International Society for Rock Mechanics and Rock Engineering
Norwegian Group for Rock Mechanics

ISRM International Symposium
Eurock 2025 – Expanding the Underground Space
Trondheim, Norway, 16-20 June
ISBN 978-82-8208-079-8

Exposing the rock mass response by means of radar technologies

J.A Maritz
University of Pretoria, Pretoria, South Africa
jannie.maritz@up.ac.za (email of corresponding author)

M. Nel
Reutech Mining, Stellenbosch, South Africa

Abstract

Optimization of pillar design within the South African mining industry is an ongoing process with regards to both conventional and bord-and-pillar layouts. Bord-and-pillar designs are sometimes considered conservative as the pillars appear to be much stronger compared to what the empirical design models predict. Owing to the traditional conservative methods of design, optimization of pillar designs for underground mining in South Africa has commenced, with the incorporation of a better understanding of the rock mass and its response. This has resulted in the valued mineral lock up of reserves in pillars over the past decades. Rock quality and geological features play a significant role in this as these are directly link to the rock strength parameters of the pillars. The understanding and collection of the rock mass from historic pillars and newly designed pillars, allows for not only a refinement of the designs, but possible future secondary extraction opportunities.

The constant risk for underground mine personnel, without the ability to see beyond the hangingwall can be reduced with radar technologies. The ability to allow for an internal hangingwall representation can assists in the prevention of falls of ground. Development in radar technologies purposed for military application were applied in the mining environment with great success previously, however the refinement of the processes with additional possibilities has allowed for more representable scans, that can be achieve in restricted areas. The scans don't only allow for pillar assessment and design but assist with the overall risk profile of hangingwall conditions.

Discontinuities can be detected and visualised almost immediately, providing the interpreter with sound geotechnical information to act upon. Being able to analyse the quality of the rock mass remotely and internally, allows the engineer to better calibrate numerical models and ultimately present optimised layouts whilst stability management improve with the knowledge of the immediate geotechnical hazards within the working area.

Keywords

Rock mass response, ground penetrating radar, pillar design

ISRM

NBG

1 Introduction

The geological setting of a mineral deposit is crucial in determining the mining and support methodologies. The mining approach is influenced by the geological context, including the support systems used. Due to the limitations of visual continuity between underground excavations, the interpretation of geological features largely depends on the Geology department's expertise. This interpretative process, while informed by orebody knowledge and geologist experience, is inherently unclear. Therefore, supplementary methods to enhance prediction accuracy are advantageous.

A case was presented Hartzenberg (2019) indicating that geological feature and structural mechanisms can contribute greatly to large-scale instabilities in underground environments. In her studies, she indicated that the formation of the orebody and the subsequent geological structures create complex hangingwall conditions (see Fig 1).

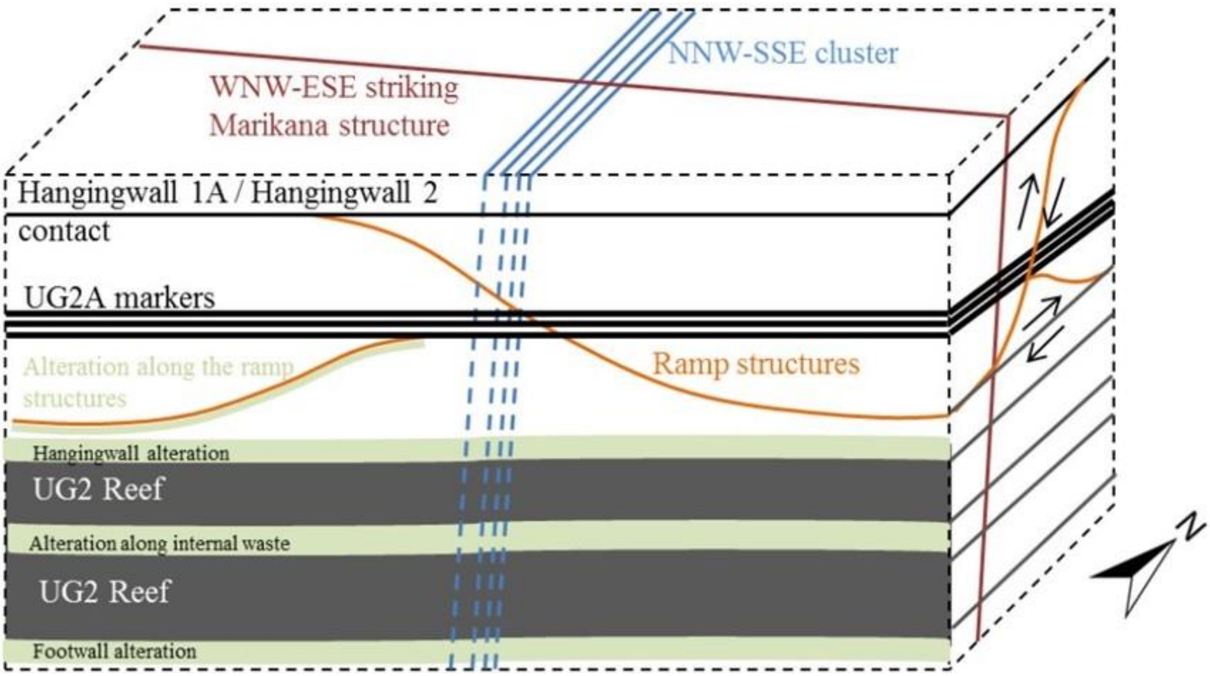

Fig 1 A schematic of a complex hangingwall rock mass (Hartzenberg (2019).

Fig 2 below indicates the underground ground observations and interpretation made by Hartzenberg (2019).

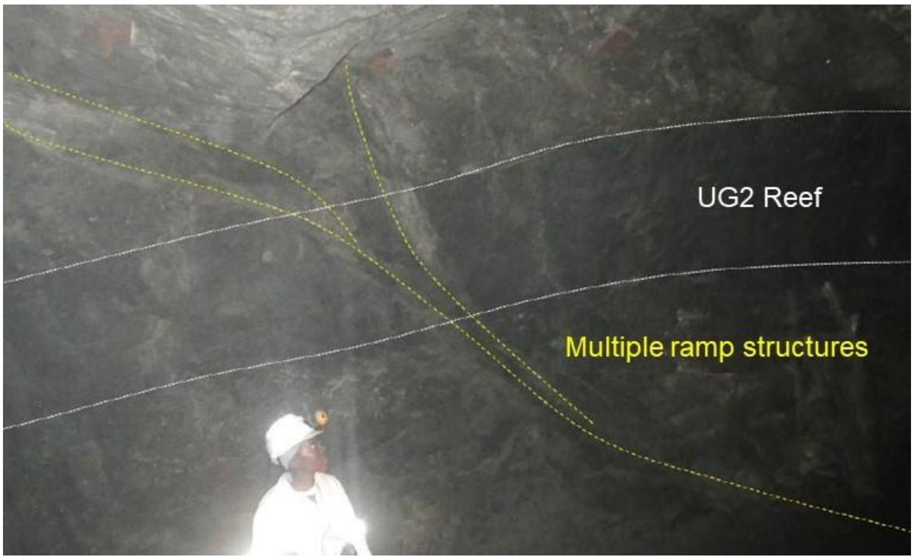

Fig 2: Exposed geological structures on working face (after Hartzenberg 2019)

As these structures can be found in any direction within the rock mass and the exposure to the face, instability could be obvious.

Platinum mines on the eastern bushveld have a geological formation, that was formed during the geological sequence (Couto P and Theron W 2014). This presence has been highlighted (Hartzenberg 2019) and is a prominent feature and affects the hangingwall stability. The identification of this geological features (Hartzenberg 2019; Couto P and Theron W 2014) can be challenging to the untrained eye. Identification of these features are critical to understanding the hanging wall stability.

The history of current and future designs of mine pillars has been questioned (Malan D and Napier J 2011) with advances made on pillar designs and understanding of the rock mass and its behaviour (Du Plessis M and Malan D 2013). This is an important question and years later advances have been made with regards to pillar design, however the older operations have locked up resources that remain in-situ. This has allowed for the possibility of better understanding the pillars abilities, designs and conditions which benefit future pillar designs in similar rock masses but also allows for a possibility of safe secondary extraction.

Underground observations and collected data from the collapsed Everest Platinum Mine (Couto P 2022) show better understanding of the collapse in pillar layouts and subsequently calibration on a new design method for ground with similar conditions was presented. The implementation of the design method is reliant on the ground conditions and the ground conditions can now be identified using numerous new technologies, with one of them being radar technologies. This could result in a more accurate mine design and a better economic outcome for the mining companies.

2 Ground penetrating radar

Knowledge of the ground conditions are of at most importance when designing stable underground excavations. A common method for the evaluation and assessment of the ground condition within the rock mass surrounding the excavation would be the use of visual observations and well as borehole cameras. In this method, a hole is drilled in the rock mass in which a camera is inserted. Visual observations are made along the length of the hole to determine among others geological discontinuities and blasting damage. The method of borehole camera observations does not allow for remote observations and is reliant on other personnel for the drilling of the boreholes. This can delay the response time. This paper focusses on the use of radar technology to derive these observations base on a quick and no-destructive method, that can be conducted independently and timeously.

Ground penetrating radar (GPR) technology has for several years been utilised in underground mining for the identification of discontinuities during structural assessment, design calibration and monitoring. GPR products have been applied in the detection of unknown discontinuities (both natural and resulting to mining) within the rock mass, which allows for the calculation of support requirements for the mitigation and prevention of fall of ground events for primary and secondary access, as well as extending the life of mine openings and stopes.

GPRs were traditionally developed for utilities tracking (such as underground pipes and cables) in the civil environment and not fundamentally designed for the technical challenges faced in the underground mining environment. A strategy was developed for a GPR to be innovatively designed to combat the difficulties of the application of this technology underground.

The principal design drivers were:

- Ease of use from a safety and practical perspective
- Weight and application of the instrument to the face to be scanned
- User friendly, intuitive software
- Real-time observation of the sub-surface

A GPR system was conceptualised that utilises a swept frequency bandwidth between 300 MHz and 1 GHz, with a single antenna being used, to achieve the required penetration depth and resolution. The system has been tested extensively in the Bushveld Complex in South Africa, where a maximum penetration depth of 10 m was achieved.

The newly developed GPR makes use of Frequency Modulated Continuous Wave (FMCW) radar, which continuously transmits electromagnetic waves rather than a pulsed waveform. These electromagnetic waves are transmitted continuously using a swept frequency waveform, whilst return signals are simultaneously received, processed and the data displayed in real time. This type of architecture enables the radar's radio frequency power source to be smaller, thereby reducing the sensor's size and weight. The system can be operated by a single user who can both conduct the scan and assess the data immediately after the scan, or by a two-person team with one operator conducting the scan (see Fig 3) and the other assessing the data being collected in real time. This is in contradiction with the traditional pulse systems which required a larger number of personal to operate with data only being available after post-processing on the surface.

Fig 3 Side wall scanning conducted using Frequency Modulated Continuous Wave radar device.

The identification of discontinuities varies from structures in the side wall and hanging wall and includes high to low angled faults, fault zones, shear zones, discrete as well as larger domal features, joint sets (that may be observed to be intersecting), parted planes (stratigraphic and igneous), dykes and sills as well as igneous structures such as Bushveld Complex chromite stringers.

The system has also proven to be beneficial in assessing pre-conditioning blasts to ensure that the blast was conducted effectively by presenting the depth of fracturing of the pre-conditioning holes. Fracturing of the rock mass to the desired level to assist with the reduction and prevention of rock bursts at the face or for deep mining scenarios remains essential.

3 South African hard rock mine case studies

Two case studies are presented to highlight the application of the GPR technology in an underground hard rock mine in South Africa.

3.1 Case study 1: Hangingwall

Old and abandon working are sometimes returned to as economic climates and commodity prices fluctuate. Such was the case in a South African platinum mine where a section of the mine was re-opened. The excavations were predominately supported by shotcrete, rending visual mapping of geological features impossible for most part of the mine. Being abandoned for a long period, services to the area were also non-existing, making drilling of boreholes for camera work challenging. Radar technologies in conjunction with traditional rock mass investigation methods were applied to establish a better understanding of the ground conditions.

Historically the mine was pestered with falls of ground due to geological alternations in the immediate roof rock mass as well as discontinuities that created wedges. The radar scan was used on the hangingwall contact, to identify possible instabilities.

Numerous scans were conducted underground and compared to visual observations, and where data existed on borehole camera data. This allowed for confirmation of the findings of the radar output. This allowed for the radar setting to be calibrated with the other methods used. The findings were that the radar scan could present discontinuities as well as lithology in the rock mass. Micro voids between geological features and the changes in rock density allowed for changes in frequency from the radar. Fig 4 below indicates an example radar scan, ran over 5 m (read from left to right), indicating lithology (vertical position) and geological intrusion (noise on the plot).

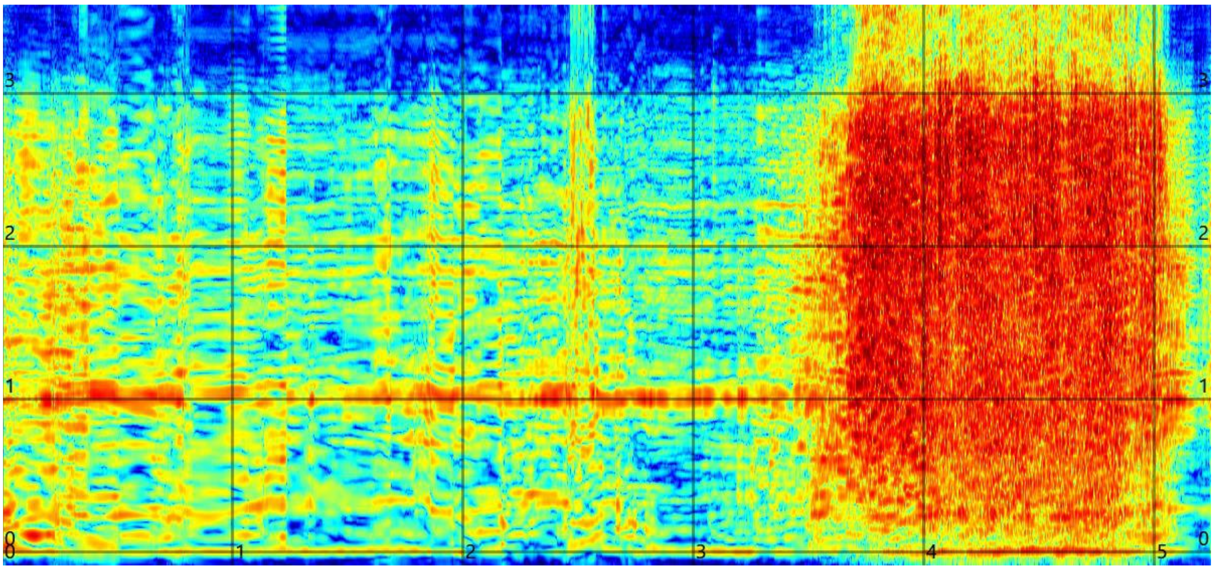

Fig 4 Radar scan indicating lithology and geological intrusion.

From the plot above the 1.5m intrusion was highlighted between distances 3.5m and 5.0m along the scan with a lithology change at 1.0m into the hangingwall. As the radar data is not yet geo-referenced, these distances are currently accepted as an indication.

Fig 5 below presents an example scan where the radar scan data again indicates the change in lithology, however the thickness of this zone provides an indication of the thickness of the layer. This provided valuable information for designing for stability and support lengths to achieve anchorage in the stable zone.

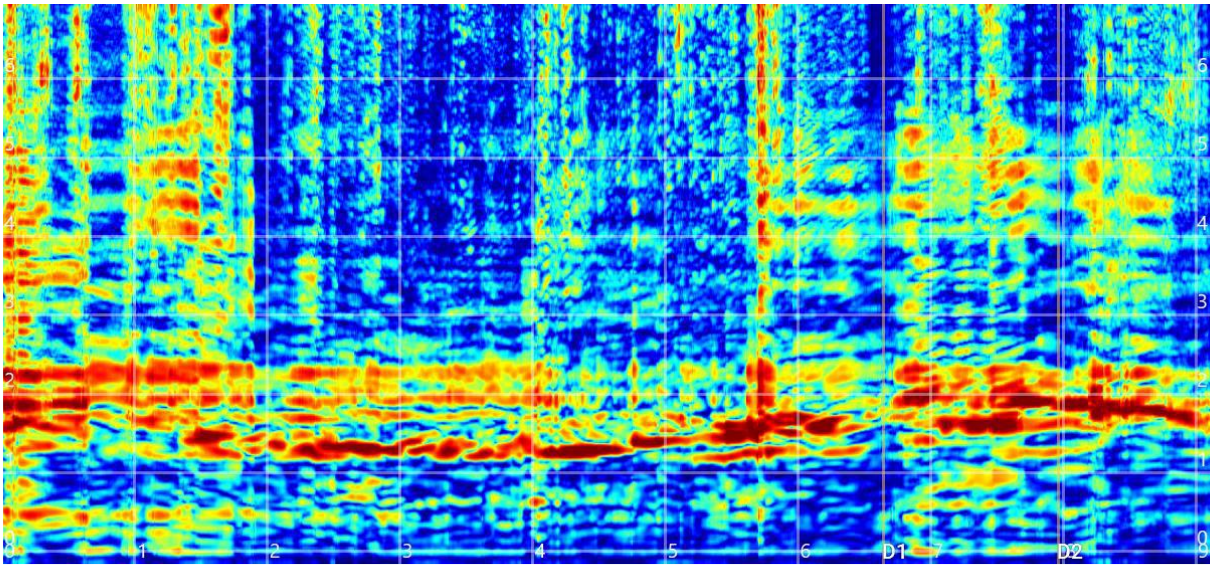

Fig 5 Lithological change with indication of thickness.

The scans were all done through wire mesh, which traditional are expected to interfere with radar signals. However, the instrument used does not compare with units with a limited bandwidth or single frequency for scanning. As it utilises the FMCW scanning technology, sweeping frequencies 300 MHz to 1 GHz, the instrument can scan through typical mesh apertures used in mining.

3.2 Case study 2: Pillar scaling

During a pillar monitoring program, an existing pillar has been observed during the extraction phase at a working hard rock mine, using the bord-and-pillar mining method. This pillar had been drilled for borehole camera analysis and findings were recorded. These stated facture zones within the pillar side up to a depth of 0.5m from the collar of the hole. Fig 6 below presents the pillar on plan as well as a schematic showing the pillar dimensions.

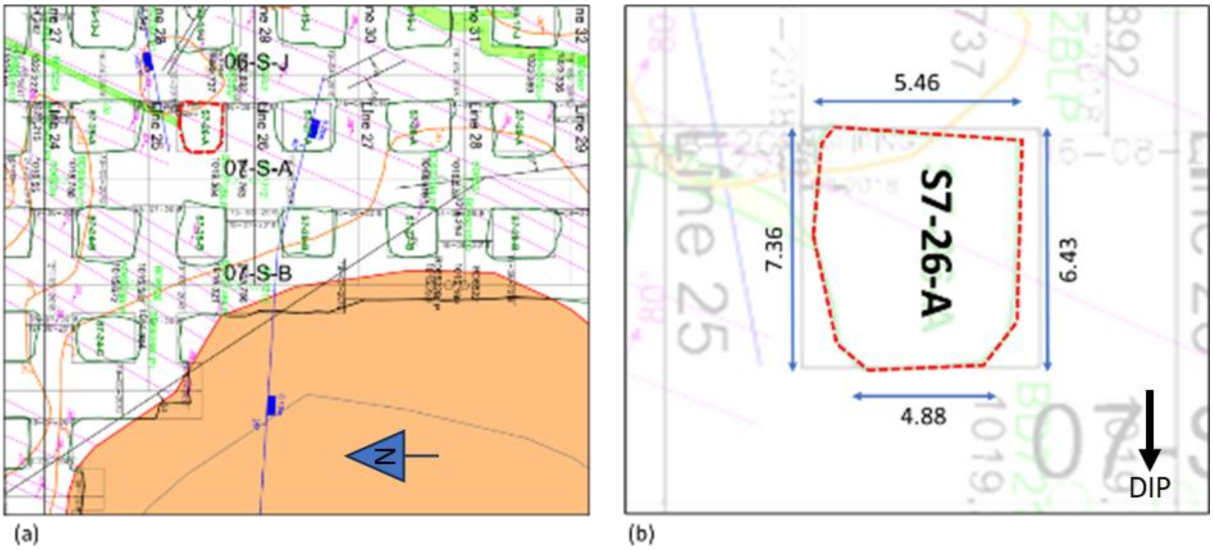

Fig 6 Schematics of actual pillar scanned using ground penetrating radar (Dipping to the West).

It should be noted that these scans are not geo-referenced and interpretation is required to obtain the information lock within the data. Fig 7 presents an uninterpreted scan from the updip side (eastern sidewall) of the pillar.

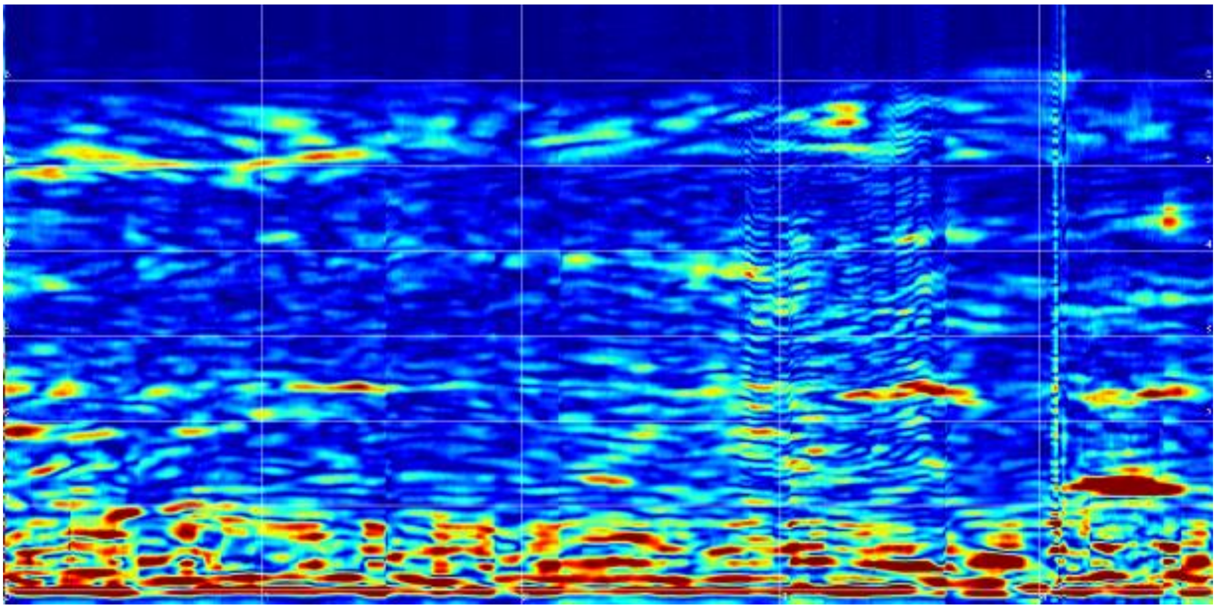

Fig 7 Uninterpreted radar scan image for pillar (Scan 1).

Once interpreted, the scans from all four sides are presented, indicating the position of the previously drilled camara hole, as well as the fracturing around the pillar (see Fig 8).

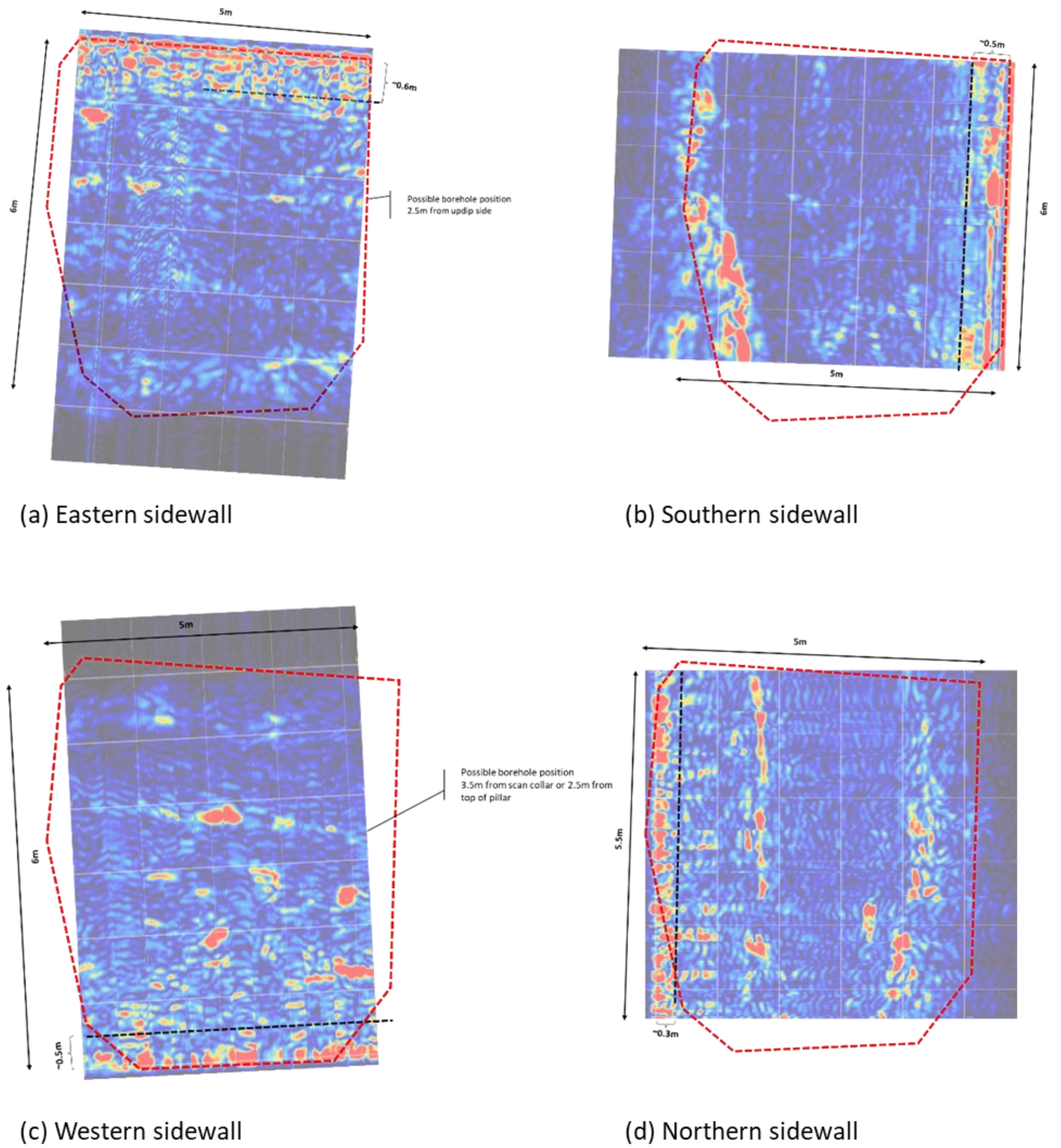

Fig 8 Interpreted radar scans around pillar of interest.

The scans confirmed that over the observation period, no additional fracturing occurred within the pillar, suggesting the design proves to be adequate.

4 Conclusion

The mining process inherently alters the rock mass due to its destructive nature. The extraction of ore can result in wedges forming and geological discontinuities to become unstable. Combined with blast-induced fractures and other potential weaknesses in the rock mass, this can lead to hazardous ground conditions.

Owning to the advancements made in using ground penetrating radar, the assessment of the rock mass conditions without the use of destructive methods allow for better understanding of the rock mass response.

Radar's capability to penetrate beyond the rock skin offers several advantages. It facilitates the identification of geological discontinuities that may impact hangingwall stability by influencing wedge formations. It also helps assess rock mass conditions in relation to blast damage and determines the location of various rock types behind areal support. Additionally, radar allows for remote scanning, eliminating the need for invasive techniques. Post-mining, it aids in understanding the behaviour of pillars within the rock mass. Furthermore, it can be utilized to scan each blast face prior to subsequent blasts. The early successes in achieving credible scans thru blast on wire mesh, appears to be beneficial in the advancement of the technology.

References

Hartzenberg AG (2019) Structural mechanisms contributing to large-scale hangingwall instabilities on the UG2 reef horizon. Dissertation at University of Pretoria

Couto P, Theron W (2014) Flexural slip thrust faulting on Booysendal Platinum Mine and the implications for rock engineering. The 6th International Platinum Conference, ‘Platinum–Metal for the Future’, Southern African Institute of Mining and Metallurgy

Malan D, Napier J (2011) The design of stable pillars in the Bushveld Complex mines: a problem solved? The Journal of the Southern African Institute of Mining and Metallurgy, Vol 111: No 12 p 821

Du Plessis M, Malan D (2013) Mining with crush pillars, The Journal of the Southern African Institute of Mining and Metallurgy, Volume 118, pp 211 – 216

Couto P (2022) The effect of a geological alteration on UG2 pillars. Masters Dissertation at University of Pretoria.