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The Equotip hardness method for spatial geotechnical assessment of a Northparkes Mine block cave

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Abstract

One of the biggest challenges in characterising a rock mass during block cave feasibility is to determine the spatial distribution of intact rock strength. Traditional methods such as uniaxial compression and the less accurate point load test require the selection and destruction of drillcore specimens. This is not always possible due to the large amount of core required and the expense of testing. Due to the low number of specimens usually sent for test work, the spatial distribution of rock strength is normally characterised by a few data points applied to geological rock units. This homogenises the rock mass and omits any variation in rock strength within each large-scale unit. To enable more accurate numerical modelling and geotechnical assessment, the Equotip hardness tester has been implemented onsite at CMOC-Northparkes. The method consists of a spring-loaded impact device which strikes the specimen and records the rebound velocity. The measure is then converted to Leeb hardness. At Northparkes Mine, the sampling of diamond drillcore at half metre intervals using this method provides significantly more data than traditional test work. The hardness values for rocks are then converted to uniaxial compressive strength (UCS) via site calibrated relationships. This then creates large spatially oriented datasets for use in geotechnical assessment. This paper highlights the recent Equotip logging of the MJH block cave prospect. The logging procedure, calibration and analysis methodology is presented which shows the quantitative and spatial strength distribution of the deposit. It was also found that the Equotip logging method could identify and delineate weakness zones within the deposit due to geological contacts and other structural features. This led to the ability to characterise the thickness and shape of these zones for future use in numerical modelling. Overall, the Equotip core logging method developed and implemented onsite, provides larger more spatially relevant datasets than UCS testing alone. The ability to develop and calibrate relationships to other physical measures of the rock enables more accurate assessment along with future potential in geometallurgical studies. This, combined with higher accuracy compared to point load testing, has cemented the process in geotechnical core logging at Northparkes Mine.

Keywords: *Equotip hardness, rock strength, rock mass characterisation, geotechnical domaining*

1 Introduction

1.1 Background

The Equotip hardness tester employs a concept first demonstrated in 1948 in the Schmidt hammer. This apparatus measured the height of rebound of a small steel ball after its collision with the test surface. This allowed non-destructive test work to be conducted on concrete (Schmidt 1951). The Equotip apparatus is a battery-operated, spring-loaded impact device. It comprises a 3 mm diameter spherical tungsten carbide test tip that is spring mounted in an impact body (Figure 1). During a hardness test, the tungsten carbide test tip impacts under spring force against the test surface and then rebounds. The measurement is obtained by a permanent magnet built into the impact body which passes through a wire coil. During movement of the magnet through the coil, an electrical voltage is generated that is proportional to the velocity of the impact tip. The Leeb hardness is then calculated using Equation 1 (Proceq SA 2016).

$$L = V_r/V_i \times 1000 \quad (1)$$

where:

L = Leeb Hardness

V_i = impact velocity

V_r = rebound velocity

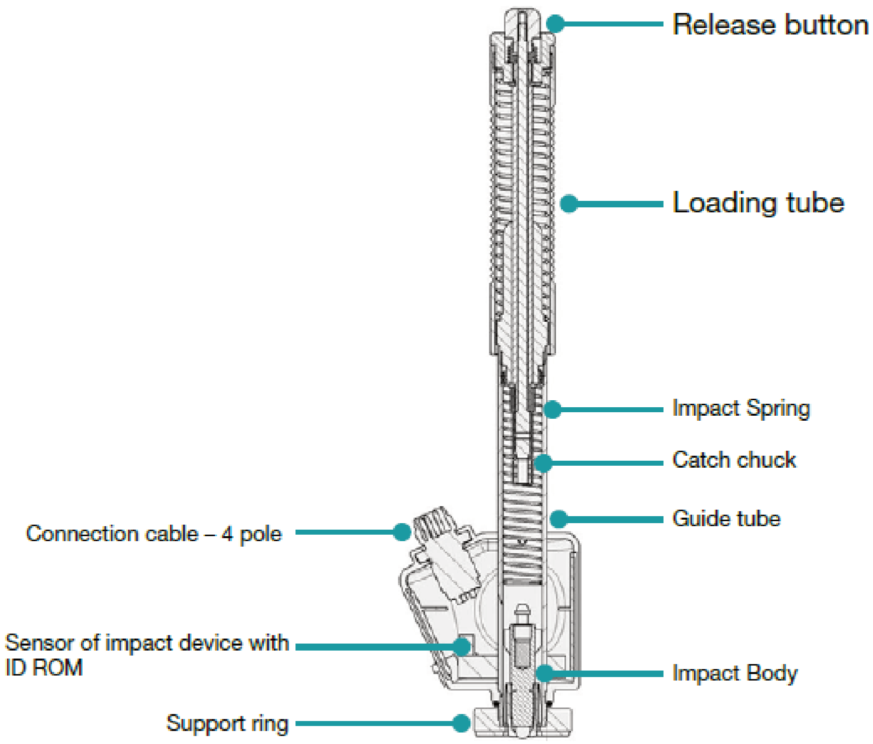

Figure 1 Equotip impact device

The main advantages of the Equotip are (Aoki & Matsukura 2008):

- It is battery powered and portable which facilitates its use in the field.
- The direction of impact can be applied at 45°, 90°, 135°, or 180° from vertical.
- Little damage occurs at the surface of material due to low impact energy.
- Can be used on a curved surface due to the small impact area required.
- Repeatability is good regardless of operator.

As such, Equotip hardness testing has been widely applied in many industries including material science, agriculture and mining. The first study conducted in rock mechanics was by Hack et al. in 1993 which utilised the hardness apparatus to describe the discontinuity wall strength in terms of uniaxial compressive strength (UCS). The study established relationships between the UCS and Leeb hardness to typify the discontinuity strength along the surface of an excavation. Using samples of various rock types, Verwaal & Mulder (1993) also investigated the relationship between Equotip hardness values and the UCS of the material. They presented a relationship shown in Figure 2 and discussed the effect of specimen roughness on the results.

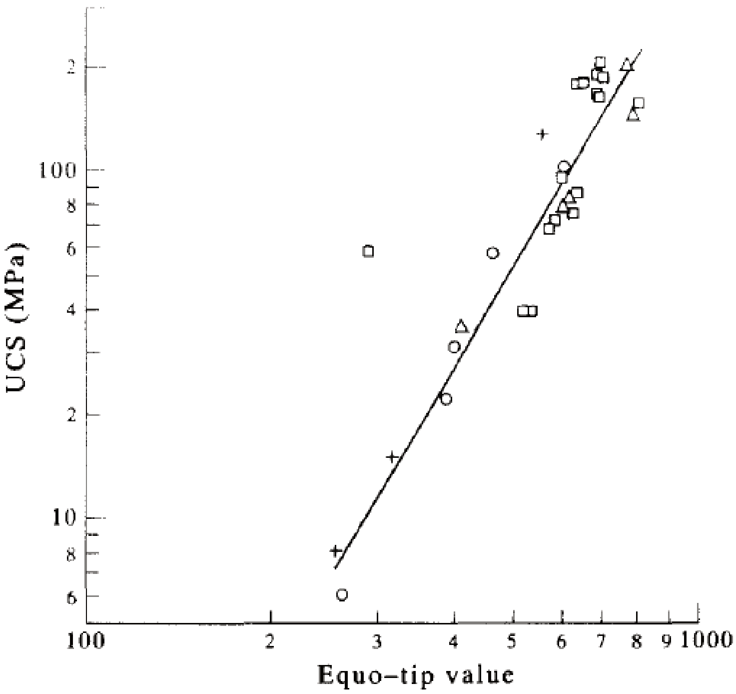

Figure 2 Relationship between Leeb hardness and UCS (from Verwaal & Mulder 1993)

Later works by Meulenkamp & Grima (1999), Kawasaki et al. (2000, 2002) and Aoki & Matsukura (2008) expanded the evidence and test work for an inherent relationship between Equotip hardness and the UCS of various rock types.

Most studies in literature seek to form a relationship between the Equotip hardness measure and other parameters associated with rock mechanics, primarily UCS. They then expand to comment on the effectiveness of the test method given varied surface and material conditions. However, the predominant application of the method is to provide a measure of laboratory specimens and infer the connection to general rock types. This paper details the work conducted by the team onsite at Northparkes Mine to utilise this method in the standard core logging procedure. It then explores the applicability of the method to estimate the quantitative rock mass properties in a spatial context as well as its use in mapping of weak rocks and structures. This work lays the foundations for better understanding of the spatial rock mass strength with more accurate and higher resolution geotechnical block modelling made possible.

1.2 Sampling methodology

The Equotip 550 testing apparatus with a ‘S’ type impact device is used onsite at Northparkes Mine to measure hardness values (in Leeb) for diamond drillcore (Figure 3). To ensure adequate spatial resolution for each drillhole, hardness values are obtained every 0.5 m along the core run. The specific sampling methodology adopted onsite is detailed below:

1. Set up an appropriate naming convention for the drillhole file by changing the information in the ID+ field.
2. Attach the core support foot to the impact device.
3. Take a reading every 0.5 m down the core run. Ensuring to place the impact device on core at least 5 cm in length to allow for a representative reading to be taken.
4. If there is no core present greater than 5 cm in length for an interval, take a reading on a piece of PVC pipe with approximately the same diameter (dummy shot). This will record a distinct low reading (~450 HLS) and allow for filtering of the data.

5. Collect as many 'dummy shots' as required until competent core is again encountered. For example, if there is one metre of core which does not have a piece greater than 5 cm in length, then two dummy shots would be taken.
6. Occasionally, a reading may not appear to be representative of the rock strength observed. This can occur if the core is compromised by a hairline crack, or there is material on the surface of the core interfering with the impact. With such readings, the 'tone' created by the impact on the core will sound different and result in a reading much lower than expected. If such a reading occurs or is suspected, the reading should be deleted and repeated by deleting the reading and performing another impact close to the interval site (within 10 cm).
7. If a 'true-repeatable' reading is taken on core which is less than 550 HLS, keep the data point and fill out the Equotip log sheet with reasons for the low value.
8. Once the entire core run has had readings taken, check the file name is correct and save the file.

Figure 3 The Equotip 550 hardness tester

Once an entire core run is sampled, the data is manipulated to produce drillhole hardness and UCS plots to offer an initial appraisal of the rocks encountered by each drillhole and if any major structures are encountered. An example of a drillhole plot is given in Figure 4, which showed that the drillhole intersected the Altona regional fault.

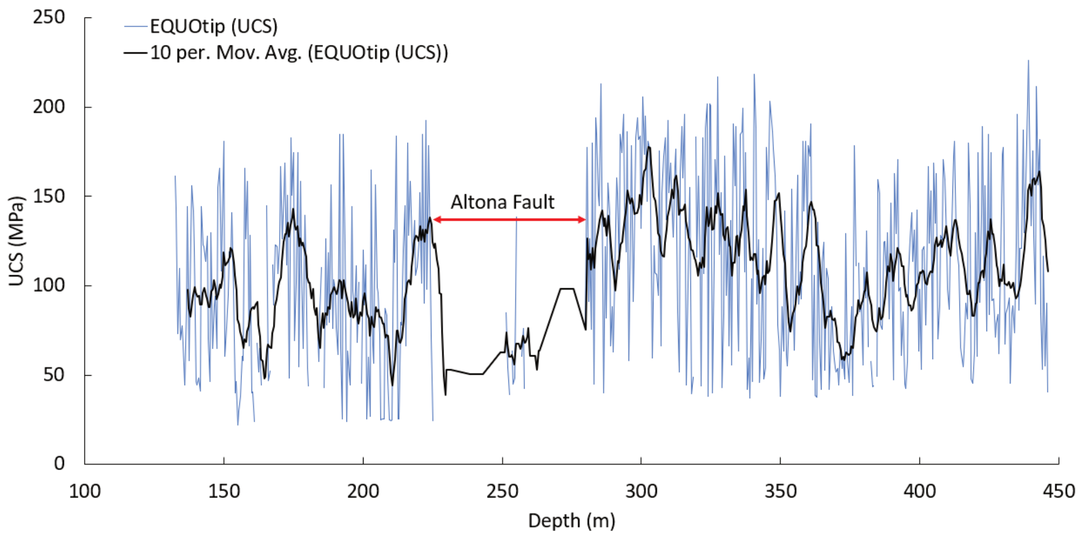

Figure 4 Drillhole UCS plot for GD916 showing the intersection of the Altona Fault

2 UCS calibration

The Equotip sampling onsite is primarily conducted to determine a spatial representation of intact rock strength. Therefore, the first step in utilising this technique was to calibrate the Leeb hardness values to known measures of intact strength. For this study, the UCS sampling and testing was modified to include averaged Equotip hardness measures to allow for direct comparison. The relationship formed from these tests were then cross-referenced against point load tests conducted at regular intervals along the drillholes.

2.1 UCS test work

To begin to calibrate the method, UCS samples were sourced from core from drilling conducted for various deposits onsite. From these specimens, the Equotip harness was measured from 20 points along the specimen, five along the length on four different sides of the intact core. These measurements were then used to determine the average hardness of the sample. Finally, the specimens were sent to an offsite laboratory to undergo ISRM standard UCS tests. Due to the vein structures within the rock mass at Northparkes, the variability in test work is generally high. Therefore, to develop the hardness-UCS calibration, the low strength, structurally weakened tests have been omitted. Additionally, the UCS values for each ten Leeb range have been averaged to reduce the structurally controlled variability of the dataset. Figure 5 shows the calibration of the curve to yield Equation 2.

$$UCS = 11e^{0.0023(HLS)} + 0.19e^{0.0068(HLS)} \quad (2)$$

where:

UCS is the uniaxial compressive strength in MPa.

HLS is the Leeb hardness value measured with the ‘S’ type impact device.

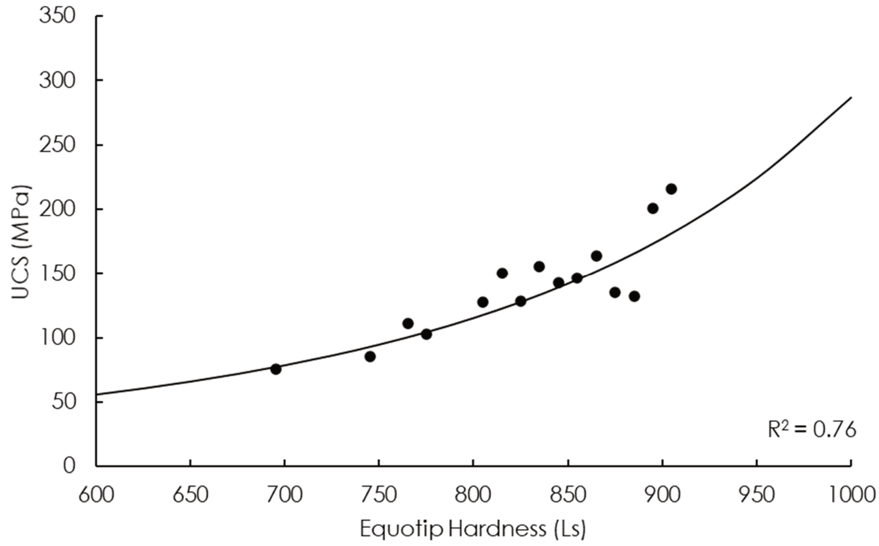

Figure 5 Site UCS calibration curve for the Equotip strength equation

Figure 6 presents the test results for the main geotechnical classes of rocks found onsite along with the Verwaal & Mulder (1993) equation and site curve fit for the data. It can be seen that rocks found onsite generally lie within the 750 to 900 Leeb hardness range. As such, the variability in strength is more localised in that region. It can be seen that this leads to a low correlation between the site calibrated curve and individual tests. This is due to the inherent variability and heterogeneity of specimens selected for UCS testing. This curve was a first attempt at site calibration and based on a relatively small number of UCS tests. The cores sampling methods at Northparkes have been updated to include hardness testing of all specimens going forward. As such, it is expected that the relationship will be continually updated to better reflect rock types onsite.

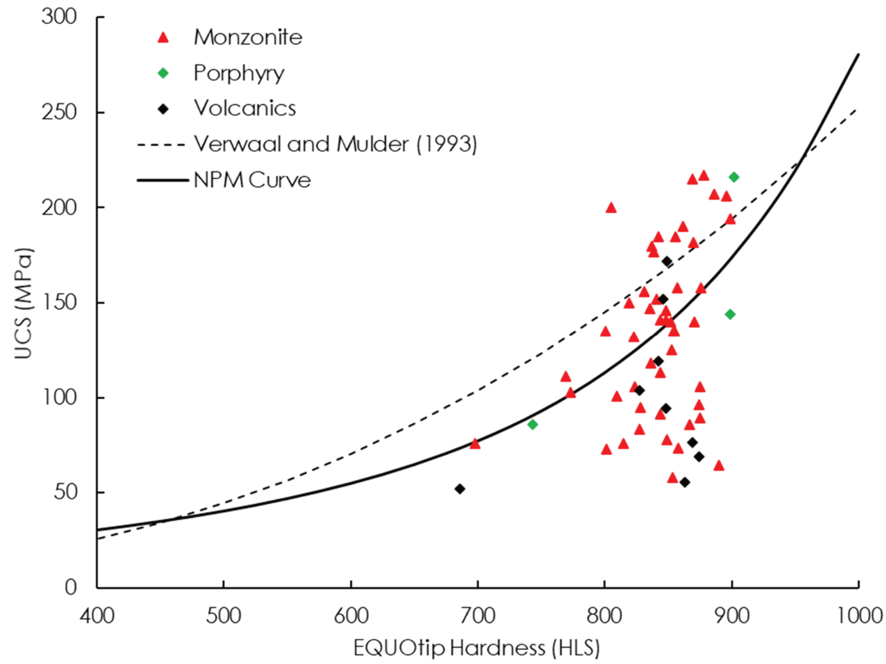

Figure 6 Site calibration curve comparison to all test results

2.2 Point load test work

To provide another dataset to check the calibration of the site Equotip curve, point load tests were conducted for several drillholes for comparison. As shown in Figures 7 to 10, the point load tests correlate well to the magnitude and variability of the hardness method. However, it is also clear that the Equotip method allows for higher spatial resolution along the drillhole. Another advantage of the method is that the inherent variability present in the point load test (Figure 6) is eliminated and replaced with a more controllable and repeatable indirect UCS measurement technique.

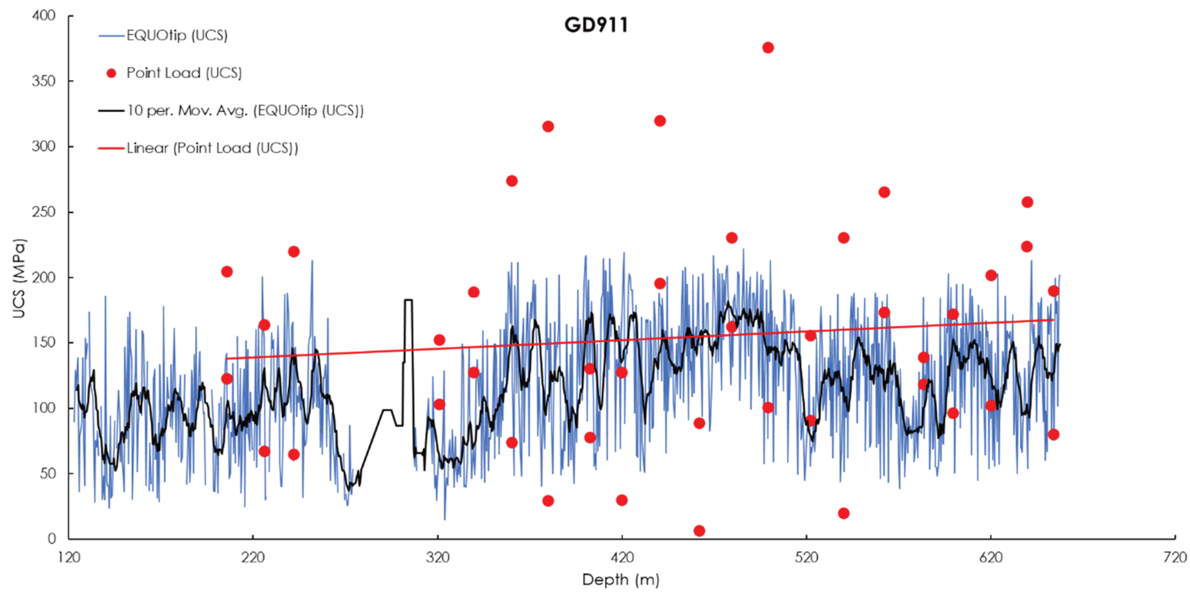

Figure 7 GD911 drillhole UCS prediction using point load test and Equotip hardness

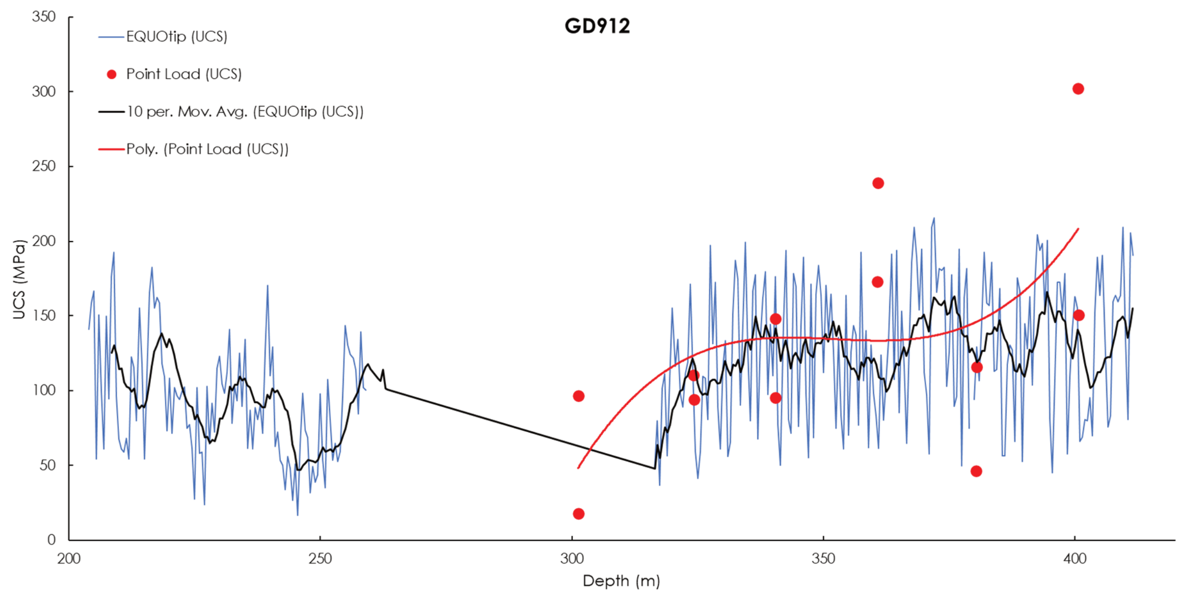

Figure 8 GD912 drillhole UCS prediction using point load test and Equotip hardness

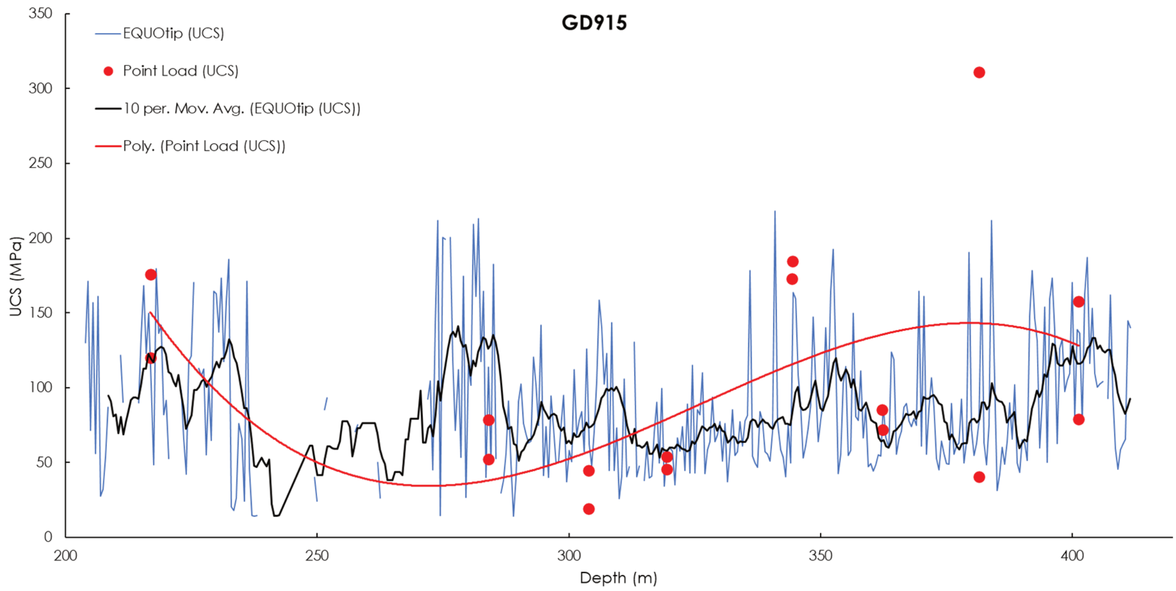

Figure 9 GD915 drillhole UCS prediction using point load test and Equotip hardness

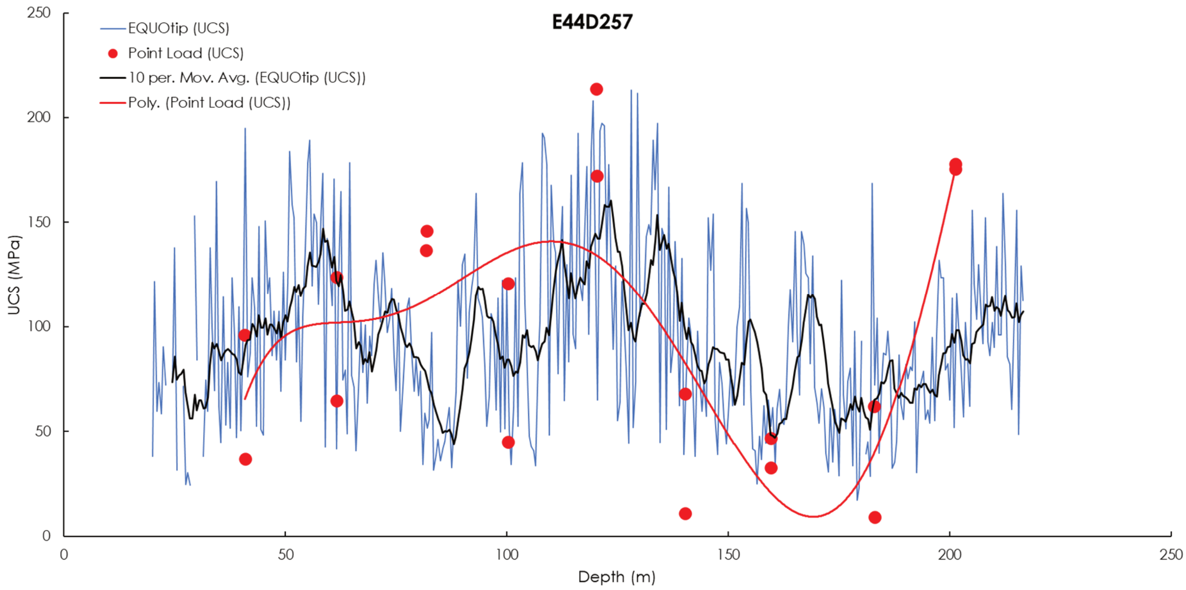

Figure 10 E44D257 drillhole UCS prediction using point load test and Equotip hardness

3 Quantitative strength assessment

After implementation onsite in the core logging procedure, the Equotip method has started to create rock strength datasets for use in orebody characterisation. The deposit which has hosted the most drilling is a prospect named MJH. This area hosted a significant underground drilling program in 2020 of 27 diamond drillholes varying in length between 100–400 m. The Equotip UCS estimates were collected for every 0.5 m interval of core and produced a large dataset of lithology strength characteristics. Table 1 and Figure 11 show the lithological strength estimates for the geology codes used onsite. The key codes can then be further grouped into the geotechnical domains Breccia (CBX, HBX, MBX), Dyke (PBD), Monzonite (BQM, QMZ), Porphyry (POR1, POR1/2, POR2, ZERO), Replaced by silicate or Rep-Sic (SIC) and Volcanics (LTE). It is important to note that multiple logging codes for lithology are used onsite and the most applicable has been used to categorise the geotechnical domains.

It is clear in Tables 1 and 2, and Figures 11 and 12 that the Equotip method provides a high number of repeatable data to determine the overall intact strength of the rock mass units. This information could then be used directly in numerical modelling or geotechnical block modelling for further geotechnical analysis.

Table 1 Lithology strengths using the Equotip hardness estimation

Lithology	Av. hardness (Leeb)	Av. UCS (MPa)	St. dev. UCS (MPa)	Min. UCS (MPa)	Max. UCS (MPa)	Sample count
APL	831	132	14	104	151	36
BQM	825	129	15	95	167	1,045
CBX	809	120	3	117	124	8
HBX	783	108	13	85	154	4,291
LTE	820	125	11	116	146	19
MBX	800	116	14	90	167	1,093
PBD	808	119	6	103	130	29
POR1	855	146	15	112	171	161
POR1/2	860	150	20	100	190	2,858
POR2	844	139	14	109	171	353
QMZ	822	127	15	75	172	19,022
SIC	776	106	15	73	167	3,561
ZERO	831	132	15	104	162	274

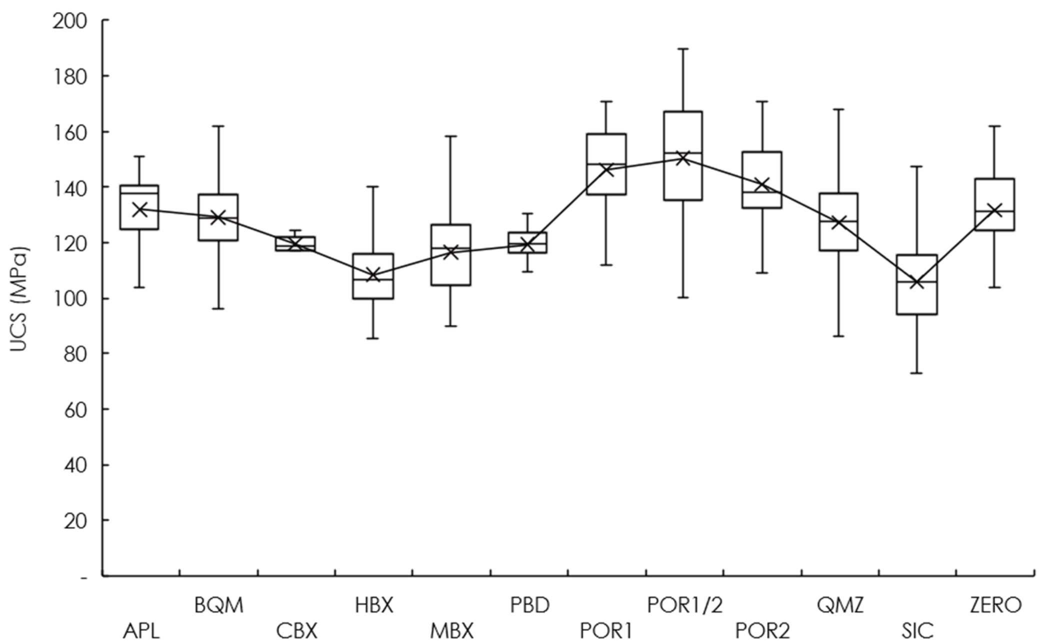

Figure 11 Box and whisker plot of lithological rock strength

Table 2 Geotechnical rock type strengths using the Equotip hardness estimation

Rock type	Av. hardness (Leeb)	Av. UCS (MPa)	St. dev. UCS (MPa)	Min. UCS (MPa)	Max. UCS (MPa)	Sample count
Breccia	797	115	14	85	167	4,694
Dyke	808	119	6	103	130	29
Monzonite	818	125	16	75	172	19,493
Porphyry	850	144	20	95	190	4,784
Rep-Sic	776	106	15	73	167	3,561
Volcanics	835	133	7	124	146	18

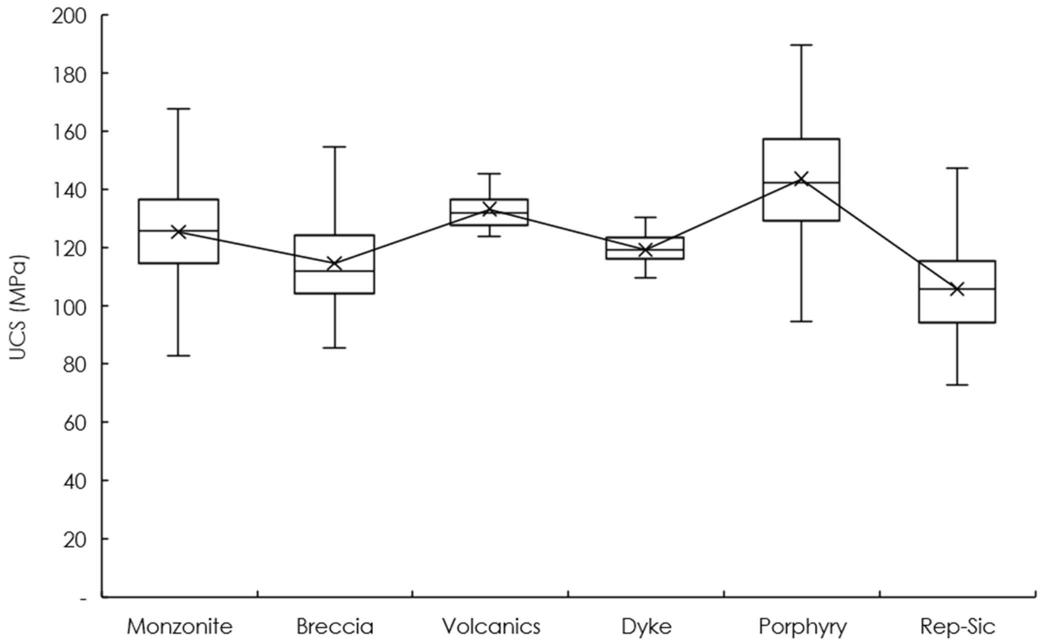

Figure 12 Box and whisker plot of geotechnical rock strength

4 Spatial strength distribution

Another key aspect of the Equotip method is the ability to spatially represent the intact rock strength of a deposit. An example of the utilisation of this method is again considered from the MJH prospect. As shown in Figures 13 and 14, the drilling sampled using the Equotip device covered a large portion of the area of interest. For this analysis the general strength classifications were:

- RED – LS – Low Strength UCS < 75 MPa.
- YELLOW – AS – Average Strength 75 < UCS < 100 MPa.
- ORANGE – GS – Good Strength 100 < UCS < 125 MPa.
- GREEN – HS – High Strength UCS > 125 MPa.

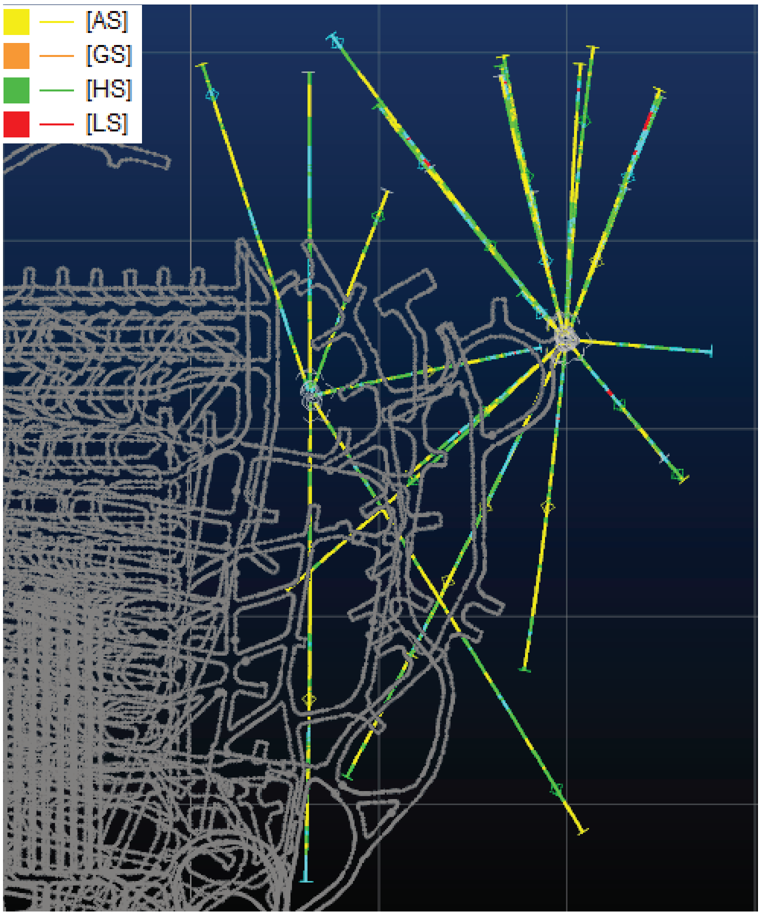

Figure 13 Plan view of MJH drilling showing relative strength intercepts

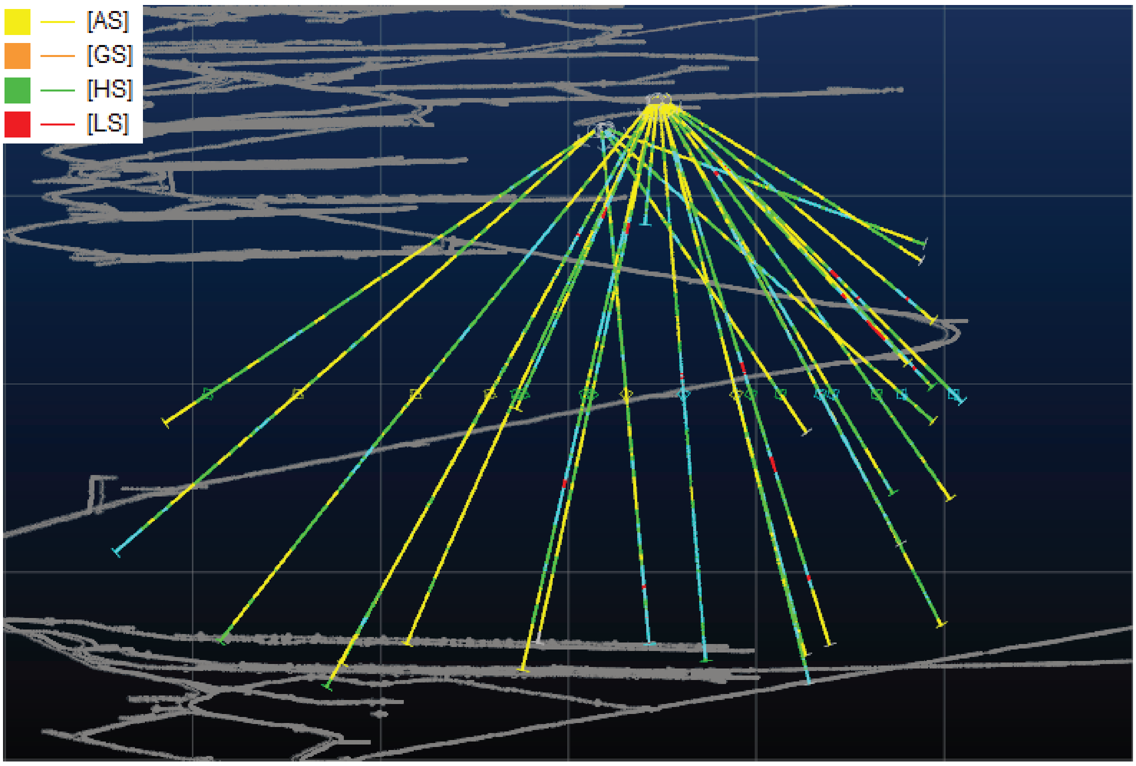

Figure 14 View looking west of MJH drilling showing relative strength intercepts

Using the geotechnical strength classifications, two distinct weakness zones were observed and wireframed. The first, shown in Figure 15 was a planar N–S feature (red) which is present along the western edge of the modelled porphyry intrusions (pink). This geotechnical feature was a result of the porphyry intrusion occurring late in the formation of the deposit and damaging the texture and competency of the rock mass. This zone of weakness around the contact was not logged during core logging and was solely identified by the Equotip method. The identification of this contact zone enables numerical modelling of this contact as a volume rather than a hard boundary.

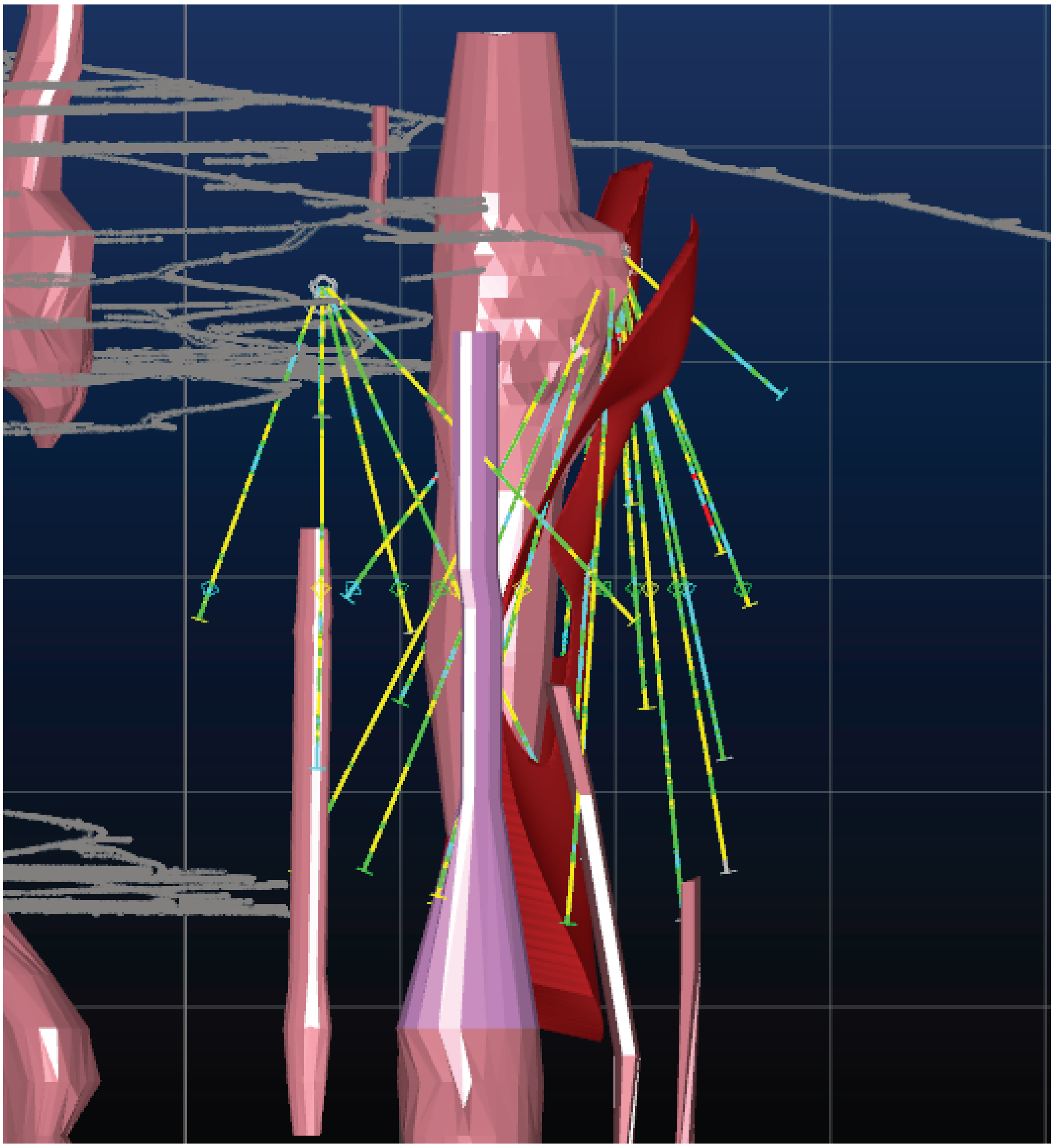

Figure 15 View looking north of weak material bounding the porphyry intrusions

The second identified structure, shown in Figure 16, was an E–W zone of weakness (magenta) along the contact between the breccia unit (yellow) and the surrounding monzonite rock mass. This particular unit is currently small due to the coverage of the drilling. However, based on this information and deposit confidence, this area will undergo further drilling to identify if this feature is continuous deeper in the rock mass. A key finding of this area is the significant thickness and E–W extent of this area with respect to the modelled breccia unit. It appears to extend well beyond the more localised contact boundary and out into the surrounding rock mass. The capture of this feature will allow for more representative numerical modelling to be performed on caveability of MJH.

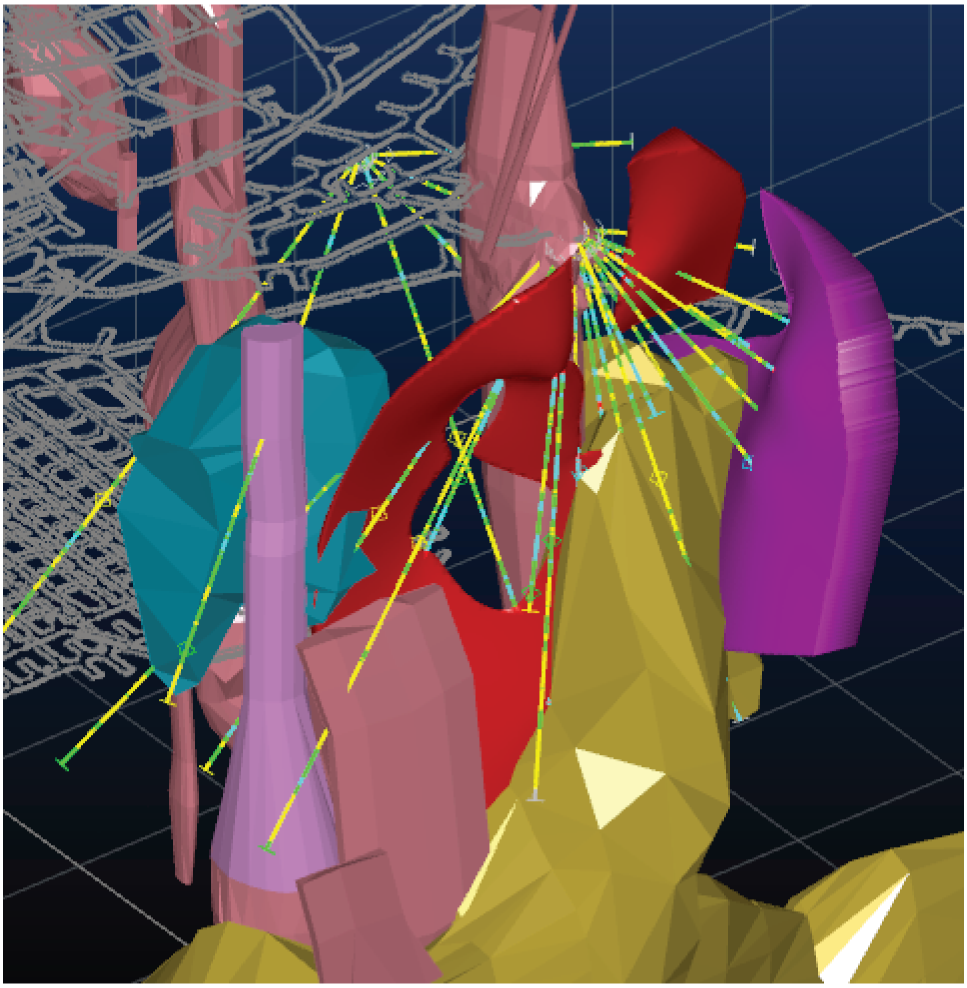

Figure 16 Oblique view looking NW of porphyry weakness zone (red) and contact weakness zone (magenta) between breccia and monzonite (ground mass) units

5 Conclusion

The block cave mining method involves large volumes of rock which can span several rock types, discontinuity sets and contacts. As such, the strength assessment of these types of ore bodies are often limited due to the large number of UCS samples that would be required to characterise the rock mass. In contrast, stoping methods tend to be limited to smaller volumes of rock and the sampling and testing of UCS specimens becomes more viable. Therefore, for block caves, it is typical to base geotechnical decisions on limited UCS results and at times it is impossible to determine the spatial variability of the deposit.

The Equotip method employs a simple, portable impact device to produce easily repeatable and accurate measures of the materials hardness. This data can then be converted to a prediction of UCS based on intact rock testing of core as described in this study. The benefits of this method will never replace the direct measurement of strength using the uniaxial strength testing apparatus. However, the great number of spatially oriented data can help geotechnical engineers identify the variability of rock mass strength within broad geotechnical domains as well as identify any zones within the rock mass which may be weaker or stronger. This relationship will be further reinforced as the intact test database increases as further drilling and sampling is conducted onsite. These interpretations can then be applied when numerical modelling or scheduling leading to more comprehensive, reliable model results and designs.

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