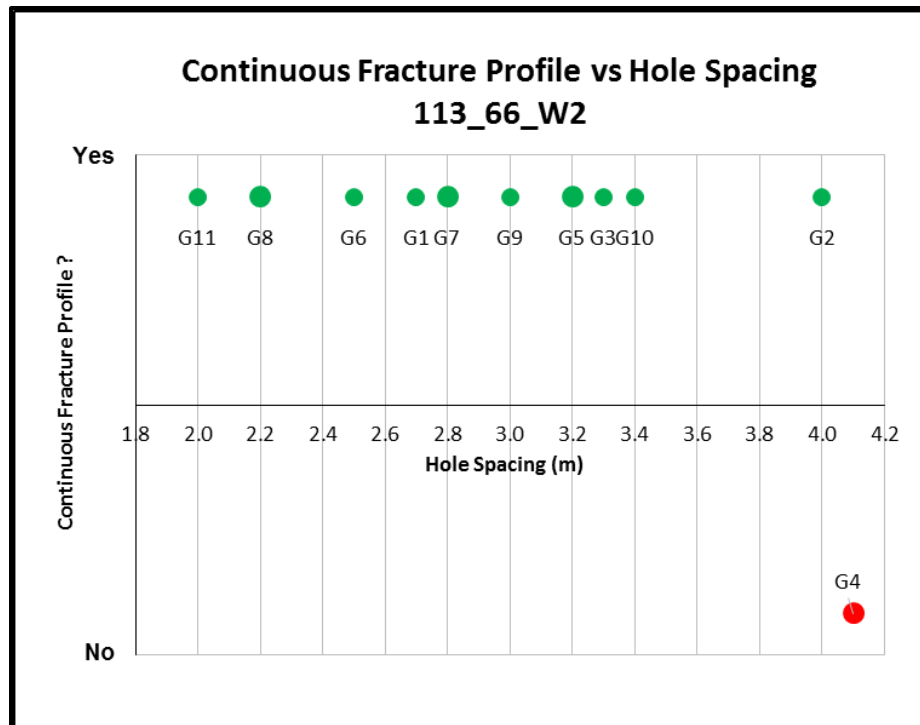


Figure 60: 113-66-W2 Continuous Fracture Profile vs Hole Spacing

5.8. SITE 8: 116-66-E2

The results to be given in this subsection are for the eighth project site at 116-66-E2 panel which was scanned on 08 December 2017.

5.8.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 30.0m and only 22.0m of the face was scanned, since the bottom 8.0m was not cleaned.
- The panel had an average stoping width of 1.4m and a channel width of 1.3m.
- Shale footwall type was encountered in this panel.
- The ERR value was given as 7MJ/m².
- General stope maturity can be observed on the panel plan indicated in Figure 61.

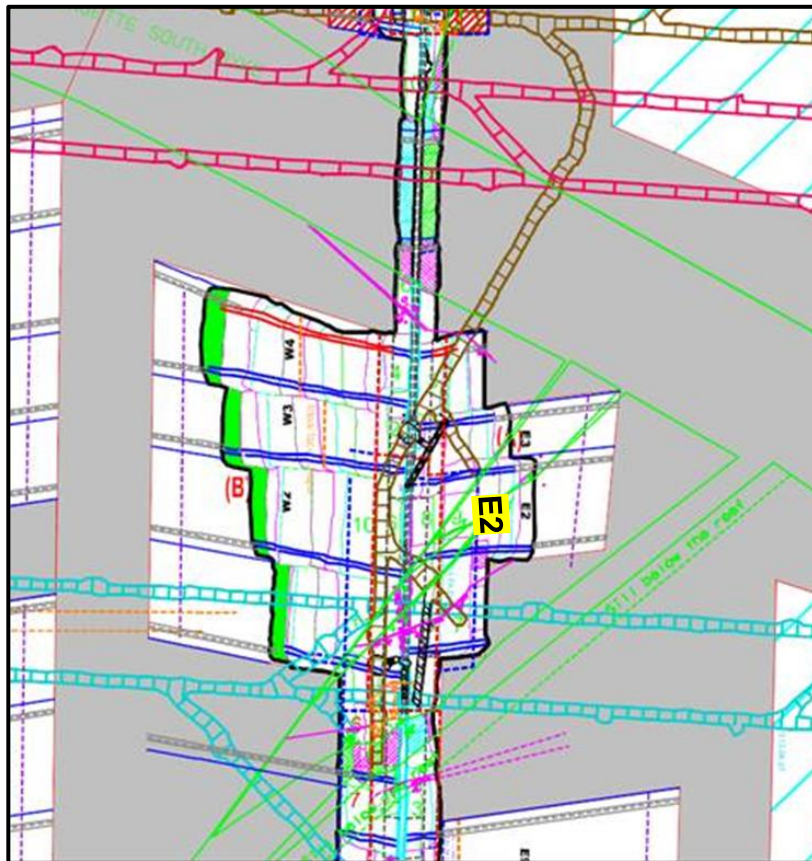


Figure 61: Plan of 116-66 Raiseline

5.8.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 62.

The following key analyses can be viewed from the figure:

- High impulse signals are observable around the positions and ahead of all the previous day's preconditioning holes.
- There is a continuous high intensity signal from hole 1 to hole 6, where the spacing between the holes is from 2.3m (min) to 3.0m (max), which is indicative of a continuous fracture profile.
- The continuity of the high intensity signal breaks midway between holes 6 and 7, where the spacing between the holes is 5.5m, which is indicative of a non-continuous fracture profile.
- The depth of fracturing also reduces between holes 6 and 7.
- The above two observations are an indication of poor hole spacing leading to an ineffective preconditioning blast, since the hole spacing exceeds the mine standard.
- There is also a continuous high intensity signal between holes 7 and 8, with a spacing between the holes of 2.9m, which is indicative of a continuous fracture profile.
- The depth of fracturing ahead of the whole panel is estimated to be 5.6m. This estimation is a good indicator for the panel since the values do not have a large variance, except between holes 6 and 7 where a low of 4.5m is observed.

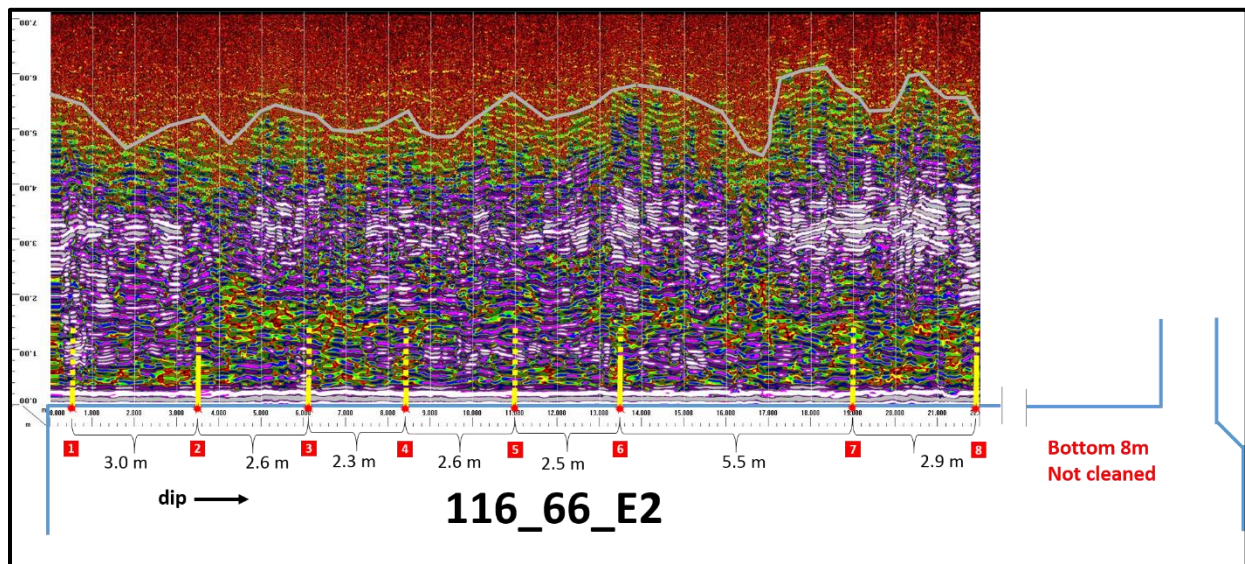


Figure 62: 116-66-E2 GPR Results @ 7.0m Depth

5.8.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 62 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 63 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 5.1m. Minima of 4.5m were observed at 3.5m and 16.5m distance markers, and a maximum of 6.1m at 18.0m distance marker.

The calculated average depth of fracturing is representative of the fracturing observed along the full length of the panel.

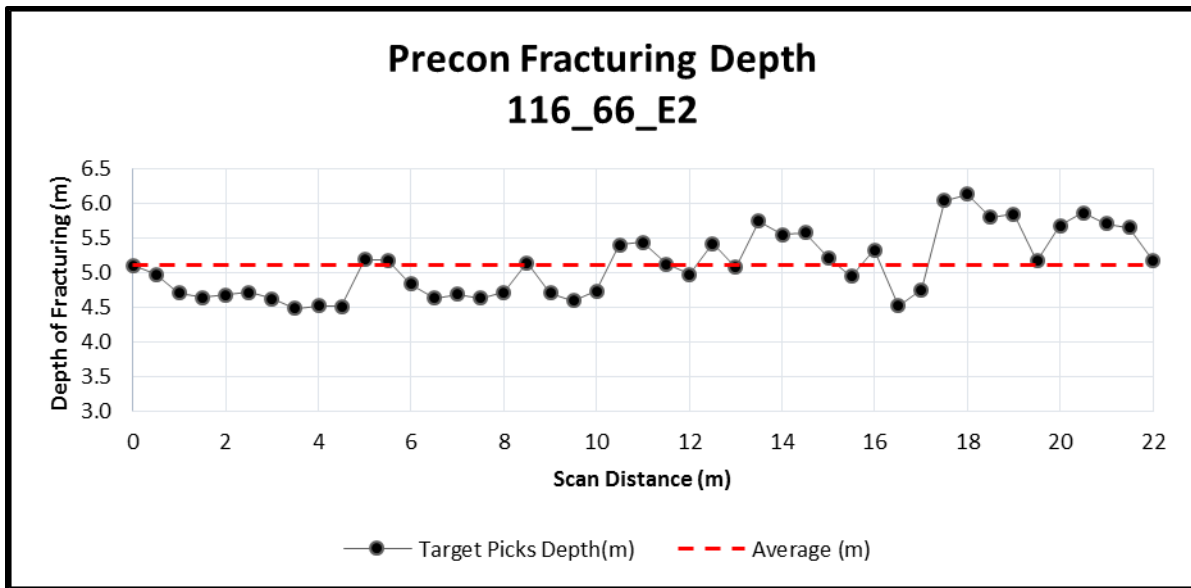


Figure 63: 116-66-E2 Depth of Fracturing

5.8.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the results data from Figure 62 are summarised in Table 10.

Table 10: Spacing Evaluation Data for 116-66-E2

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
H1	1 - 2	3.0	5.1	Y
H2	2 - 3	2.6	4.9	Y
H3	3 - 4	2.3	5.1	Y
H4	4 - 5	2.6	5.2	Y
H5	5 - 6	2.5	5.3	Y
H6	6 - 7	5.5	5.1	N
H7	7 - 8	2.9	5.6	Y

The data in Table 10 indicates a 0.7m fracture depth range, from 4.9m to 5.6m, for all the spacing sets. The majority (6 out of 7) of spacing sets indicate continuous fracture profiles, except for set id H6 which indicates a non-continuous fracture profile between holes 6 and 7.

Figure 64 developed from the data in Table 10 shows a fractional reduction in fracture depth as the hole spacing is increased. The equation of the linear regression line for the site is also given in Figure 64, and it shows a negative gradient, which is indicative of a depth of fracture reduction with hole spacing increase.

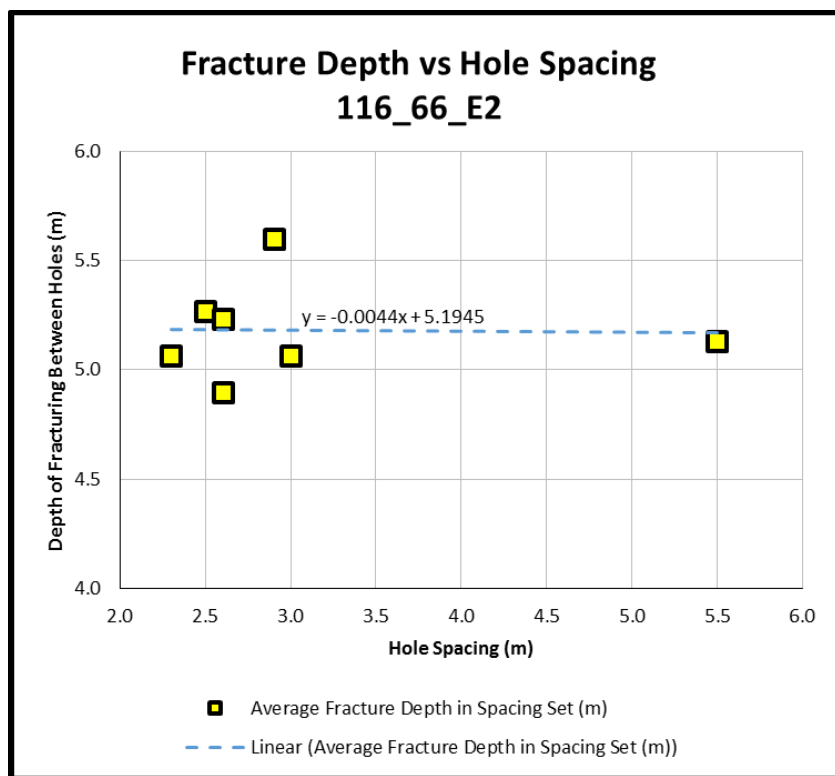


Figure 64: 116-66-E2 Fracture Depth vs Hole Spacing

Figure 65 is a graphical representation of the results observed in Figure 62, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 10. This figure indicates that continuous fracture profiles were observed for 86% of hole spacing sets mapped in the panel, with the exception of set id H6 which indicates that a non-continuous fracture profile was observed. The panel had a hole spacing range from 2.3m to 5.5m.

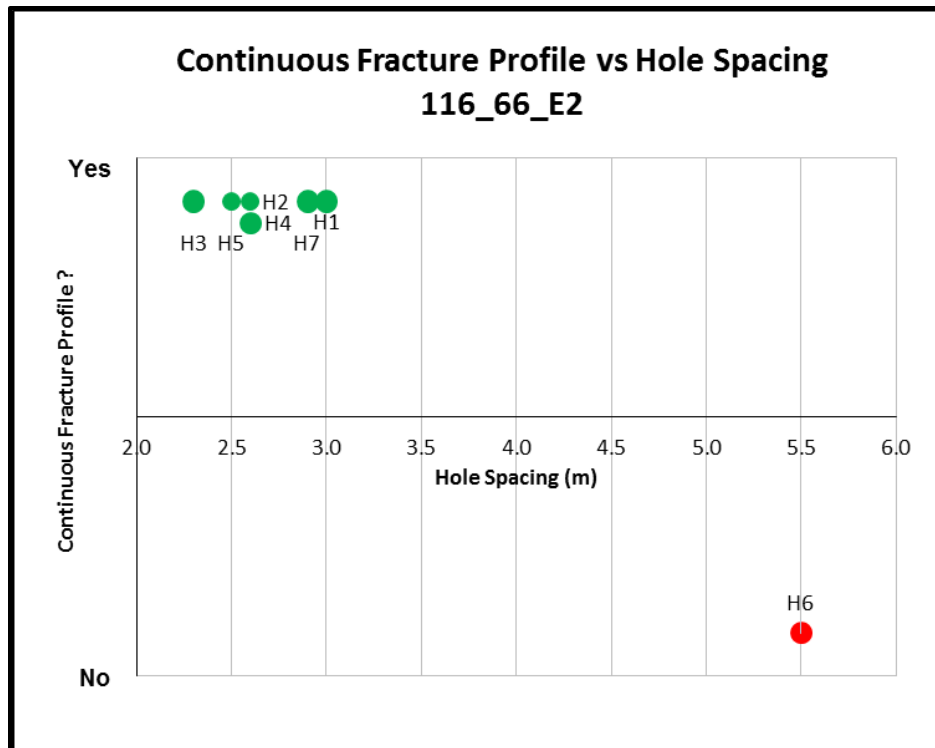


Figure 65: 116-66-E2 Continuous Fracture Profile vs Hole Spacing

5.9. SITE 9: 116-34-E5

The results given in this subsection are for the 9th project site at 116-34-E5 panel which was scanned on 25 January 2018.

5.9.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 38.2m and 38.0m of the face was scanned, starting from the top of the panel down to the gully.
- The panel had an average stoping width of 1.7m and a channel width of 1.3m.
- Quartzite footwall type was encountered in this panel.
- The ERR value was given as 12MJ/m².
- General panel maturity can be observed on the 116-34 stope plan in Figure 33.

5.9.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 66.

The following key analyses can be viewed from the figure:

- High impulse signals are observable around the positions and ahead of all the previous day's preconditioning holes.
- There is a non-continuous high intensity between holes 1 and 2, where the spacing between the holes is 5.7m, which is indicative of a non-continuous fracture profile. The depth of fracturing reduces ahead of these holes when compared to the rest of the panel. These observations are indicative of a poor preconditioning blast due to over spaced holes.

- A continuous high intensity signal from hole 2 to hole 6 can be observed, where the spacing between the holes is from 2.3m (min) to 4.0m (max), which is indicative of a continuous fracture profile.
- The continuity of the high intensity signal breaks between holes 6 and 7, where the spacing between the holes is 3.7m, which is indicative of a non-continuous fracture profile. This observation is an indication of poor hole spacing leading to an ineffective preconditioning blast, since the hole spacing exceeds the mine standard.
- There is also a continuous high intensity signal between holes 7 and 12, with a spacing between the holes from 1.8m (min) to 3.4m (max), which is indicative of a continuous fracture profile.
- The depth of fracturing ahead of the whole panel is estimated to be 4.8m. This estimation is a good indicator for the panel since the values do not have a large variance, except between holes 1 and 2 where a lower value of 4.4m is observed.

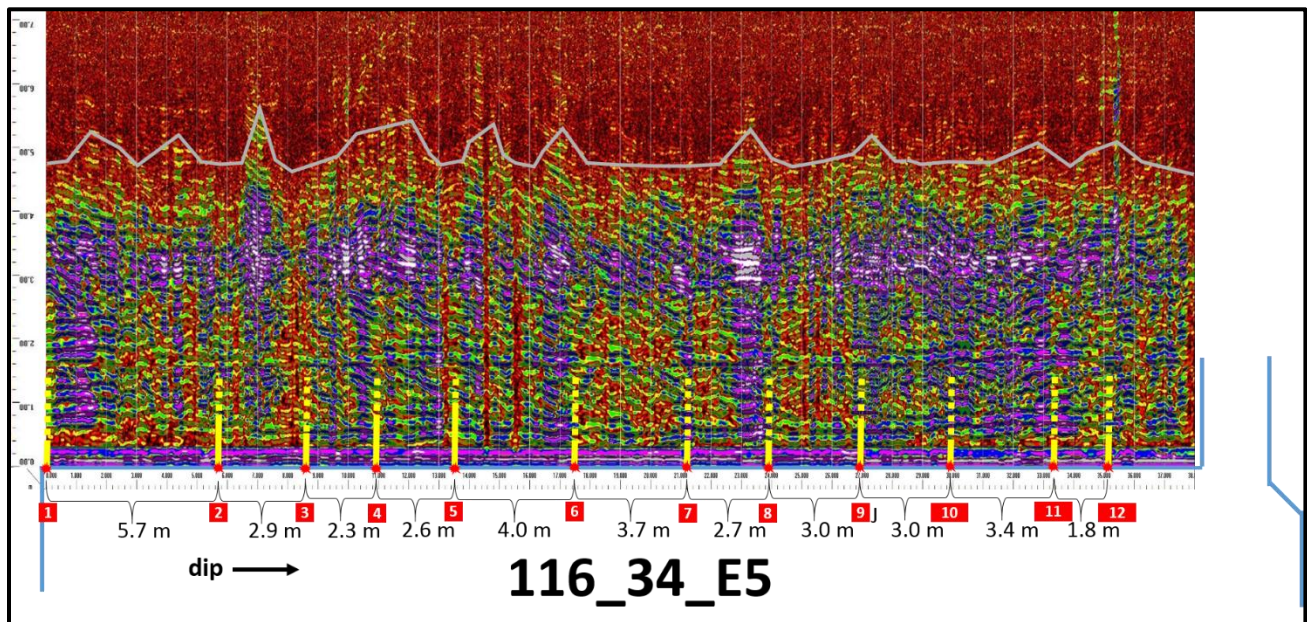


Figure 66: 116-34-E5 GPR Results @ 7.0m Depth

5.9.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 66 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 67 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 4.7m. A minimum of 4.1m was observed at the 38.0m distance marker, and maxima of 5.7m at 11.5m and 17.0m distance markers.

The calculated average depth of fracturing is representative of the fracturing observed along the full length of the panel.

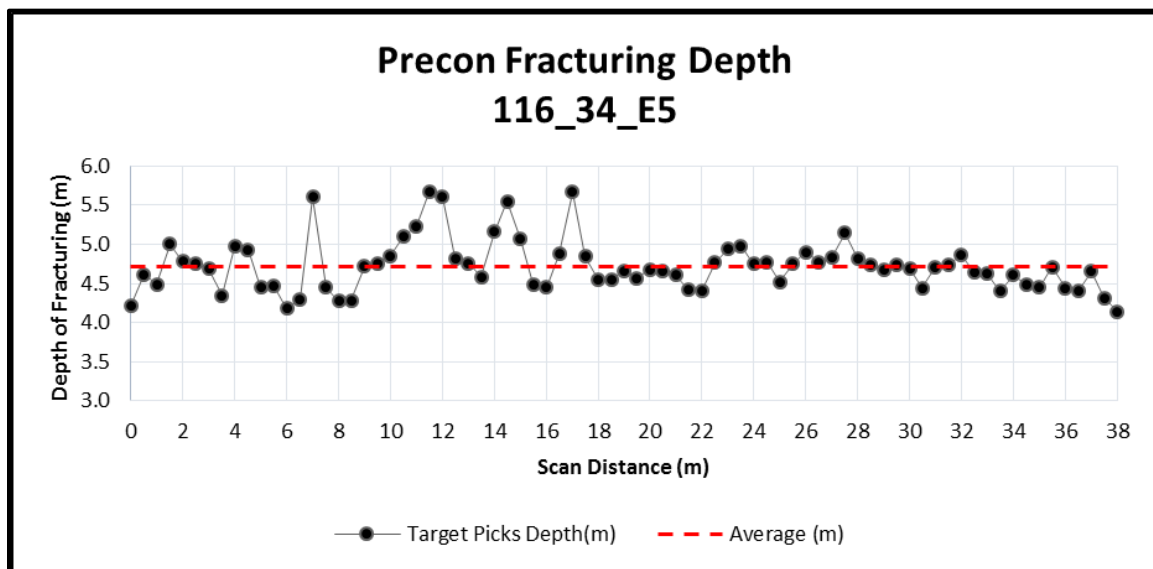


Figure 67: 116-34-E5 Depth of Fracturing

5.9.4. Burden Spacing

In order to evaluate the effect of burden spacing using statistical analyses, the results data from Figure 66 are summarised in Table 11.

Table 11: Spacing Evaluation Data for 116-34-E5

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
I1	1 - 2	5.7	4.2	N
I2	2 - 3	2.9	4.4	Y
I3	3 - 4	2.3	4.5	Y
I4	4 - 5	2.6	4.5	Y
I5	5 - 6	4.0	4.5	Y
I6	6 - 7	3.7	4.5	N
I7	7 - 8	2.7	4.6	Y
I8	8 - 9	3.0	4.6	Y
I9	9 - 10	3.0	4.6	Y
I10	10 - 11	3.4	4.5	Y
I11	11 - 12	1.8	4.5	Y

The data in Table 11 indicates a 0.4m fracture depth range, from 4.2m to 4.6m, for all the spacing sets. The majority (9 out of 11) of spacing sets indicate continuous fracture profiles, except for sets id I1 and I6 which indicates a non-continuous fracture profile.

Figure 68 developed from the data in Table 11 shows a fractional reduction in fracture depth as the hole spacing is increased. The equation of the linear regression line for the site is also given in Figure 68, and it shows a negative gradient, which is indicative of a depth of fracture reduction with hole spacing increase.

Figure 69 is a graphical representation of the results observed in Figure 66, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 11. This figure indicates that continuous fracture profiles were observed for 82% of hole spacing sets mapped in the panel, with the exception of sets id I1 and I6 which indicates that a non-continuous fracture profile was observed. The panel had a hole spacing range from 1.8m to 5.7m.

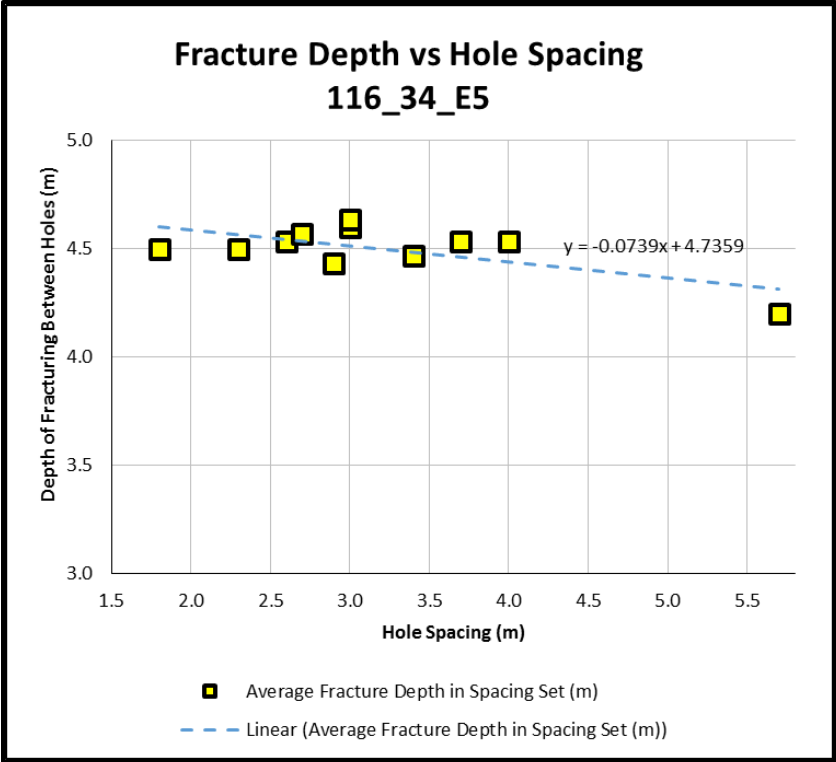


Figure 68: 116-34-E5 Fracture Depth vs Hole Spacing

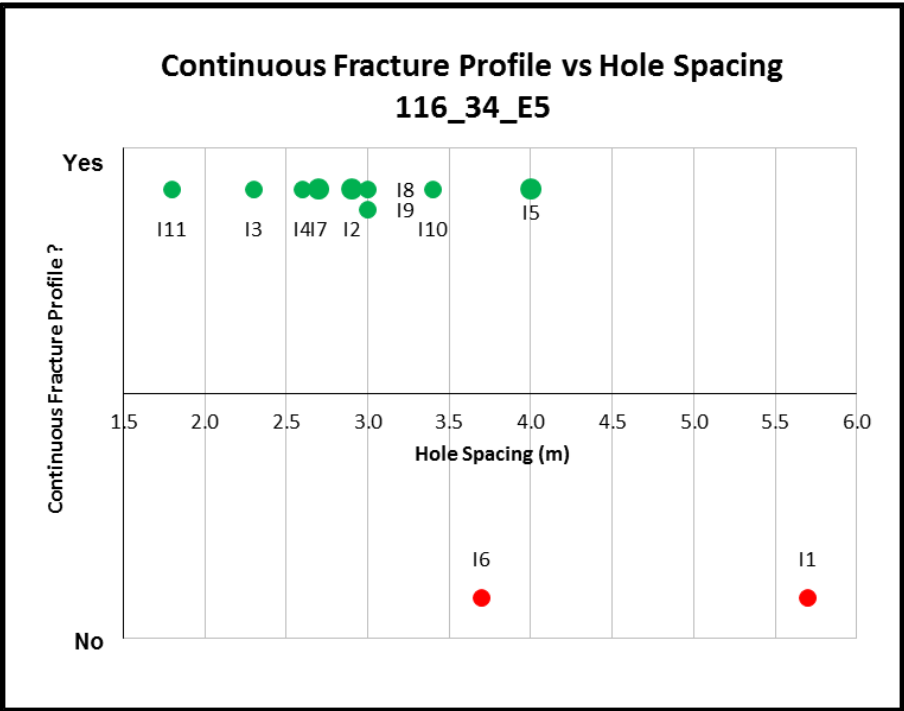


Figure 69: 116-34-E5 Continuous Fracture Profile vs Hole Spacing

5.10. SITE 10: 120-65-W5A

The results for the 10th project site at 120-65-W5A panel which was scanned on 01 February 2018 are given in this subsection.

5.10.1. Site Details and Conditions

During the panel visit the following details and issues were encountered:

- The total panel length was 23.7m and 20.0m of the face was scanned starting from the top of the panel down to the gully.
- Shale footwall type was encountered in this panel.
- The ERR value was given as 14MJ/m².
- General stope maturity can be observed on the panel plan indicated in Figure 70.

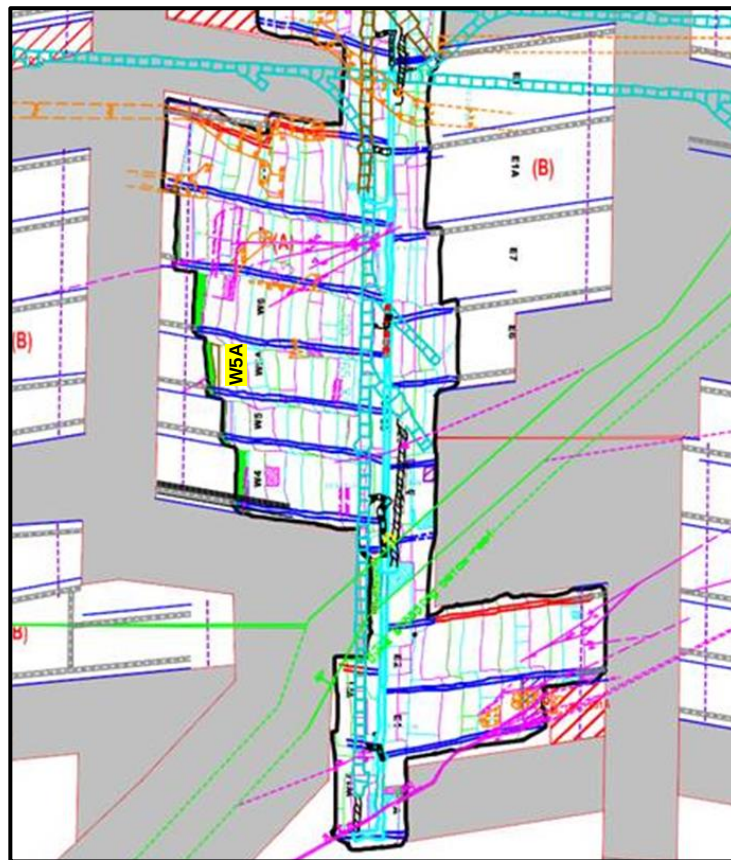


Figure 70: Plan of 120-65 Raiseline

5.10.2. GPR Results

The 7.0m depth GPR scan results as superimposed on the precon socket mapping results are shown in Figure 71.

The following key analyses can be viewed from the figure:

- High impulse signals are observable around the positions and ahead of all the previous day's preconditioning holes.
- There is a continuous high intensity from holes 1 to 8, where the spacing between the holes is from 1.8m (min) to 3.3m (max), which is indicative of a continuous fracture profile.
- These results are an indication of a good preconditioning blast since all the holes were spaced close to the standard 3.0m.
- The depth of fracturing ahead of the whole panel is estimated to be 5.0m. This estimation is a good indicator for the panel since the depth values are relatively constant along the whole panel.

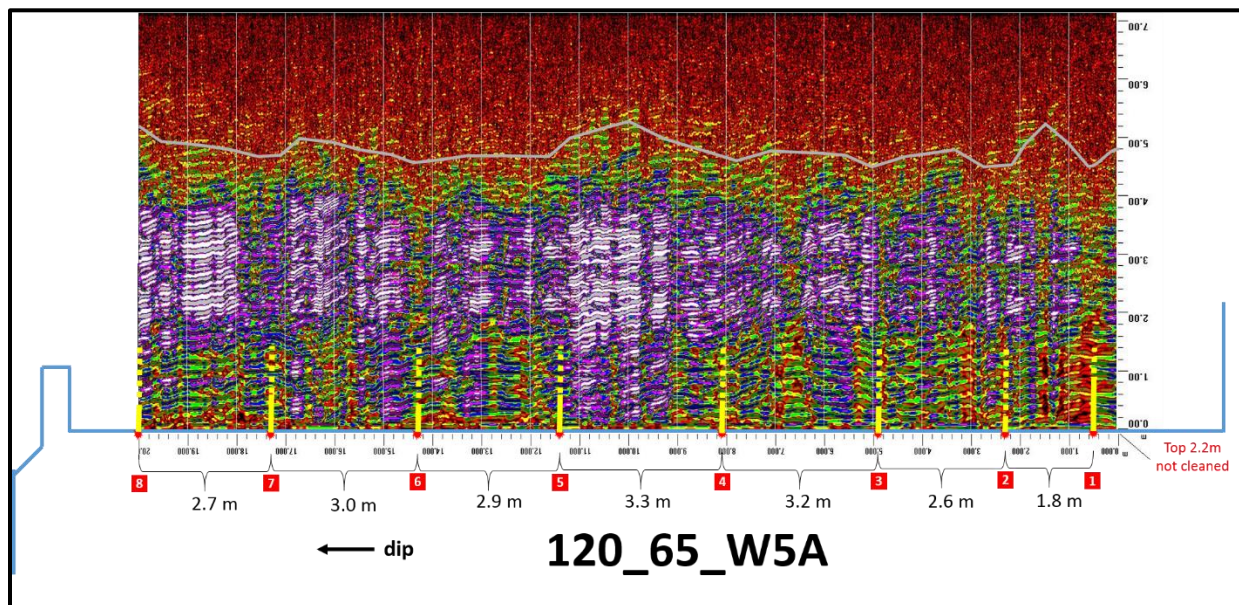


Figure 71: 120-65-W5A GPR Results @ 7.0m Depth

5.10.3. Depth of Fracturing

The depth of fracturing is also indicated in Figure 71 with a grey line indicating the extent of the fracturing on the GPR scan results.

Figure 72 further indicates the depth of fracturing by graphically plotting the depth marker positions. From the depth marker data, an average was calculated to indicate the average depth of fracturing for the entire panel, which was determined to be 4.9m. A minimum of 4.1m was observed at 0.5m distance markers, and a maximum of 5.5m at 20.0m distance marker.

The calculated average depth of fracturing is representative of the fracturing observed along the full length of the panel.

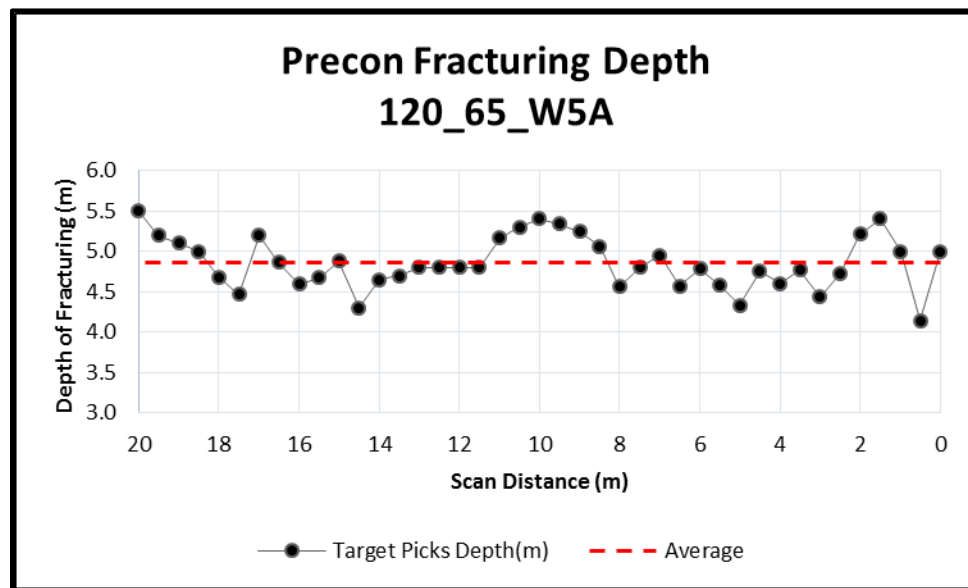


Figure 72: 120-65-W5A Depth of Fracturing

5.10.4. Burden Spacing

To evaluate the effect of burden spacing using statistical analyses, the results from Figure 71 are summarised in Table 12.

Table 12: Spacing Evaluation Data for 120-65-W5A

Set ID	Hole Spacing Set	Spacing Between Sockets (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
J1	1 - 2	1.8	5.0	Y
J2	2 - 3	2.6	4.8	Y
J3	3 - 4	3.2	4.6	Y
J4	4 - 5	3.3	5.0	Y
J5	5 - 6	2.9	4.8	Y
J6	6 - 7	3.0	4.7	Y
J7	7 - 8	2.7	5.0	Y

The data in Table 12 indicates a 0.4m fracture depth range, from 4.6m to 5.0m, for all the spacing sets. All spacing sets indicate continuous fracture profiles.

Figure 73 developed from the data in Table 12 shows a fractional reduction in fracture depth as the hole spacing is increased. The equation of the linear regression line for the site is also given in Figure 73, and it shows a negative gradient, which is indicative of a depth of fracture reduction with hole spacing increase.

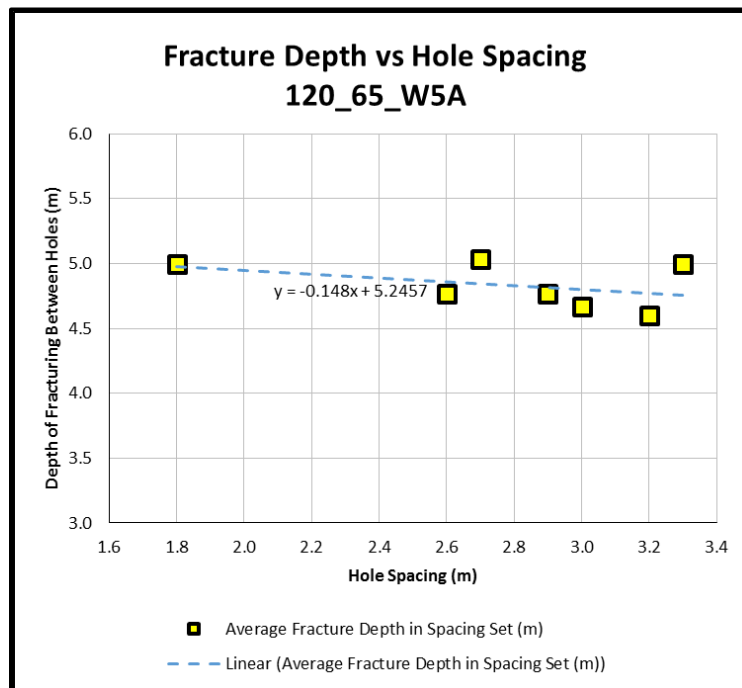


Figure 73: 120-65-W5A Fracture Depth vs Hole Spacing

Figure 74 is a graphical representation of the results observed in Figure 71, relating to the continuity of fracturing between adjacent preconditioning holes, and summarised in Table 12. This figure indicates that continuous fracture profiles were observed for all hole spacing sets mapped in the panel. The panel had a hole spacing range from 1.8m to 3.3m.

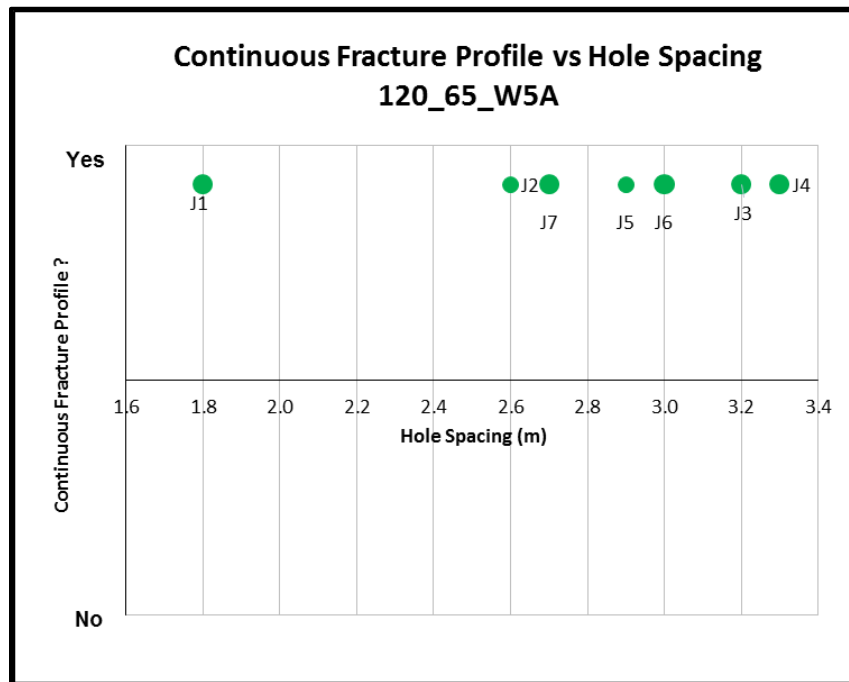


Figure 74: 120-65-W5A Continuous Fracture Profile vs Hole Spacing

6. ANALYSIS OF RESULTS

The section covers an analysis of key items required to meet the project objectives and deliver on the project outcomes. Analysis on the following items is detailed in subsections below:

- Depth of fracturing ahead of the preconditioned panel faces
- The effect of footwall types on the depth of fracturing
- The effect of stope maturity, represented by ERR values, on the depth of fracturing
- Burden spacing of precon holes for defining the effective burden spacing

6.1. Depth of Fracturing

The representative average fracture depths, including the observed minimum and maximum fracture depths from the ten project sites are summarised in Table 13.

Table 13: Average Fracture Depth per Project Site

Site No.	Panel Name	Representative Average Fracture Depth (m)	Minimum Fracture Depth (m)	Maximum Fracture Depth (m)
1	123-42-W4	5.0	4.1	6.6
2	116-34-E7	4.5	3.7	5.3
3	116-34-E4	4.1	3.2	4.6
4	116-34-E3	5.1	3.8	5.7
5	113-34-E5	5.4	3.7	6.7
6	113-35-W2	4.9	4.4	5.6
7	113-66-W2	6.0	4.3	7.0
8	116-66-E2	5.1	4.5	6.1
9	116-34-E5	4.7	4.1	5.7
10	120-65-W5A	4.9	4.1	5.5
	Average	5.0	4.0	5.9

The data indicates that all preconditioned sites have a representative depth of fracturing greater than 4.0m. The average depth of fracturing for all the sites is 5.0m, determined from a range of 4.1m to 6.0m. The minimum depth of fracturing observed was 3.2m, while the maximum was 7.0m.

6.2. Depth of Fracturing by Footwall Type

An objective specified for the project, was to determine the effect of footwall types on the depth of fracturing. This was determined by categorizing the representative average depth of fracturing by footwall types for all sites, as given in Table 14.

Table 14: Depth of Fracturing per Footwall Type

Site No.	Panel Name	Fracture Depth (m)	Footwall Type	Average per FW Type (m)
1	123-42-W4	5.0	Quartzite	4.8
2	116-34-E7	4.5	Quartzite	
3	116-34-E4	4.1	Quartzite	
4	116-34-E3	5.1	Quartzite	
5	113-34-E5	5.4	Quartzite	
6	113-35-W2	4.9	Quartzite	
9	116-34-E5	4.7	Quartzite	
7	113-66-W2	6.0	Shale	5.3
8	116-66-E2	5.1	Shale	
10	120-65-W5A	4.9	Shale	

Table 14 indicates that the depth of fracturing in shale footwall panels extends further than in quartzite footwall panels. The average depth of fracturing for shale footwall is 5.3m and for quartzite its 4.8m. Precaution should however be taken due to the small sample size for the shale footwall. The above analyses can however be taken as is until further data is made available.

6.3. Depth of Fracturing vs Stope Face Maturity (ERR)

The influence of stope maturity on the fracture profile was set as part of the objectives for the project. In order to complete an evaluation in this regard, the fracture depth data from each site and stope maturity indicator values (ERR), were collated into Table 15. The footwall types were also included, since it was noted that footwall type influences the

depth of fracturing achieved. The data was sorted in terms of footwall type and then by increasing ERR values.

Table 15: Depth of Fracturing by Stope Maturity

Site No.	Panel Name	Fracture Depth (m)	Footwall Type	ERR (MJ/m ²)
2	116-34-E7	4.5	Quartzite	9
3	116-34-E4	4.1	Quartzite	11
9	116-34-E5	4.7	Quartzite	12
4	116-34-E3	5.1	Quartzite	13
6	113-35-W2	4.9	Quartzite	14
1	123-42-W4	5.0	Quartzite	14
5	113-34-E5	5.4	Quartzite	14
7	113-66-W2	6.0	Shale	5
8	116-66-E2	5.1	Shale	7
10	120-65-W5A	4.9	Shale	14

Figure 75 is a graphical illustration of the depth of fracturing for all the quartzite footwall site against ERR values. It should be noted that a general trend can be observed from the graph, which indicates that fracture depth ahead of a preconditioned face increases with increasing face ERR values.

The trendline for the data can also observed in Figure 75, and the equation of the line is also given. A correlation coefficient of 0.752 was determined from the R^2 value given on Figure 75. The correlation coefficient value represents a strong positive linear relationship between fracture depth and ERR for sites with a quartzite footwall.

It could therefore be deduced that for every 1 unit increase in ERR, an increase of 0.1684m in fracture depth can be expected, from an expected base of 4.2m at an ERR of 9MJ/m² for quartzite footwall sites.

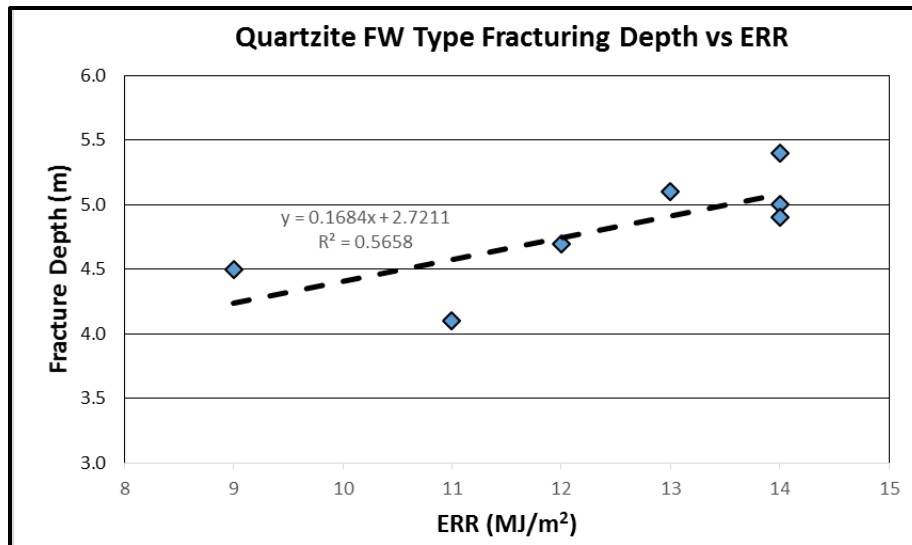


Figure 75: Fracture Depth vs ERR for Quartzite FW

Figure 76 is a graphical illustration of the depth of fracturing for the shale footwall site against ERR values. It shows that fracture depth ahead of a preconditioned face decreases with increasing face ERR values.

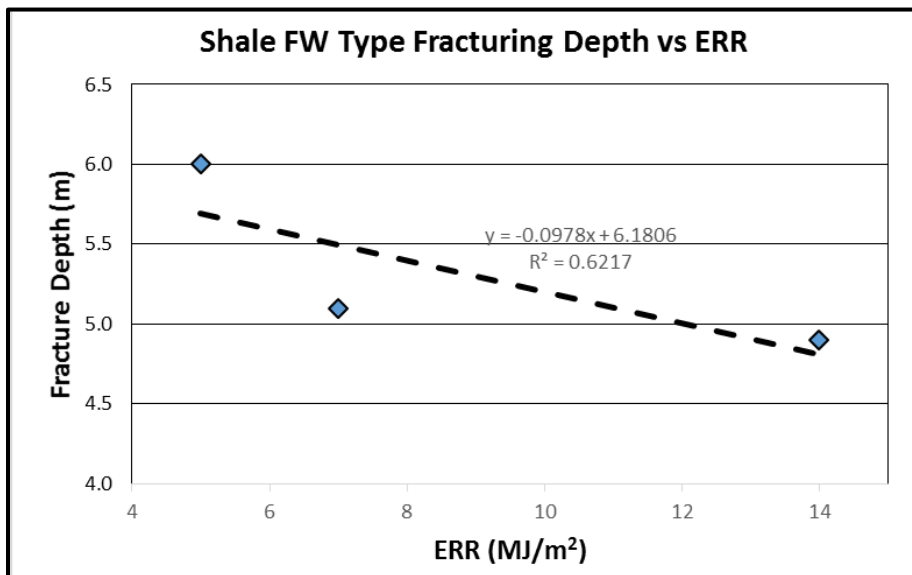


Figure 76: Fracture Depth vs ERR for Shale FW

The average trendline for the data can also be observed in Figure 76 with the line equation. A correlation coefficient of -0.78847 was determined from the R^2 value given on Figure 76. The correlation coefficient value represents a strong negative linear relationship between fracture depth and ERR for sites with shale type footwall.

From the information it can be deduced that for every 1 unit value increase in ERR, a decrease of about 0.1m in fracture depth can be expected, from an expected base of 5.7m at an ERR of 5MJ/m².

The linear relationship observed in the shale footwall sites is contradictory to the observations in the quartzite footwall sites and the generally accepted theory of fracture depth versus ERR values. There is however a reduced confidence in the shale footwall type analyses since only three data samples were available.

6.4. Precon Burden Spacing

The influence of preconditioned hole burden spacing was evaluated to meet the project objectives. It was decided to firstly assess burden spacing with regards to achieving a continuous fracture profile between the holes. The second analysis was done to determine the effect of burden spacing on the fracture depth achieved.

Figure 77 represents the combined continuous fracture profile vs burden spacing data from all the assessed project sites. The full data used are shown in Appendix 3.

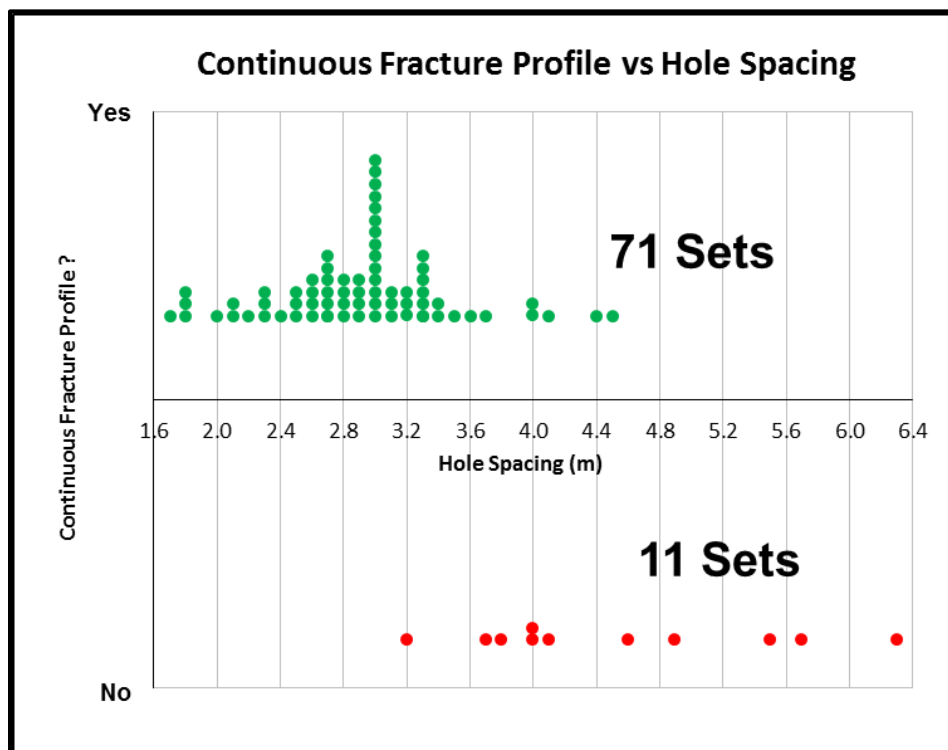


Figure 77: Continuous Fracture Profile vs Hole Spacing

The following analyses can be determined from Figure 77:

- A total of 82 burden spacing sets were analysed for the project.
- Continuous fracture profiles were achieved by 71 sets, while only 11 did not achieve continuous fracture profiles out of which 8 (73%) sets had a burden spacing of 4.0m or more.
- The smallest burden spacing to fail to achieve a continuous fracture profile burden is 3.2m, therefore 100% (11) of the burden spacing sets that had a non-continuous fracture profile were 3.2m or above. This value can therefore act as a limit for burden spacing.
- Of the 71 sets that were able to achieve continuous fracture profiles, 64 (90%) had a burden spacing less than 3.5m.
- When considering all the data sets with a burden spacing of 3.5m or less, it indicates that 98.5% (64 out of 65) achieved continuous fracture profiles.
- At a burden spacing of 3.1m and below, all sets (100%) achieved continuous fracture profiles.
- The maximum effective hole burden spacing is confirmed to be 3.0m, since all burdens below 3.1m achieved continuous fracture profiles.

The burden spacing sets were further analysed with regard to the depth of fracturing achieved. The linear average equations of fracture depth vs hole spacing determined at each site are given in Table 16.

The equations shown in Table 16 were then used to graphically plot the relationships for a burden range of interest of 2.0m to 3.5m at an increment of 0.25m. The results of the exercise are shown in Figure 78.

The linear average trendline with its equation can also be observed in Figure 78. The information in Figure 78 further illustrates that fracture depths decrease with an increase in hole burden spacing, as has been generally observed.

Table 16: Fracture Depth vs Burden Spacing Linear Equations

Site	Fracture Depth vs Hole Spacing Equation	Hole Spacing (m)						
		2.0	2.3	2.5	2.8	3.0	3.3	3.5
Site 1	$y = -0.85x + 7.1667$	5.47	5.25	5.04	4.83	4.62	4.40	4.19
Site 2	$y = 0.0391x + 4.1565$	4.23	4.24	4.25	4.26	4.27	4.28	4.29
Site 3	$y = -0.1493x + 4.5228$	4.22	4.19	4.15	4.11	4.07	4.04	4.00
Site 4	$y = -0.2051x + 5.9582$	5.55	5.50	5.45	5.39	5.34	5.29	5.24
Site 5	$y = -0.2319x + 6.0236$	5.56	5.50	5.44	5.39	5.33	5.27	5.21
Site 6	$y = -0.0037x + 5.0706$	5.06	5.06	5.06	5.06	5.06	5.06	5.06
Site 7	$y = -0.4748x + 7.0725$	6.12	6.00	5.89	5.77	5.65	5.53	5.41
Site 8	$y = -0.0044x + 5.1945$	5.19	5.18	5.18	5.18	5.18	5.18	5.18
Site 9	$y = -0.0739x + 4.7359$	4.59	4.57	4.55	4.53	4.51	4.50	4.48
Site 10	$y = -0.148x + 5.2457$	4.95	4.91	4.88	4.84	4.80	4.76	4.73
Average		5.09	5.04	4.99	4.94	4.88	4.83	4.78

It has been generally observed that the fracture depth increase achieved from reducing hole spacing below 3.0m has been little to insignificant. The trendline equation in Figure 78 indicates that for every 0.25m decrease in hole spacing, an increase of only 3cm will be achieved in the depth of fracture. This translates to about 6cm increase for a 0.5m hole spacing reduction. These figures confirm the general observations that reducing burden spacing below 3.0m achieves insignificant increase in fracture depths.

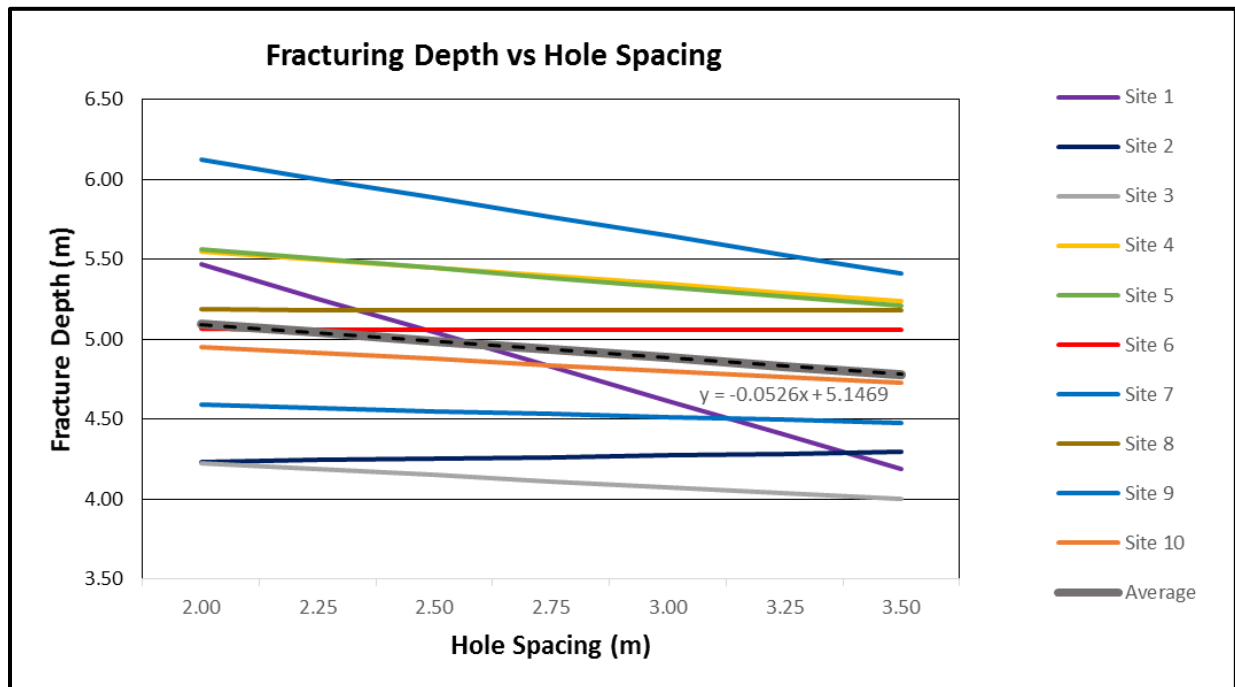


Figure 78: Fracture Depth vs Burden Spacing

The observations on hole spacing variation apply similarly to hole spacing increase when using Figure 78 in isolation. Even though there is a small decrease in fracture depth with an increase in hole spacing, there exists a limit, as indicated in Figure 77, to the hole spacing that can achieve a continuous fracture profile. It should be taken therefore that optimum hole spacing must be based on achievement of a continuous fracture profile, which indicated a limit of 3.1m and below.

7. CONCLUSIONS

The panel scan results were positive as they showed that the GPR method can be successfully applied to determine the effectiveness of preconditioning by determining the extent and intensity of fracturing ahead of the panel face.

The following conclusions can be drawn from the project work done:

- It was shown that the high fracturing indicated by the GPR results coincides with the position of the precon socket, which is as expected.
- The extent of the fractured rock ahead of the face can also be shown by the GPR system.
- The mine's fracture depth averages 5.0m which is above the 3.5m value shown on the GPR scan done during the GAP 336 project.
- The Mponeng mine preconditioning standard is adequate to achieve required fracture depth for effective preconditioning, therefore no need to amend the preconditioning hole length and spacing as used on the mine.
- The type of footwall does affect the depth of fracturing obtained, with the shale footwall panels achieving deeper fracturing than the quartzite footwall panels.
- Depth of fracturing has been shown to increase with increase in ERR values for the quartzite footwall sites. Therefore deeper fracturing ahead of the face can be expected as the stope matures.
- The expected rate of depth of fracture increase with stope maturity is 0.17m/ERR (MJ/m²), for quartzite footwall panels.
- The depth of fracturing for shale footwall sites indicates a decrease in fracture depth with an increase in ERR values. There is however reduced confidence in this analysis since only 3 data values were used.
- The GPR results were able to show the effect of preconditioning hole burden spacing on the fracturing. The precon burden spacing of 3.0m as used at Mponeng, is the effective spacing for achieving a continuous fracture profile ahead of the faces.

- There is a general increase in fracture depth when preconditioning hole burden spacing is reduced, however this benefit is insignificant at a range of 6cm increase in fracture depth for 0.5m preconditioning burden reduction. Burden spacing reduction does not significantly increase fracture depth, however it can be used to ensure a high percentage (up to 100%) probability of continuous fracture achievement.
- Where hole spacing is reduced to less than the 3.0m mine standard, the depth of fracturing is increased, and inversely wider preconditioning burden causes the depth of fracturing to be reduced.

In summary, the results of the research confirm the importance of adherence to the mine's preconditioning standard, to ensure the desired depth and continuity of fracturing along the full length of the stope face.

The following additional points on project work done should be noted:

- The effect of 3.0m long precon holes compared to 2.4m holes was not investigated since no panels using 3.0m long holes were available.
- No work on the influence of standing time on depth of fracturing was conducted as this cannot be done following the current project process. This will require a different methodology.
- The influence of high stoping width (>2.0m) was not investigated as no high stoping width panels were scanned.

8. RECOMMENDATIONS FOR FURTHER RESEARCH

The following recommendations related to preconditioning assessment must be considered for further research:

- Project sites using 3.0m long precon holes must be evaluated, to aid in assessing the difference in the depth of fracturing when using 2.4m and 3.0m hole lengths for the same footwall type, stope maturity and burden spacing.
- The influence of standing time on fracture depth and intensity must be done in a different project, where periodical scanning of a stopped panel can be done to determine the growth in fracture depth as a function of time.

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Appendix 1: Fracture Depth Evaluation Data

Site 1: 123-42-W4 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	5.0
0.5	4.9
1.0	4.8
1.5	4.7
2.0	4.5
2.5	4.9
3.0	4.6
3.5	4.3
4.0	4.3
4.5	4.3
5.0	4.2
5.5	4.1
6.0	4.1
6.5	4.1
7.0	4.6
7.5	4.3
8.0	4.7
8.5	4.7
9.0	5.4
9.5	5.3
10.0	4.1
10.5	4.6
11.0	5.6
11.5	5.8
12.0	6.1
12.5	6.6
13.0	6.2
13.5	6.3
14.0	6.1
14.5	6.1
15.0	5.9
15.5	5.8
16.0	5.6
Average	5.0
Minimum	4.1
Maximum	6.6

Site 2: 116-34-E7 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	4.6
0.5	4.7
1.0	4.6
1.5	4.4
2.0	4.6
2.5	4.4
3.0	4.5
3.5	4.3
4.0	4.2
4.5	4.5
5.0	4.1
5.5	5.3
6.0	4.4
6.5	4.5
7.0	3.8
7.5	4.7
8.0	4.0
8.5	4.9
9.0	4.2
9.5	4.5
10.0	4.3
10.5	4.0
11.0	4.5
11.5	3.8
12.0	4.0
12.5	3.9
13.0	3.7
13.5	4.3
14.0	4.7
14.5	4.5
15.0	4.6
15.5	4.4
16.0	4.8
16.5	4.5
17.0	4.3
17.5	4.1
18.0	3.9
18.5	5.1
19.0	4.5
19.5	4.5
20.0	4.4
20.5	4.7

Dist.(m)	Target Picks Depth(m)
21.0	4.8
21.5	4.5
22.0	4.8
22.5	5.0
23.0	4.5
23.5	5.0
24.0	4.7
24.5	4.5
25.0	4.6
25.5	4.5
26.0	4.1
26.5	4.7
27.0	4.7
Average	4.5
Minimum	3.7
Maximum	5.3

Site 3: 116-34-E4 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	4.2
0.5	3.6
1.0	4.2
1.5	4.2
2.0	4.2
2.5	4.2
3.0	4.2
3.5	4.2
4.0	4.1
4.5	4.0
5.0	3.8
5.5	3.8
6.0	3.9
6.6	4.2
7.0	4.3
7.6	4.4
8.0	4.1
8.5	4.5
9.0	4.5
9.5	4.2
10.0	4.4
10.5	4.4
11.0	4.6
11.5	4.3
12.0	4.3
12.5	3.6
13.0	4.2
13.5	4.5
14.0	4.3
14.5	4.1
15.0	3.8
15.5	3.5
16.0	3.5
15.5	3.5
17.0	3.3
17.5	3.6
18.0	3.2
18.5	3.5
19.0	3.8
19.5	4.0
20.0	3.7

Dist.(m)	Target Picks Depth(m)
20.5	4.0
21.0	3.9
21.5	3.6
22.0	3.5
22.5	4.0
23.0	4.3
23.5	4.1
24.0	4.1
24.5	4.3
25.0	4.3
25.5	4.2
26.0	4.2
26.5	4.1
27.0	4.4
27.5	4.2
28.0	4.4
28.5	4.1
29.0	4.3
29.5	4.4
30.0	4.4
30.5	4.4
31.0	4.4
31.5	4.4
32.0	4.4
32.5	4.6
33.0	4.1
Average	4.1
Minimum	3.2
Maximum	4.6

Site 4: 116-34-E3 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	5.0
0.5	4.9
1.0	5.0
1.5	4.7
2.0	4.8
2.5	5.0
3.0	5.1
3.5	5.4
4.0	5.4
4.5	5.3
5.0	5.4
5.5	5.1
6.0	5.1
6.5	5.2
7.0	5.7
7.5	5.4
8.0	5.1
8.5	5.1
9.0	5.2
9.5	5.2
10.0	5.1
10.5	5.3
11.0	5.2
11.5	5.3
12.0	5.3
12.5	5.3
13.0	5.4
13.5	5.2
14.0	5.2
14.5	5.3
15.0	5.3
15.5	5.3
16.0	5.2
16.5	5.2
17.0	5.2
17.5	5.2
18.0	5.2
18.5	5.2
19.0	5.2
19.5	5.1
20.0	5.1

Dist.(m)	Target Picks Depth(m)
20.5	5.2
21.0	5.0
21.5	5.0
22.0	5.2
22.5	5.0
23.0	5.0
23.5	4.8
24.0	4.3
24.5	4.2
25.0	4.2
25.5	3.9
26.0	3.8
Average	5.1
Minimum	3.8
Maximum	5.7

Site 5: 113-34-E5 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	6.2
0.5	5.8
1.0	5.6
1.5	5.7
2.0	5.6
2.5	5.2
3.0	5.6
3.5	5.7
4.0	6.3
4.5	5.5
5.0	6.7
5.5	5.7
6.0	6.0
6.5	4.7
7.0	5.2
7.5	4.6
8.0	4.7
8.5	4.6
9.0	4.2
9.5	4.2
10.0	3.7
10.5	4.5
11.0	4.4
11.5	4.6
12.0	4.1
12.5	4.6
13.0	3.8
13.5	3.7
14.0	3.7
14.5	3.9
15.0	3.7
15.5	3.7
16.0	3.7
16.5	3.8
17.0	4.1
17.5	5.7
18.0	5.4
18.5	5.3
19.0	5.8
19.5	5.4
20.0	5.4

Dist.(m)	Target Picks Depth(m)
20.5	6.0
21.0	5.9
21.5	5.6
22.0	5.9
22.5	5.5
23.0	5.0
23.5	4.5
24.0	4.6
24.5	4.9
25.0	5.6
25.5	5.3
26.0	5.1
26.5	5.4
27.0	5.1
27.5	4.8
28.0	4.8
28.5	4.8
29.0	4.3
29.5	5.5
30.0	5.6
Average	5.0
Minimum	3.7
Maximum	6.7

Site 6: 113-35-W2 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	4.7
0.5	5.3
1.0	5.0
1.5	4.8
2.0	5.0
2.5	5.0
3.0	5.2
3.5	5.1
4.0	5.2
4.5	4.8
5.0	4.7
5.5	4.6
6.0	4.8
6.5	4.7
7.0	4.7
7.5	5.0
8.0	4.9
8.5	5.1
9.0	5.4
9.5	5.3
10.0	5.6
10.5	5.6
11.0	5.6
11.5	5.2
12.0	5.3
12.5	5.1
13.0	4.8
13.5	5.0
14.0	5.0
14.5	4.9
15.0	5.1
15.5	5.0
16.0	4.9
16.5	5.1
17.0	5.0
17.5	4.9
18.0	5.3
18.5	5.1
19.0	4.9
19.5	4.8
20.0	5.1
20.5	4.8

Dist.(m)	Target Picks Depth(m)
20.5	4.8
21.0	4.5
21.5	4.4
22.0	4.6
22.5	4.6
23.0	4.5
23.5	4.8
24.0	4.5
24.5	4.5
25.0	4.5
25.5	4.4
26.0	4.8
26.5	4.5
27.0	4.9
27.5	4.8
28.0	4.8
28.5	4.7
29.0	4.8
29.5	5.0
30.0	5.0
Average	4.9
Minimum	4.4
Maximum	5.6

Site 7: 113-66-W2 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	4.8
0.5	5.2
1.0	4.8
1.5	4.8
2.0	4.7
2.5	4.8
3.0	4.8
3.5	4.7
4.0	4.6
4.5	6.3
5.0	6.1
5.5	5.0
6.0	5.0
6.5	5.1
7.0	5.7
7.5	5.2
8.0	5.1
8.5	5.6
9.0	5.1
9.5	4.9
10.0	4.8
10.5	4.5
11.0	4.5
11.5	4.5
12.0	4.5
12.5	4.3
13.0	4.4
13.5	4.5
14.0	4.3
14.5	4.5
15.0	4.5
15.5	5.0
16.0	5.5
16.5	5.4
17.0	5.6
17.5	5.6
18.0	5.7
18.5	5.7
19.0	5.8
19.5	6.0
20.0	6.0

Dist.(m)	Target Picks Depth(m)
20.5	5.7
21.0	5.6
21.5	5.4
22.0	5.9
22.5	5.4
23.0	5.4
23.5	5.3
24.0	5.6
24.5	5.5
25.0	5.2
25.5	5.3
26.0	5.4
26.5	5.6
27.0	5.6
27.5	5.8
28.0	5.8
28.5	5.6
29.0	5.8
29.5	6.9
30.0	6.3
30.5	6.7
31.0	6.6
31.5	6.6
32.0	6.8
32.5	6.5
33.0	6.5
33.5	6.6
34.0	6.9
34.5	7.0
35.0	7.0
35.5	6.9
36.0	6.8
Average	5.5
Minimum	4.3
Maximum	7.0

Site 8: 116-66-E2 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	5.1
0.5	5.0
1.0	4.7
1.5	4.6
2.0	4.7
2.5	4.7
3.0	4.6
3.5	4.5
4.0	4.5
4.5	4.5
5.0	5.2
5.5	5.2
6.0	4.8
6.5	4.6
7.0	4.7
7.5	4.6
8.0	4.7
8.5	5.1
9.0	4.7
9.5	4.6
10.0	4.7
10.5	5.4
11.0	5.4
11.5	5.1
12.0	5.0
12.5	5.4
13.0	5.1
13.5	5.7
14.0	5.5
14.5	5.6
15.0	5.2
15.5	4.9
16.0	5.3
16.5	4.5
17.0	4.8
17.5	6.0
18.0	6.1
18.5	5.8
19.0	5.8
19.5	5.2
20.0	5.7

Dist.(m)	Target Picks Depth(m)
20.5	5.9
21.0	5.7
21.5	5.6
22.0	5.2
Average	5.1
Minimum	4.5
Maximum	6.1

Site 9: 116-34-E5 Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	4.2
0.5	4.6
1.0	4.5
1.5	5.0
2.0	4.8
2.5	4.8
3.0	4.7
3.5	4.3
4.0	5.0
4.5	4.9
5.0	4.5
5.5	4.5
6.0	4.2
6.5	4.3
7.0	5.6
7.5	4.5
8.0	4.3
8.5	4.3
9.0	4.7
9.5	4.8
10.0	4.9
10.5	5.1
11.0	5.2
11.5	5.7
12.0	5.6
12.5	4.8
13.0	4.8
13.5	4.6
14.0	5.2
14.5	5.6
15.0	5.1
15.5	4.5
16.0	4.5
16.5	4.9
17.0	5.7
17.5	4.8
18.0	4.5
18.5	4.6
19.0	4.7
19.5	4.6
20.0	4.7

Dist.(m)	Target Picks Depth(m)
20.5	4.7
21.0	4.6
21.5	4.4
22.0	4.4
22.5	4.8
23.0	4.9
23.5	5.0
24.0	4.8
24.5	4.8
25.0	4.5
25.5	4.8
26.0	4.9
26.5	4.8
27.0	4.8
27.5	5.1
28.0	4.8
28.5	4.7
29.0	4.7
29.5	4.7
30.0	4.7
30.5	4.4
31.0	4.7
31.5	4.7
32.0	4.9
32.5	4.6
33.0	4.6
33.5	4.4
34.0	4.6
34.5	4.5
35.0	4.5
35.5	4.7
36.0	4.4
36.5	4.4
37.0	4.7
37.5	4.3
38.0	4.1
Average	4.7
Minimum	4.1
Maximum	5.7

Site 10: 120-65-W5A Depth data at 0.5m sampling spacing

Dist.(m)	Target Picks Depth(m)
0.0	5.0
0.5	4.1
1.0	5.0
1.5	5.4
2.0	5.2
2.5	4.7
3.0	4.4
3.5	4.8
4.0	4.6
4.5	4.8
5.0	4.3
5.5	4.6
6.0	4.8
6.5	4.6
7.0	5.0
7.5	4.8
8.0	4.6
8.5	5.1
9.0	5.2
9.5	5.3
10.0	5.4
10.5	5.3
11.0	5.2
11.5	4.8
12.0	4.8
12.5	4.8
13.0	4.8
13.5	4.7
14.0	4.7
14.5	4.3
15.0	4.9
15.5	4.7
16.0	4.6
16.5	4.9
17.0	5.2
17.5	4.5
18.0	4.7
18.5	5.0
19.0	5.1
19.5	5.2
20.0	5.5
Average	4.9
Minimum	4.1
Maximum	5.5

Appendix 2: Burden Spacing Evaluation Data

Site 1: 123-42-W4 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	4.9					
2	5.0	1 - 2	4.9	4.1	4.7	N
3	6.6	2 - 3	4.6	4.3	5.3	N
4	6.5	3 - 4	4.1	6.2	6.4	Y
Average	5.8					

Site 2: 116-34-E7 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	3.9					
2	4.1	1 - 2	2.8	4.1	4.0	Y
3	4.4	2 - 3	3.5	4.6	4.4	Y
4	4.1	3 - 4	3.1	4.6	4.4	Y
5	4.6	4 - 5	4.0	3.6	4.1	N
6	4.1	5 - 6	2.7	4.4	4.4	Y
7	4.4	6 - 7	2.7	4.6	4.4	Y
8	4.3	7 - 8	4.5	4.6	4.4	Y
9	3.9	8 - 9	1.8	4.1	4.2	Y
Average	4.2			4.3		

Site 3: 116-34-E4 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	4.1					
2	4.4	1 - 2	2.1	4.3	4.3	Y
3	4.2	2 - 3	3.0	4.2	4.1	Y
4	4.4	3 - 4	3.0	4.7	4.4	Y
5	4.3	4 - 5	3.1	4.4	4.4	Y
6	4.2	5 - 6	1.7	3.6	4.0	Y
7	3.2	6 - 7	3.7	3.5	3.6	Y
8	4.0	7 - 8	3.0	3.5	3.6	Y
9	4.0	8 - 9	3.0	3.6	3.9	Y
10	4.2	9 - 10	3.3	4.4	4.2	Y
11	4.4	10 - 11	3.3	3.9	4.2	Y
12	4.4	11 - 12	2.4	4.4	4.4	Y
Average	4.2			4.0		

Site 4: 116-34-E3 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	5.0					
2	5.3	1 - 2	3.2	4.9	5.1	N
3	5.8	2 - 3	2.8	5.2	5.4	Y
4	5.3	3 - 4	3.0	5.2	5.4	Y
5	5.6	4 - 5	3.0	5.3	5.4	Y
6	5.4	5 - 6	3.3	5.3	5.4	Y
7	5.4	6 - 7	2.7	5.3	5.4	Y
8	5.2	7 - 8	3.0	5.2	5.3	Y
Average	5.4			5.2		

Site 5: 113-34-E5 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	6.0					
2	6.8	1 - 2	2.8	5.7	6.2	Y
3	4.0	2 - 3	6.3	4.4	5.1	N
4	3.8	3 - 4	4.0	4.0	3.9	N
5	5.6	4 - 5	3.8	3.8	4.4	N
6	6.2	5 - 6	2.9	5.5	5.8	Y
7	5.1	6 - 7	3.6	5.3	5.5	Y
8	5.5	7 - 8	2.3	5.5	5.4	Y
9	5.7	8 - 9	3.0	4.7	5.3	Y
Average	5.4			4.9		

Site 6: 113-35-W2 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	4.9					
2	5.4	1 - 2	3.0	4.9	5.1	Y
3	5.0	2 - 3	2.1	4.9	5.1	Y
4	5.2	3 - 4	3.3	5.0	5.1	Y
5	5.3	4 - 5	3.1	5.5	5.3	Y
6	5.0	5 - 6	3.2	4.9	5.1	Y
7	5.1	6 - 7	4.4	5.0	5.0	Y
8	5.1	7 - 8	3.3	4.5	4.9	Y
9	5.1	8 - 9	2.5	4.5	4.9	Y
10	5.2	9 - 10	2.7	4.9	5.1	Y
Average	5.1			4.9		

Site 7: 113-66-W2 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	4.8					
2	5.6	1 - 2	2.7	4.6	5.0	Y
3	5.6	2 - 3	4.0	5.2	5.5	Y
4	4.5	3 - 4	3.3	4.1	4.7	Y
5	5.0	4 - 5	4.1	4.1	4.5	N
6	6.2	5 - 6	3.2	5.6	5.6	Y
7	5.7	6 - 7	2.5	6.0	6.0	Y
8	5.7	7 - 8	2.8	5.5	5.6	Y
9	6.0	8 - 9	2.2	5.2	5.6	Y
10	7.0	9 - 10	3.0	6.0	6.3	Y
11	6.4	10 - 11	3.4	6.4	6.6	Y
12	7.0	11 - 12	2.0	6.2	6.5	Y
Average	5.8			5.4		

Site 8: 116-66-E2 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	5.1					
2	5.2	1 - 2	3.0	4.9	5.1	Y
3	5.1	2 - 3	2.6	5.0	5.1	Y
4	5.3	3 - 4	2.3	4.8	5.1	Y
5	5.6	4 - 5	2.6	4.8	5.2	Y
6	5.6	5 - 6	2.5	5.2	5.5	Y
7	5.5	6 - 7	5.5	4.3	5.1	N
8	5.3	7 - 8	2.9	6.0	5.6	Y
Average	5.3			5.0		

Site 9: 116-34-E5 Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	4.4					
2	4.1	1 - 2	5.7	4.1	4.2	N
3	4.4	2 - 3	2.9	4.8	4.4	Y
4	4.6	3 - 4	2.3	4.5	4.5	Y
5	4.5	4 - 5	2.6	4.5	4.5	Y
6	4.6	5 - 6	4.0	4.5	4.5	N
7	4.5	6 - 7	3.7	4.5	4.5	Y
8	4.6	7 - 8	2.7	4.6	4.6	Y
9	4.8	8 - 9	3.0	4.4	4.6	Y
10	4.6	9 - 10	3.0	4.5	4.6	Y
11	4.3	10 - 11	3.4	4.5	4.5	Y
12	4.8	11 - 12	1.8	4.4	4.5	Y
Average	4.5			4.5		

Site 10: 120-65-W5A Hole spacing and evaluation data

Precon Socket No.	Fracture Depth at Socket Position (m)	Hole Spacing Set	Spacing Between Sockets (m)	Fracture Depth at Spacing Set Midpoint (m)	Average Fracture Depth in Spacing Set (m)	Continuous Fracturing (Y/N)
1	4.7					
2	4.9	1 - 2	1.8	5.4	5.0	Y
3	4.6	2 - 3	2.6	4.8	4.8	Y
4	4.9	3 - 4	3.2	4.3	4.6	Y
5	4.9	4 - 5	3.3	5.2	5.0	Y
6	4.8	5 - 6	2.9	4.6	4.8	Y
7	4.8	6 - 7	3.0	4.4	4.7	Y
8	5.4	7 - 8	2.7	4.9	5.0	Y
Average	4.9			4.8		

Appendix 3: Burden Spacing Analyses Data

No.	Set ID	Spacing Between Sockets (m)	Continuous Fracturing (Y/N)
1	C5	1.7	Y
2	B8	1.8	Y
3	I11	1.8	Y
4	J1	1.8	Y
5	G11	2.0	Y
6	C1	2.1	Y
7	F2	2.1	Y
8	G8	2.2	Y
9	E7	2.3	Y
10	H3	2.3	Y
11	I3	2.3	Y
12	C11	2.4	Y
13	F8	2.5	Y
14	G6	2.5	Y
15	H5	2.5	Y
16	H2	2.6	Y
17	H4	2.6	Y
18	I4	2.6	Y
19	J2	2.6	Y
20	B5	2.7	Y
21	B6	2.7	Y
22	D6	2.7	Y
23	F9	2.7	Y
24	G1	2.7	Y
25	I7	2.7	Y
26	J7	2.7	Y
27	B1	2.8	Y
28	D2	2.8	Y
29	E1	2.8	Y
30	G7	2.8	Y
31	E5	2.9	Y
32	H7	2.9	Y
33	I2	2.9	Y
34	J5	2.9	Y
35	C2	3.0	Y
36	C3	3.0	Y
37	C7	3.0	Y
38	C8	3.0	Y
39	D3	3.0	Y

No.	Set ID	Spacing Between Sockets (m)	Continuous Fracturing (Y/N)
40	D4	3.0	Y
41	D7	3.0	Y
42	E8	3.0	Y
43	F1	3.0	Y
44	G9	3.0	Y
45	H1	3.0	Y
46	I8	3.0	Y
47	I9	3.0	Y
48	J6	3.0	Y
49	B3	3.1	Y
50	C4	3.1	Y
51	F4	3.1	Y
54	G5	3.2	Y
53	F5	3.2	Y
55	J3	3.2	Y
52	D1	3.2	N
56	C10	3.3	Y
57	C9	3.3	Y
58	D5	3.3	Y
59	F3	3.3	Y
60	F7	3.3	Y
61	G3	3.3	Y
62	J4	3.3	Y
63	G10	3.4	Y
64	I10	3.4	Y
65	B2	3.5	Y
66	E6	3.6	Y
67	C6	3.7	Y
68	I6	3.7	N
69	E4	3.8	N
70	B4	4.0	N
71	E3	4.0	N
72	G2	4.0	Y
73	I5	4.0	Y
74	A3	4.1	Y
75	G4	4.1	N
76	F6	4.4	Y
77	B7	4.5	Y
78	A2	4.6	N
79	A1	4.9	N
80	H6	5.5	N
81	I1	5.7	N
82	E2	6.3	N

Appendix 4: Mponeng Mine 2003 Preconditioning Campaign

Passport to preconditioning

Nobody comes to Mponeng to get injured

The problem

The mining of reefs at depths induces extremely high stresses in the rockmass in the vicinity of any excavation. In slopes, in particular, such high stresses induced by mining increase the strain energy stored in the rockmass. The violent release of accumulated strain energy may result in a rockburst, with its severity depending on the event magnitude, the distance between the source and the excavation and ground conditions around that excavation. A seismic event can cause extensive damage to underground workings, and injures and even fatalities.

What is a "faceburst"?

The violent release of accumulated strain energy causes the ejection of rock from mining faces into the mine openings at a very high velocity. This is called a "faceburst".

What is preconditioning?

Preconditioning, also called "destress blasting", is a rockburst control technique that involves setting off designed blasting ahead of the slope face. By doing so, it re-mobilises the existing fractures in the rockmass and prevents the accumulation of strain energy ahead of the working face. The stress redistribution away from the working face, due to preconditioning blasts provides a low-

stress cushion ahead of the slope face that is able to absorb the energy of a seismic event.

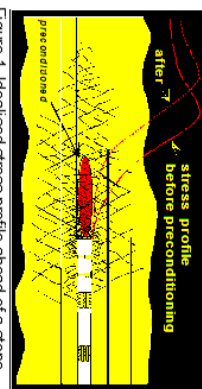


Figure 1. Idealised stress profile ahead of a slope face and intended stress transfer by preconditioning

The preconditioning technique involves the drilling and blasting of longer face-perpendicular holes as an integral part of the actual production blast cycle. Face perpendicular preconditioning is suited to normal production faces as it integrates well into the mining cycle.

Layout

Face preconditioning uses standard diameter blastholes drilled perpendicular to the slope face to a depth of minimum 2,4 m and fired as an integral part of the production blast. The spacing between preconditioning holes is 3 m maximum measured along the face of the panel.

The standard for pre-conditioning is illustrated in Figure 3.

Positioning the preconditioning holes

The preconditioning holes should be drilled at right angles to the face and at about midway between the hanging wall and footwall contact. (For stopping widths up to 150cm) Figure 4 illustrates the relative positions of the preconditioning and production holes. The closest point between the production and the preconditioning holes is at the collar and, when properly drilled, the production holes are drilled away from the preconditioning holes. Figure 4 is a cross-section ahead of the slope face, illustrating the relative positions of the production and preconditioning holes.

Charging?

Explosives must be charged in the front 1m of the hole, with the remaining of the hole being stemmed as shown in Figure 4. The detonation of preconditioning holes must be by top-priming the explosive charge, to facilitate removal of primers from misfired preconditioning holes.

Stemming?

Stemming is very important as an effective stemming will maximise the stemming retention time, which will contain the explosive energy in the hole as long as possible. The stemming also helps to protect the detonator and ensures that the primer cartridge remains in place while neighbouring holes are firing.

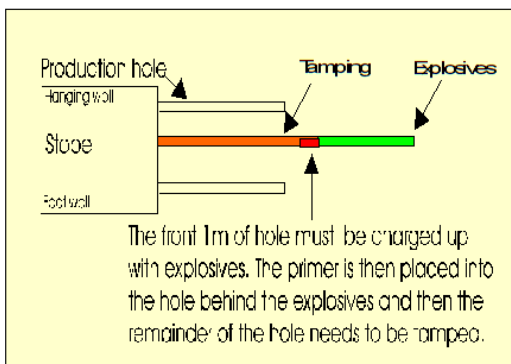


Figure 4: Charging up of pre-condition holes

The preconditioning holes are drilled together with the production holes and blasted.

Once the face is cleaned and made safe. The marking of the next round of hole can be done.

The preconditioning holes must be offset at least 50cm from the sockets of the previous day's preconditioning holes.

Using this system, the panel face is advanced at least 3 m during these three blast cycles. Thus, the preconditioning holes on the third day are drilled in the same positions as on the first day, as the face has advanced beyond the ends of those holes.

Detonation sequence?

Since the preconditioning holes are blasted as part of the production blast round, timing of them relative to production blastholes is very important and any mistiming may lead to ineffective preconditioning and/or misfires.

Regardless of the type of initiation system is used, the common rule is that each preconditioning hole must be initiated with a minimum of 1 m burden before the neighbouring production holes were fired. This means that the timing must be three holes ahead of the normal production holes.

Handling of Misfires?

In addition to the requirement to examine the production holes for the possibility of misfires, the sockets of the preconditioning holes must also be examined after each blast. Every preconditioning hole should be identified, treated, marked in the case of misfire, and plugged in the case of a socket.

When encountering a down roll?

When a roll is encountered, the pre-condition holes need to be marked off lower on the face and drilled at an angle down to prevent the pre-conditioning from damaging the hanging wall.

Higher stopping widths?

When the slope width exceeds 1,5m the position of the pre-condition hole needs to be approximately 50cm from the hanging wall contact.

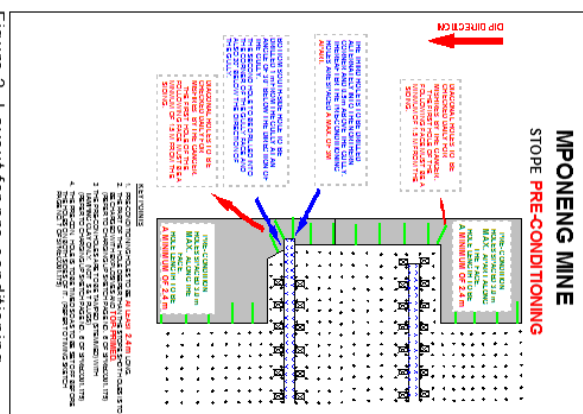


Figure 3. Layout for pre-conditioning

Passport to preconditioning
What are the benefits of preconditioning?

The benefits of preconditioning are as follows:

- Minimised / eliminated face burst hazard
- Reduced damage by distant seismic events
- Reduced accident / injury rate (seismicity, f.o.g.)
- Improved hanging wall conditions (Figure 5)
- Better stopping width control
- Improved face conditions (clean and straight break, no sockets)
- Improved hangingwall fracturing (less shallow dipping fractures)
- Increased face advance per blast
- Increased drilling rate
- Reduced fragment size of blasted reef
- Reduced dilution
- Reduced stopping cost
- Increased workers morale