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The effectiveness of preconditioning: utilising mXrap for analysing data and transforming raw scans into a functional database

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Abstract

Preconditioning in mining face areas prone to strainbursting is one of the most effective controls available to the geotechnical engineer. Although historical studies have focused on conventional narrow-reef tabular mining, the same outcomes can be assumed for high-profile de-stress excavations as utilised at Gold Fields' South Deep mine, i.e. 6 × 5.5 m (width to height). As a concept, preconditioning dates to the early 1950s, indicating its longstanding relevance in mining operations. South Deep utilises a face perpendicular preconditioning technique which is 1.5 m longer than the normal blast round.

In contemporary mining operations, the effective utilisation of data plays a pivotal role in enhancing safety protocols and operational efficiency. This paper delves into the use of an IGM Geotechnical (IGM) mXrap application for visualising (the interface) and analysing data collected underground using the Sub-Surface Profiler (SSP). The application specifically focuses on transforming raw scans into functional data, which helps in assessing the effectiveness of face preconditioning.

Through a combination of case studies (including the use of borehole cameras in the calibration phase) and theoretical analysis, the tangible benefits of employing the IGM application/mXrap, including improved accuracy, reduced processing time and enhanced decision-making capabilities for determining face preconditioning accuracy using a non-invasive method like the SSP, are showcased. Additionally, the integration of mXrap into existing mining frameworks is discussed and potential avenues for further development are highlighted. The findings presented underscore the significance of leveraging technology to optimise preconditioning processes and procedures to pave the way for a safer and more efficient mining operation.

Keywords: *preconditioning, de-stress, Sub-Surface Profiler, scans, surveys, borehole camera, borehole logging, database, mXrap*

1 Introduction

Currently, South Deep (SD) is mining at depths nearing 3,000 m below surface and will soon descend further during the exploitation of the South of Wrench mining block. At these depths, the stresses around the excavation (de-stress ends) are significantly elevated, generating significant seismic hazard which could lead to damaging events. Although the mine has made considerable efforts to minimise the presence of personnel at the face for extended periods, mitigating the severity of potential rockbursts remains crucial.

One of the key strategies employed at SD to mitigate the inherent risk of rockbursts is the utilisation of a face perpendicular preconditioning technique. This technique, alongside the use of face support

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(e.g. 5 mm gauge × 100 mm aperture-yielding perimeter welded mesh and 2.4 m-long splitsets), aims to reduce the likelihood and severity of rockbursts. Additionally, the Sub-Surface Profiler (SSP) a ground penetrating radar (GPR) tool, was introduced at SD in 2016. Over time, the SSP has undergone various developments and enhancements to improve practicality, scan resolution and penetration depth into the face. A crucial factor in using the SSP tool was the confidence in its applicability at advancing development faces where welded mesh was installed.

To assess the effectiveness of preconditioning in high-profile de-stressing cuts, a calibration project was completed in which observation holes in the development face were used to calibrate the SSP data. SSP scans are non-intrusive and therefore some constants (e.g. dielectric) must be calibrated for the rock mass.

Mine-wide de-stressing is achieved by mining out portions of ground to divert stress further into solid rock through a modified bord and pillar method with crush pillars, referred to as a de-stress cut, that allows longhole stoping to be undertaken in its stress shadow. An illustration of this method is shown in Figure 1, with advancing de-stress ends and longhole stoping taking place in the de-stress shadow.

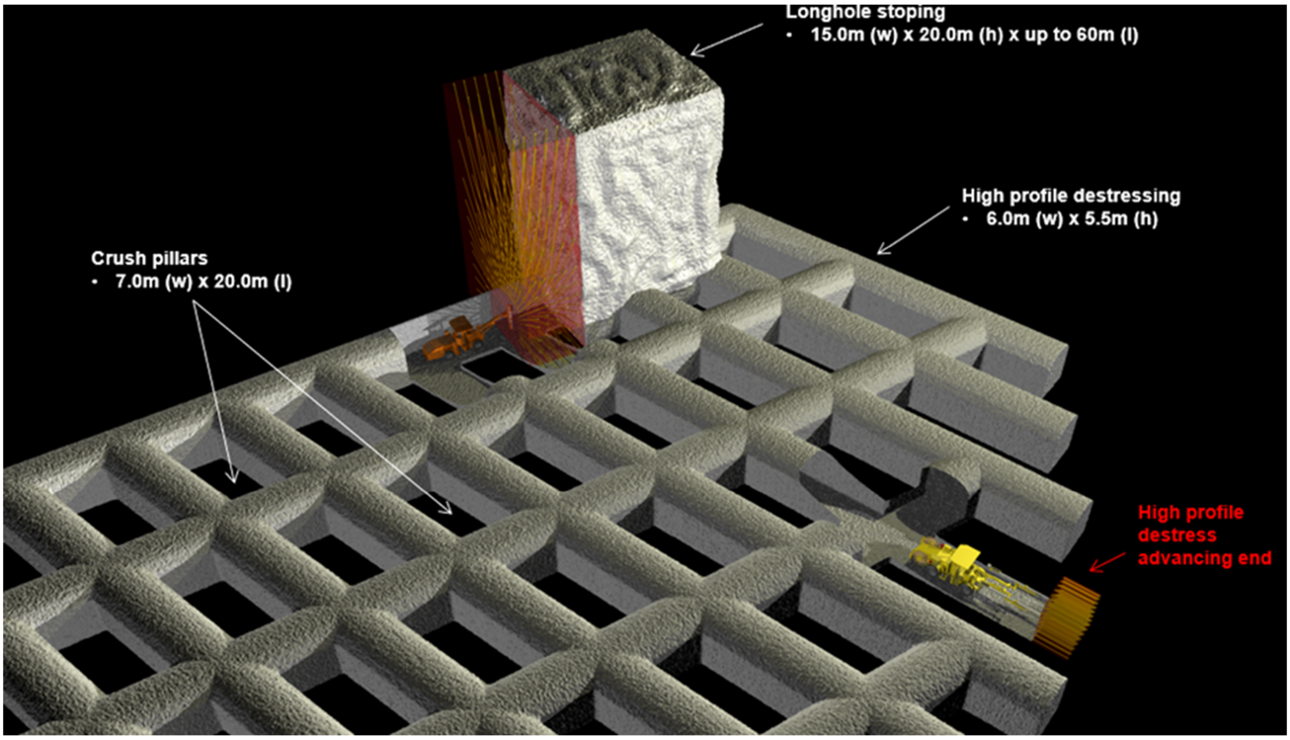


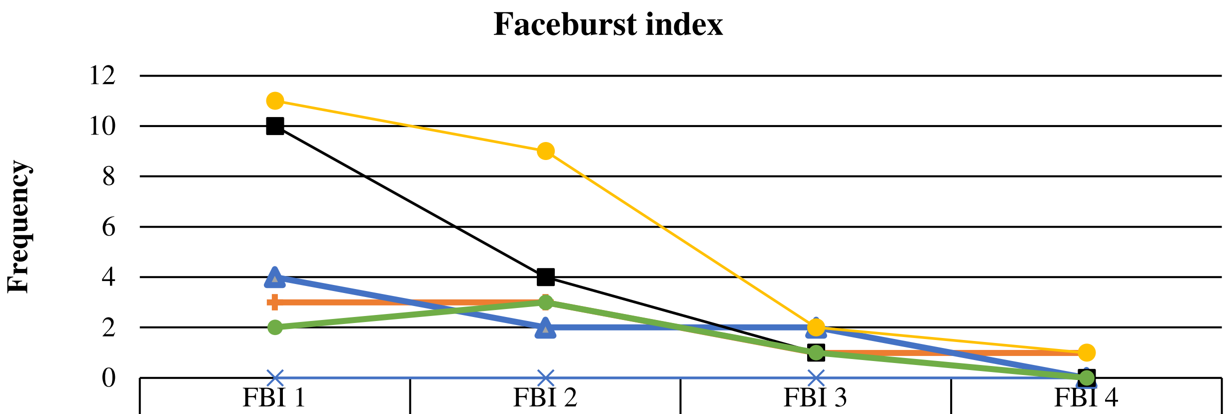
Figure 1 Bord and pillar de-stressing mining method and subsequent longhole stoping in a low-stress environment

Since the inception of the preconditioning concept at SD, the verification has predominantly been carried out visually. This renders it heavily reliant on the experience of the person observing the face, which introduces subjectivity as to whether effective preconditioning was achieved. GPR measurements allow practitioners to evaluate the effectiveness of preconditioning through a non-invasive method. However, such a method must be calibrated as the instrumentation is sensitive to user settings and lithology type. It was observed that despite the available preset feature, the scan results are highly reliant on the user, especially given the sensitive settings of the SSP and varying rock types within the massive deposit exploited by the mine.

The challenges mentioned are not exclusive to SD and have been deliberated by Kgarume et al. (2019). They compiled a list of challenges, which included the main difference between the traditional 2D GPR method and a 3D approach. The latter was suggested to provide decision-makers with more comprehensive information. To minimise bias, a tool that can graphically distinguish the quality of preconditioning is presented through an IGM Geotechnical (IGM) application using the mXrap interface, providing an opportunity for direct transfer of SSP data.

1.1 Seismic setting

In high-stress mining settings the rock can fail violently, which can lead to damaged excavations. A failure like this is called a rockburst and it can have a significant impact on the mine's safety and economics. For high-stress development ends, rockbursts tend to be driven by strain release and therefore are typically called strainbursts or facebursts. Since preconditioning was implemented as one of the risk management techniques at SD de-stress ends there has been a noticeable decrease in the severity and extent of facebursts rather than a regression in the number of rockburst incidents. The faceburst index (FBI) classification relates seismic damage to the effectiveness of the installed support. In this system FBI1 indicates no damage while FBI4 signifies completely damaged and thus ineffective support. This trend, depicted in Figure 2 and initially outlined by Heal et al. (2006) and later modified by Gouvea & Du Plessis (2022), underscores the effectiveness of preconditioning at reducing the severity of facebursts. This showcases the importance of effective preconditioning, and the need for a method to ensure the QA/QC and empower the operator at the face.



	FBI 1	FBI 2	FBI 3	FBI 4
2018	0	0	0	0
2019	3	3	1	1
2020	4	2	2	0
2021	11	9	2	1
2022	10	4	1	0
2023	2	3	1	0

Damage rating

Figure 2 Faceburst index (FBI) damage classification for the period from January 2018 to December 2023

2 Preconditioning at South Deep

The bulk of the SSP scans were collected in 2022, with a minimum of 30 scans achieved per month. The SSP scan data was accompanied by borehole logging for calibration purposes. This data was ultimately used in the calibration process of the SSP instrumentation.

The perimeter-yielding welded mesh used at the de-stress faces has the potential to distort the scan results by interfering with the SSP signal. The first point of departure was to investigate whether the SSP was an appropriate tool to use for a rock-fracturing assessment in high-stress excavations where welded mesh was installed. SSP data acquisition, borehole logging and visualisation will be discussed in this section. The preconditioning journey towards improved safety at the face area is depicted in Figure 3.

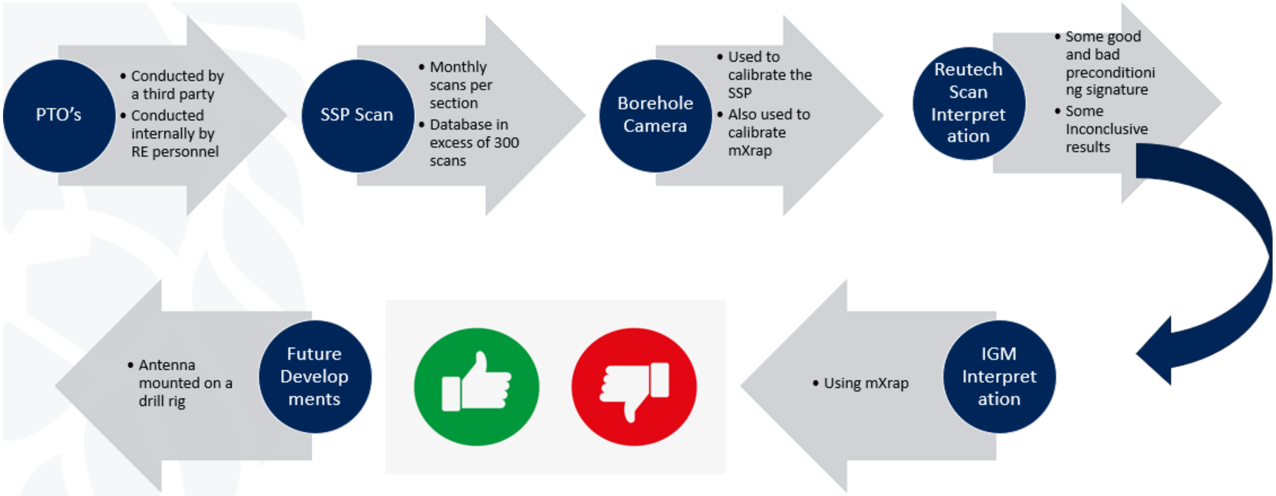


Figure 3 **Preconditioning tool journey showing significant milestones reached in the pursuit of improved safety in advancing de-stress ends**

2.1 Baseline study on varying mesh aperture size

The SSP is a frequency modulated continuous wave system which generates a frequency sweep (Reutech Mining 2022). One of the challenges when using the SSP instrument is the impact of welded mesh installed on the scanned faces. The metal composition of the mesh has the potential to distort the scan results by interfering with the SSP signal. In a study undertaken by Gold Fields South Africa in collaboration with Reutech Mining (Reutech Mining 2022), SSP wavelengths were tested to determine how much the returns are impacted by the welded mesh interface. It was found that when the wavelength is too long it cannot pass through welded mesh, thus the signal is filtered, or even blocked in some instances, depending on the mesh's aperture size.

To understand how the mesh might distort a scan, a set of experiments was carried out using welded meshes of various aperture sizes commonly used in the gold mining industry. A baseline scan was produced by scanning a granite bench with known geological features and without any mesh, as shown in Figure 4.

Figure 4 **Granite bench with identifiable geological structures used in a baseline scan to investigate the impact of mesh aperture size**

2.2 Survey scans data acquisition

Traditional GPRs operate in one of two ways: pulsed or stepped frequencies (Persico 2014). The latter, which is true of an SSP, breaks down the electromagnetic pulse into its spectral components and then emits them in a sequential manner. The scans' data acquisition was based on existing preconditioning standards, as shown in Figure 3, with each SSP survey totalling five scans at each site. The configuration of the survey is such that there is contact between the vertical and horizontal scans.

To facilitate data acquisition the following activities were maintained:

- Mapping of significant geological structures to better understand what was ahead of the advancing face (dip, extent and orientation).
- Extensive planned task observations focusing on each activity prior to the blasting of preconditioning holes (marking, drilling, charging up, tamping and timing of the face).

Data acquisition was carried out using an SSP with frequencies that vary between 300 MHz and 1 GHz. This frequency range ensures good resolution up to a depth of 10 m. The characteristics of the medium, particularly its dielectric properties, determine both the velocity of the GPR signals within the material and how these signals behave when encountering interfaces (Markovaara-Koivisto et al. 2014). The site-specific dielectric constant used was 17.2, after an extensive calibration process involving known hole characteristics.

2.3 Borehole logging

To gain in situ sub-surface information, borehole logging was undertaken through the drilling of 89 mm-diameter, 10 m-long holes at the advancing de-stress ends. Two holes were drilled, spaced 2.0 m apart at the grade line elevation, as part of the normal blast round (Figure 5a). The method of assessment is described in Figure 5b, using the fracture frequency as the criterion to determine the degree of preconditioning at the face.

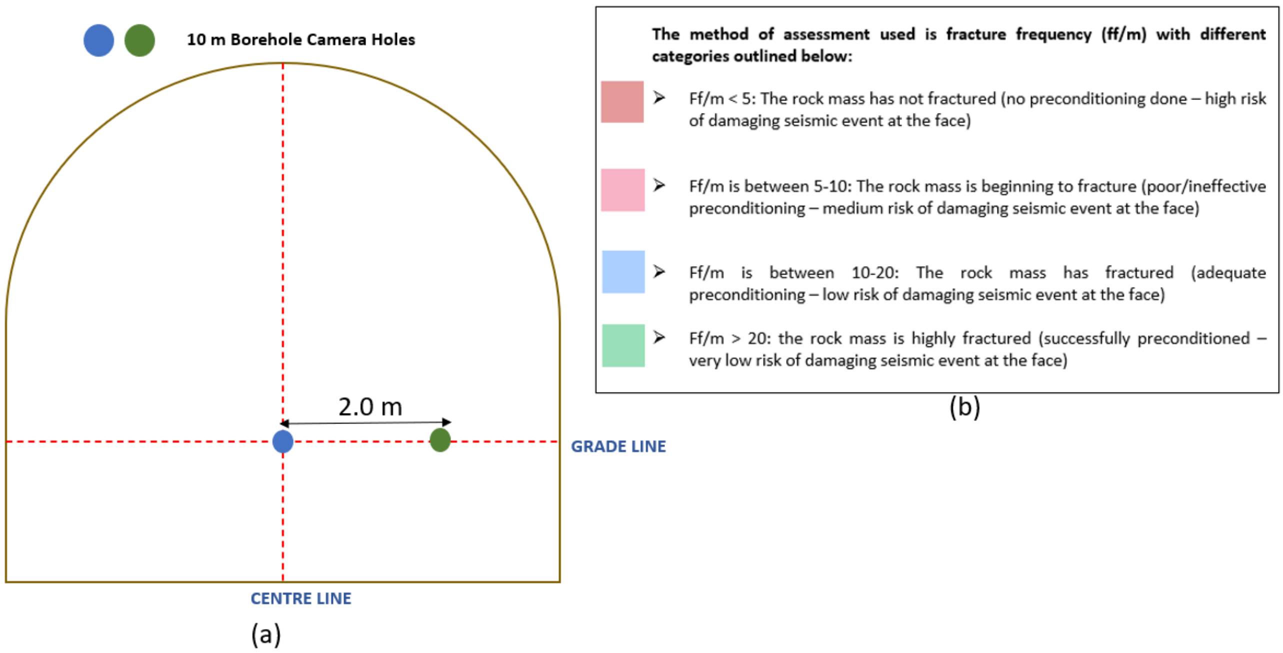


Figure 5 Borehole logging: (a) position of drilled boreholes; (b) method of fracture frequency assessment to determine the effectiveness of preconditioning

2.4 Face perpendicular preconditioning

As part of the design layout, SD employs flat lead/lag distances (ranging from 0 to 6 m) to concentrate high stresses directly in front of, and immediately ahead of, the face. A technique involving face perpendicular preconditioning is utilised to disperse these high stresses further into the face. The rationale behind this technique was based on the concept that drilling holes perpendicular to the surface would increase the depth of fracturing (Toper et al. 2000). Moreover, in the event of sudden failure occurring in the high-stress region, any resulting damage would be contained due to the cushioning effect provided by preconditioning.

Toper et al. (1998) suggested, based on their study of preconditioning mechanisms, that the objective of a preconditioning blast is not to generate new fractures as a fracture zone under face stress already exists ahead of the face. Figure 6 illustrates the preconditioning technique utilised at the mine, which involved the use of five holes arranged in a staggered pattern of three by two on consecutive blasts. Each hole has a length of 4.5 m, with 1 m from the toe being charged and top primed, 0.3 m reserved for gassing, and the remaining length of the hole being tamped.

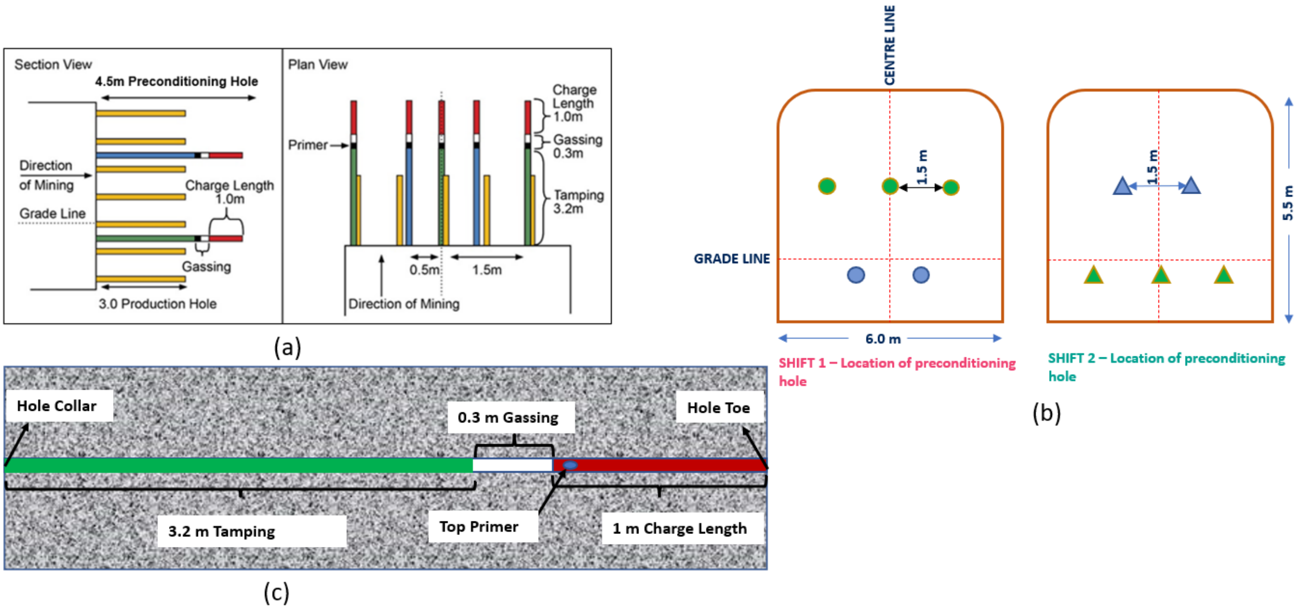


Figure 6 Face perpendicular preconditioning: (a) Section and plan view showing preconditioning holes relative to the production round; (b) Front view showing preconditioning holes with a pattern staggered per successive shifts/blast; (c) Enlarged view of preconditioning hole showing the contents required to blast

2.5 Post-processing of data

To ensure that the SSP data can be used to make consistent decisions it must be calibrated to the borehole data, resulting in a calibration algorithm with fracture density (or equivalent) as an output. This is not currently achieved as the SSP software produces pictures requiring geotechnical interpretation. Further to this, the software aims to identify significant structures and not minor structures, which would be associated with rock mass fracturing. Third party software had to be developed to eliminate these short comings and achieve the required outcomes, particularly those involving estimation of the rock mass condition immediately ahead of the face.

The current procedure for importing data into the IGM application is to export the SSP data in an E57 file format, import this into CloudCompare, export it as CSV and, finally, import it into the IGM app. Ultimately, the IGM app will also ensure SD can maintain a database for easier statistical analysis and periodic compliance checks. The app relates the return signal intensity to fracture abundance. As noted by Ortega et al. (2006), traditional measurement methods inadequately address intensity because they fail to account for the diverse range of fracture sizes within the material of interest. The intensity ranges considered by the SSP software begin at 0.5 to 1, thereby excluding any fractures that fall outside of this range.

3 Results

3.1 Scanning through welded mesh

SSP scanning was performed across square aperture mesh of various sizes (25 to 100 mm), as depicted in Figure 7. The findings indicate a direct correlation between the size of the aperture and the distortion of the SSP signal, with larger apertures resulting in less signal interference from the metal. Among the tested sizes, the 100 mm aperture square mesh closely resembled the baseline scans, exhibiting minimal signal distortions. Despite the presence of the mesh, geological structures remained distinguishable, even directly beneath the mesh sheet. The grid pattern from the mesh was consistently visible at the top of the scan images across all mesh scans.

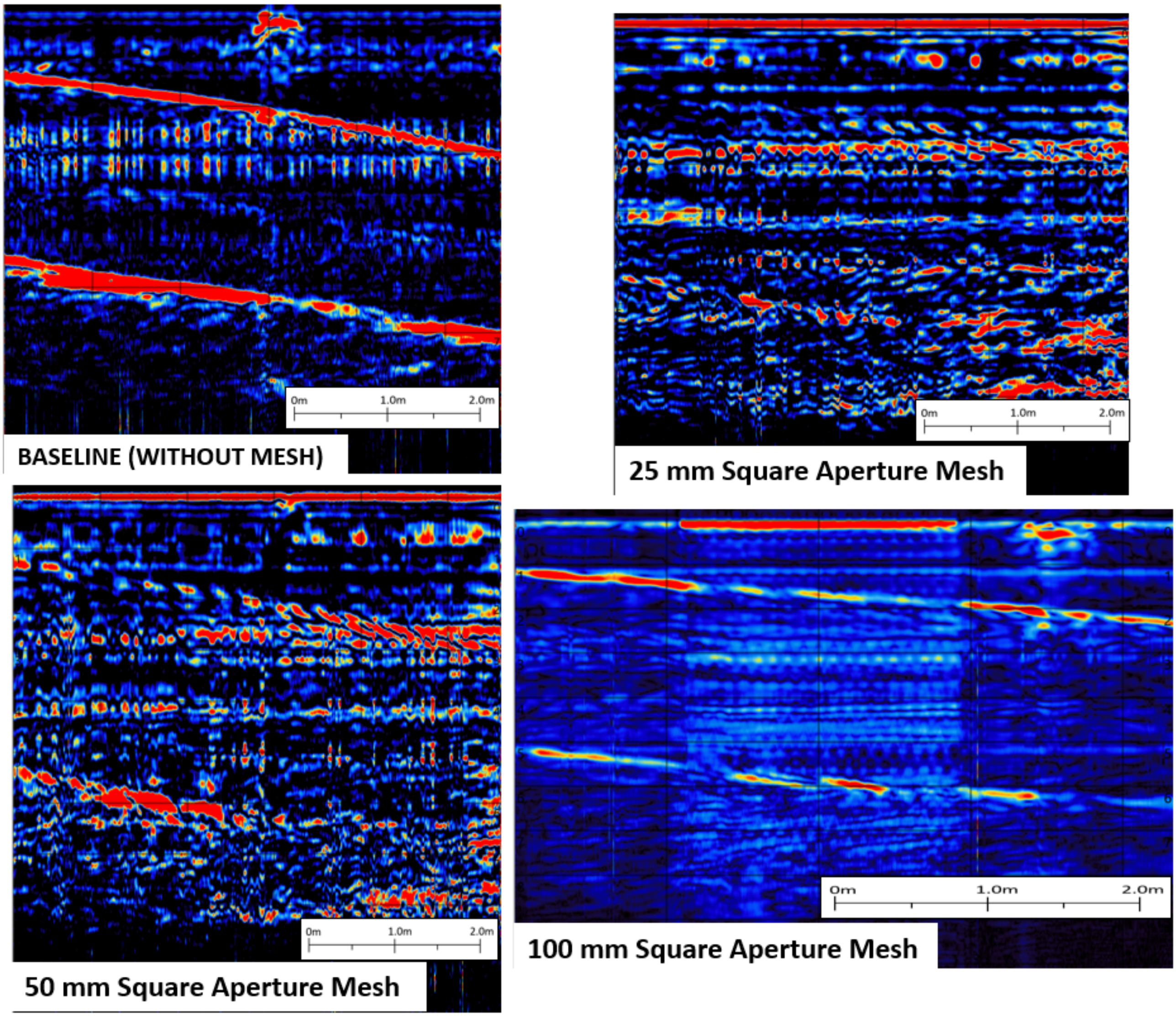


Figure 7 Scanning through mesh showing an improved signal with increasing aperture size square mesh

Additionally, a 200 mm aperture square mesh was included in the study to further explore the relationship between aperture size and signal distortion. Although not commonly used in South African deep gold mining, this larger aperture size yielded superior results, enhancing understanding of signal behaviour in relation to mesh aperture square size. This phenomenon is illustrated in Figure 8.

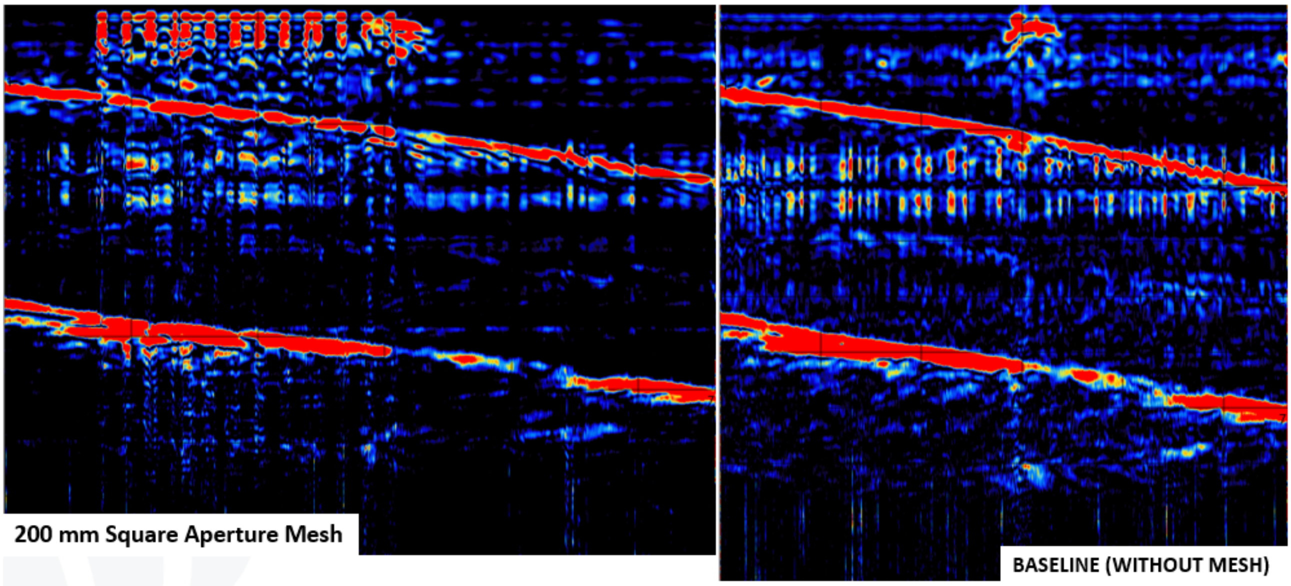


Figure 8 Scanning through mesh showing an improved signal with a minimal effect of welded mesh metal on the SSP signal

3.2 Calibration

The borehole camera-recorded holes were drilled into the mining face and show highly fractured/pulverised/crushed ground from the immediate collar up to 0.6 m. Adequate fracturing was observed from 0.6 m to about 3.0 m. A fracture zone with open discontinuities can be seen from 3.2 m to 5 m. Beyond the 5.0 m mark, the rock mass appears to be more competent/solid/intact, with minimal fractures observed, as depicted in Figure 9.

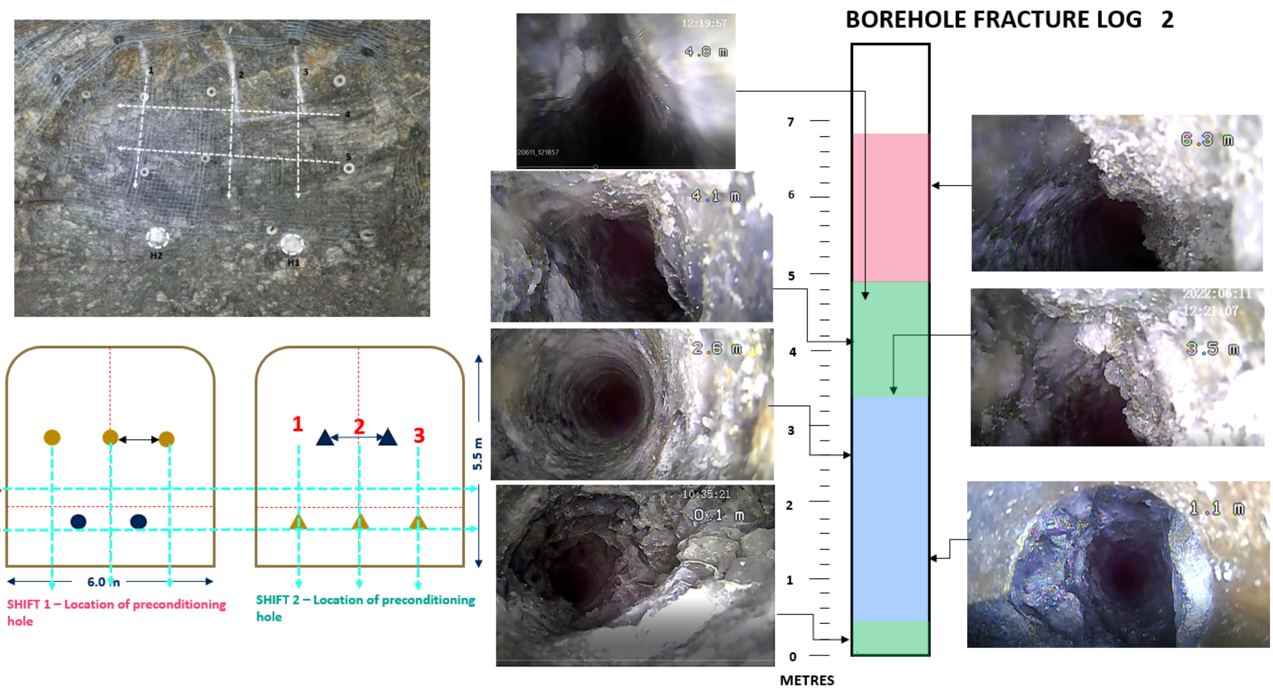


Figure 9 Borehole camera position at a de-stress end face, with snapshots showing fracture conditions along the length of the hole

The borehole data was double-checked against the SSP scans to ascertain that what was observed in the hole agreed with sub-surface profiling. Figure 10 shows scan results of the same face through which a borehole was drilled. The scan results agreed with the borehole visual analysis. At this stage it was with increased confidence that the data was exported to mXrap for a more visual representation.

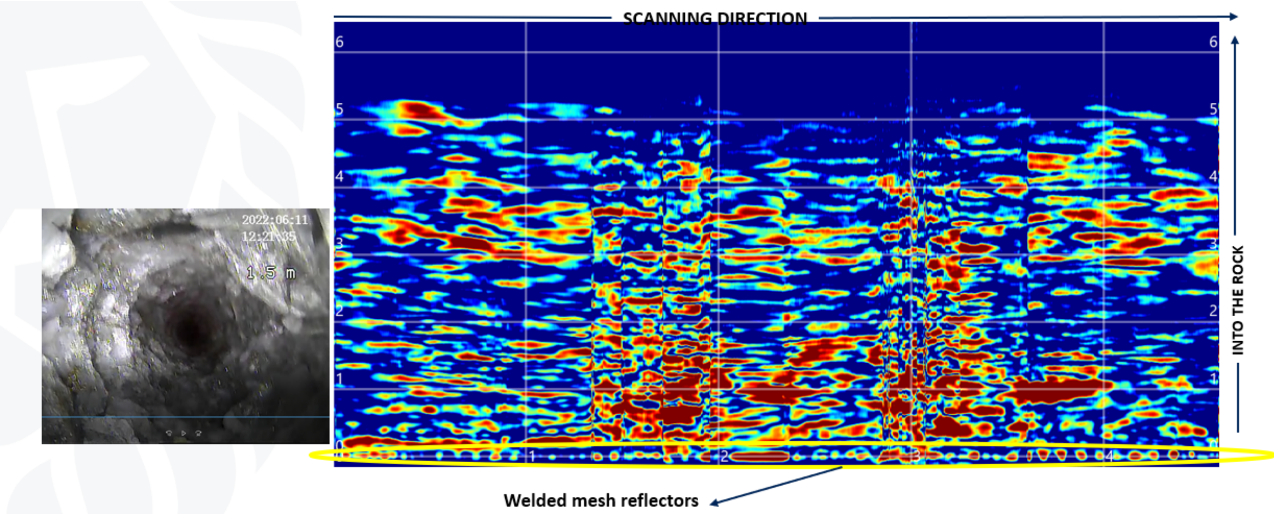


Figure 10 SSP scan illustrating fracturing ahead of an advancing face post preconditioning

3.3 Visualisation and analysis of SSP raw data in mXrap

The IGM app in mXrap is used to determine the rock mass quality of the section being investigated, thereby assisting rock engineers in determining the approximate condition of the rock mass and, in turn, the preconditioning effectiveness. In Figures 11 and 12, SSP data for a typical development face is shown.

Figure 11 illustrates a 3D plot of the SSP scan data. This face was scanned five times: three vertical and two horizontal scans. This allowed for a comprehensive evaluation of the rock mass immediately ahead of the face. In the figure, only intensities between 0.5 and 1.0 are shown. Intensity is expressed as a value between 0 and 1. This visualisation allows the user to get a spatial overview of the data.

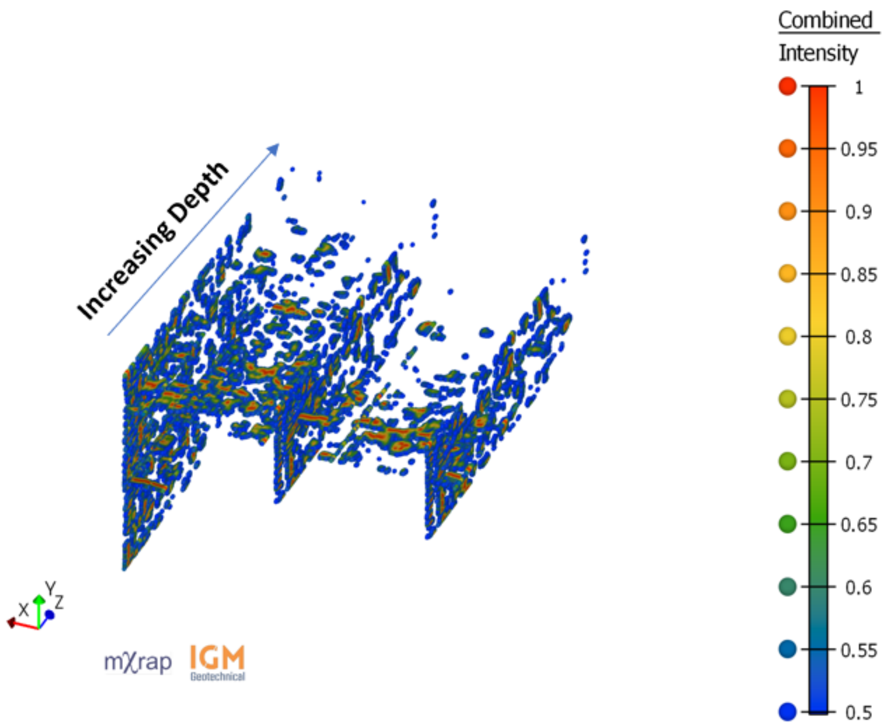


Figure 11 3D plot of face scans for a typical development end. The scan data is coloured by intensity

Figure 12 illustrates the analysis window of the IGM application for a typical development face. The analysis window is separated into three sections:

- Left section – the expected rock mass quality based on the SSP scan data (intensity) is indicated on the coloured bar. These values are determined through the calibration algorithm which relates the historical intensity to the observation hole data. The bar colours have the following meaning:
  - red – crushed ground (intensity count > 20,000)
  - yellow – fractured ground (15,000 < intensity count < 20,000)
  - green – intact ground (intensity < 15,000).
- Middle section – a top view of the SSP scan data, coloured by scan intensity. Only intensities between 0.5 and 1.0 are shown.
- Right section – illustrates a histogram displaying the count of intensities as depth increases. The coloured histograms represent individual scans while the black histogram shows the integrated count where these scans overlap. The combined histogram plot is used in the calibrated algorithm to determine the expected rock mass quality.

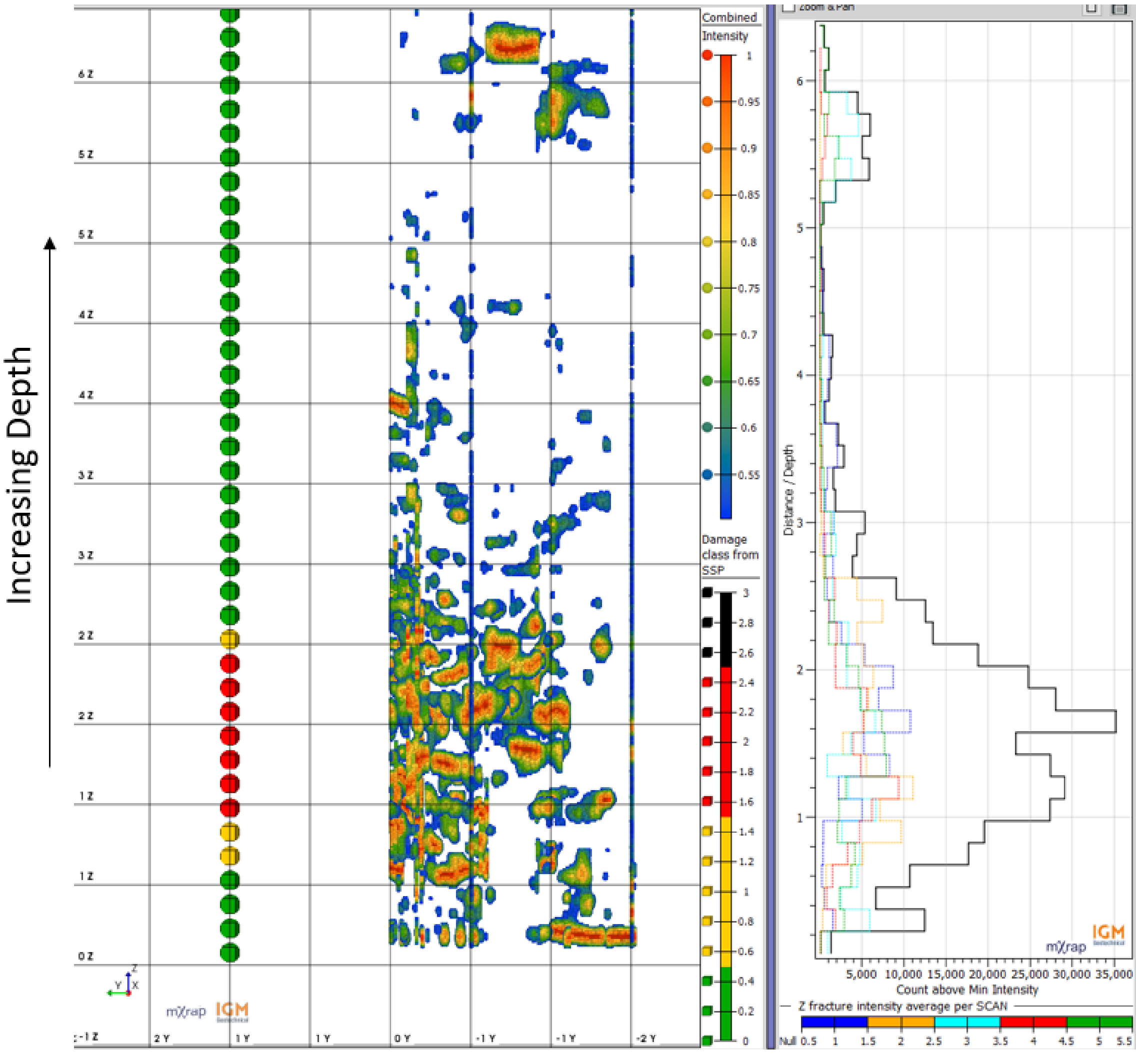


Figure 12 Middle section – top view of 3D scan data coloured according to intensity. Right section – stacked intensity histogram, binned according to depth. Left section – estimated rock mass condition (based on calibration algorithm), where red indicates crushed, yellow indicates fractured and green indicates intact

4 Conclusion

This paper emphasises the enduring importance of preconditioning in mining operations and the pivotal role of advanced technologies such as the IGM app in mXrap in enhancing data processing and decision-making processes, ultimately contributing to safer and more efficient mining practices. The paper also investigated the applicability of the SSP as a valid tool to verify the effectiveness of preconditioning in de-stress faces, particularly where 100 mm square mesh aperture size was used. The results showed that the frequency sweep is not completely blocked by typical mining mesh apertures and, therefore, allows the SSP to scan through mesh. Although some of the emitted waves are expected to interact and be reflected at lower frequencies, the higher end of the spectrum still passes through the mesh into the rock mass.

The calibration efforts conducted during the study yielded valuable insights. The data from various instruments exhibited correlation, validating the utilisation of a third party software tool for post-processing, visualisation and interpretation. Consequently the emphasis shifted towards assessing whether the desired fracture cushion ahead of the face was attained. The study has shown that the minimum fractured depth of 1.5 m from preconditioning is achieved, thus successfully creating a cushion ahead of the advancing face. The histograms generated by mXrap effectively depicted the depth of fracturing. Furthermore, this facilitated the creation of a database documenting preconditioning compliance.

5 Future work

Although the work presented in this paper has led to an improvement in the current management of preconditioning, the authors acknowledge that more work is required to ensure confidence in the processes discussed above. Work currently being undertaken involves:

- obtaining more observation hole data, which will be used in the calibration process
- including the dielectric constant as a calibration factor
- changing the calibration process to consider the statistics of all intensity values from 0 to 1. This will be implemented when this function is added to the SSP software
- refining the database in the IGM app, which can be exported to Excel
- adding a summary page in the IGM app that prompts practitioners to add observation holes to the database to confirm whether or not the current algorithm is still relevant.

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