Caving 2026 – A van As, D Cumming-Potvin & J Wesseloo (eds)

doi:10.36487/ACG_repo/2645_65

Advancing orebody knowledge for cave mining using high-resolution rock strength measurements

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Abstract

Cave mining projects rely on an accurate understanding of rock mass strength and variability to inform cave design, draw strategy and geotechnical risk management. However, conventional geotechnical testing is typically limited by cost, sample availability and testing throughput, which restricts the spatial resolution of data available for cave mining applications.

The Minpraxis Tester (MPT) is a compression-breakage test device that continuously treats half-core samples along their length while operating within a conventional assay preparation workflow. By extracting strength, hardness and density information during sample preparation, the MPT enables geotechnical and geometallurgical characterisation of resource core that would otherwise not be tested using industry-standard methods. This approach substantially increases the volume and resolution of measured data, capturing variability at the centimetre scale along core intervals.

The MPT generates continuous estimates of rock strength and hardness parameters, including point load index (IS50) and drop weight index, while preserving the ability to process samples for assay. In addition, the device can test irregular lump samples, allowing strength estimates to be derived from broken core pieces and remnants from other laboratory tests that would normally lack valid measurements.

This paper presents an ongoing validation study using drill core samples from the Oyu Tolgoi mine. MPT measurements were conducted on selected core intervals, with conventional geotechnical testing performed on neighbouring material to provide reference datasets. The work focuses on evaluating how high-resolution, continuous strength measurements can support cave mine design and geotechnical modelling.

The results demonstrate the potential for significantly increasing data density for cave mining projects, as well as other mining methods, and highlight how continuous strength characterisation may support improved orebody knowledge, geotechnical block modelling and more-informed cave design decisions.

Keywords: *cave mining, Oyu Tolgoi, rock strength characterisation, geotechnical testing, orebody knowledge, high-resolution data*

1 Introduction

Cave mining is an underground mining method used to extract large, low-grade orebodies at depth. It can deliver high production rates at operating costs that are often comparable to open pit mining (Moss et al. 2018).

In recent years, the industry has increasingly shifted towards deeper and lower-grade deposits as near-surface resources are depleted and existing open pits reach their financial limits.

Cave mining performance is strongly influenced by how the rock mass caves, breaks (fragmentation) and flows, which in turn controls draw performance, dilution, production and overall geotechnical risk (Castro et

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al. 2007; Pierce 2019). As a result, there is a strong need to understand and represent rock mass behaviour within mine design and planning workflows.

This reflects a broader industry shift towards spatially predictive 3D block models that integrate geotechnical and geometallurgical parameters (Dominy et al. 2018). In cave mining, these models are especially important for representing rock mass behaviour and informing cave design and draw strategy. However, building such models requires sample characterisation tools and methods that can generate large volumes of data at the required composite sizes, with practical unit costs and turnaround times.

A key limitation in current practice is the lack of data density in geotechnical characterisation. During project assessment stages, drilling is the only practical access to the orebody and represents a very small fraction of the total volume to be mined. Of the limited drill core available, most is allocated to assay, while only a small proportion is used for geotechnical and geometallurgical testing. As a result, testing datasets are inherently sparse and often fail to capture local variability in lithology, alteration and rock strength. This can lead to block models being populated with limited or averaged inputs, reducing confidence in orebody knowledge, geotechnical block modelling and cave design decisions.

1.1 Background to the Minpraxis Tester

The MPT was developed to meet the demand for low-cost geotechnical and geometallurgical tests that can be applied to small sample volumes in large quantities, such as resource core, to generate large datasets for mine and mill engineering (Nadolski 2019; Nadolski 2020).

The MPT, shown in Figure 1, is a compression-breakage test device that processes half-core samples continuously lengthwise, as well as lump samples, providing a higher degree of rock characterisation compared to conventional methods. A core sizer device is integrated with the MPT and is used for automated size measurements as samples are fed, enabling density to be calculated for each half-core piece based on measured volume and mass.

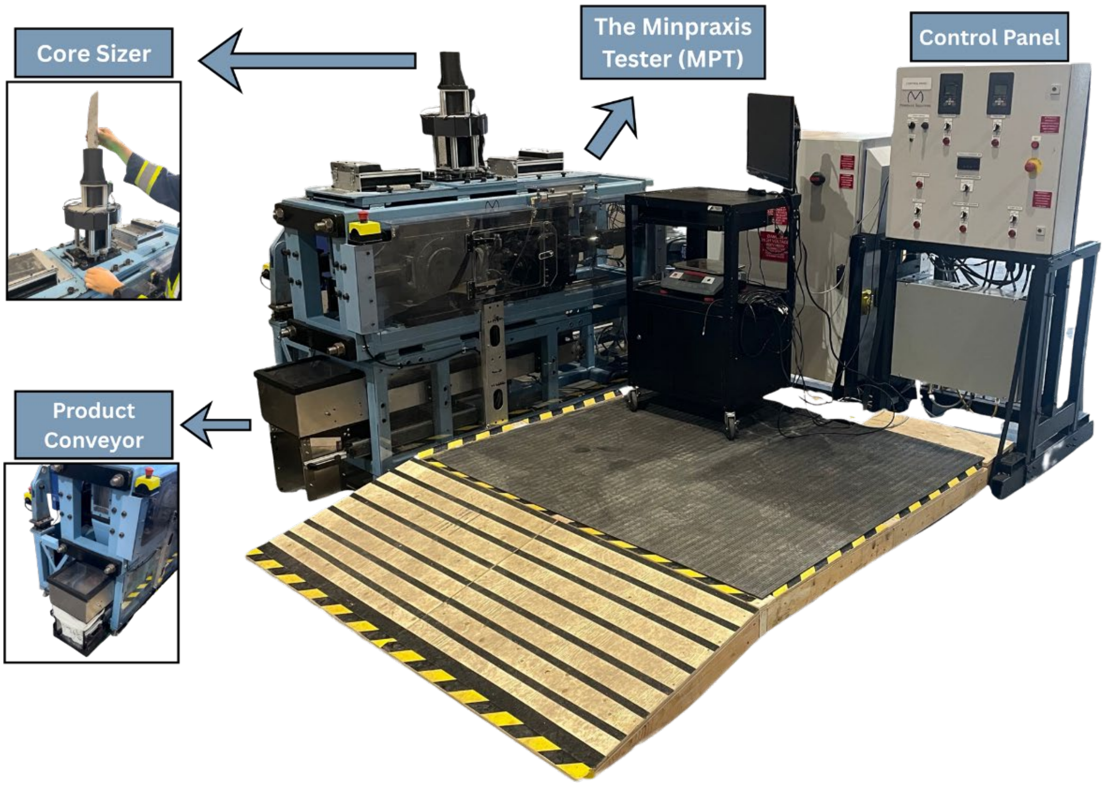


Figure 1 Minpraxis Tester, version MPT-II

The MPT has been designed and built to provide high-resolution measurement of half-core sample compressive strength while being able to process large sample volumes (+200 m of samples per 8-hour day). This allows geotechnical and geometallurgical strength information, including point load index (IS50) and drop weight index, to be extracted while the device operates as a crusher within a conventional assay preparation workflow. In turn, this expands the characterised volume of a rock mass to include samples recovered for assay purposes, i.e. resource core, which would otherwise not be measured using industry-standard methods.

The additional resolution at a local scale (on the order of 1 cm), combined with the ability to test samples during assay preparation, results in a significant increase in characterisation data compared to conventional methods. Such high-density data can be used to support 3D block models that integrate geotechnical and geometallurgical parameters.

1.2 Test program overview

This project aimed to demonstrate the impact of high-resolution strength measurements on core samples from the Oyu Tolgoi deposit in Mongolia using the MPT, with the goal of generating geotechnical data that support more reliable mine design and 3D geotechnical block modelling. Increasing the density of geotechnical data and improving overall orebody knowledge is particularly important for caving operations such as Oyu Tolgoi, where limited selectivity and restricted access reduce the ability to respond to adverse mining conditions.

The MPT test campaign was designed to generate continuous geotechnical data from Oyu Tolgoi core samples and to evaluate how well these measurements capture key rock mass characteristics. MPT-derived strength values were compared with logged vein intensity, as well as with established geotechnical strength indices, including point load index (IS50), indirect tensile strength (Brazilian test) and unconfined compressive strength (UCS).

2 Test program and sample description

The test program consisted of four main components:

- sample marking and logging, including selection of samples for conventional geotechnical testing and logging of vein intensity
- conventional geotechnical testing, conducted to provide comparative data (indirect tensile strength, point load strength and UCS)
- MPT testing on half-core samples
- data analysis, including evaluation of relationships between strength measurements (MPT and conventional tests) and vein intensity, and comparison of MPT-derived values with conventional geotechnical test results.

The test work included:

- 44 m of PQ3 core across five boreholes (EGD174, EGD177, EGD176, EGD182 and EGD187)
- 22 m of HQ3 core across three boreholes (UGD187, UGD786 and UGD824).

Table 1 summarises the number of tests carried out for each borehole, with total test counts shown in parentheses. The target was to conduct 35 point load tests (PLTs), 25 indirect tensile tests and 5 UCS tests per borehole. In practice, fewer tests were completed for some boreholes due to limited sample availability and suitability constraints for specific test methods.

The MPT tests (n = 548) were conducted on approximately 46 m of core and completed within a single day. Point load tests (n = 264) and indirect tensile strength tests (n = 210) were conducted in-house, taking approximately 1 week and 2 weeks, respectively. The UCS tests (n = 24) were outsourced to an external laboratory.

Table 1 Summary of core lengths and number of MPT tests, and valid point load, indirect tensile and uniaxial compressive strength (UCS) tests for each borehole, with total tests shown in parentheses

Borehole ID	Core size	Length (m)	Number of MPT tests	Number of point load tests	Number of indirect tensile strength tests	Number of UCS tests
EGD174	PQ3	9.5	77	22 (33)	16 (29)	6 (6)
EGD176	PQ3	8.2	59	32 (35)	24 (25)	4 (5)
EGD177	PQ3	10.1	75	29 (35)	22 (25)	4 (5)
EGD182	PQ3	7.2	56	23 (35)	19 (22)	No tests
EGD187	PQ3	9.5	62	23 (34)	21 (25)	5 (5)
UGD187	HQ3	9.0	87	23 (33)	17 (24)	No tests
UGD786	HQ3	8.4	91	19 (33)	24 (32)	3 (3)
UGD824	HQ3	4.5	41	12 (26)	28 (28)	No tests
	Total	**66.4**	**548**	**183 (264)**	**171 (210)**	**22 (24)**

Figure 2 presents the distribution of testing along each borehole, showing the location and type of tests conducted. Irregular sampling depths reflect the core intervals made available by the mine site from the selected boreholes, rather than a systematic sampling design.

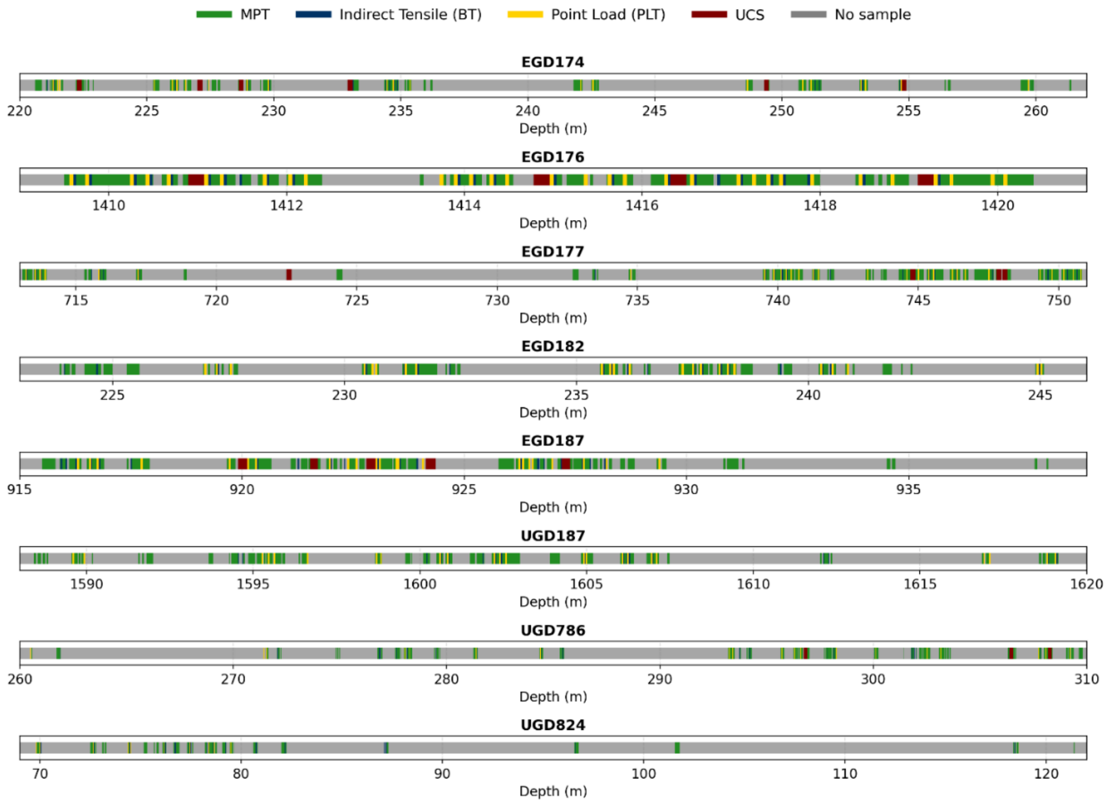


Figure 2 Distribution of available samples and geotechnical tests along core intervals for each borehole

2.1 Core logging and characterisation

Vein intensity was quantified as vein counts per metre: total number of veins (classified as <1 mm, 1–5 mm and >5 mm) observed on each core sample, normalised by core length.

Figure 3 shows the PQ3 core samples laid out prior to the determination of vein intensity.

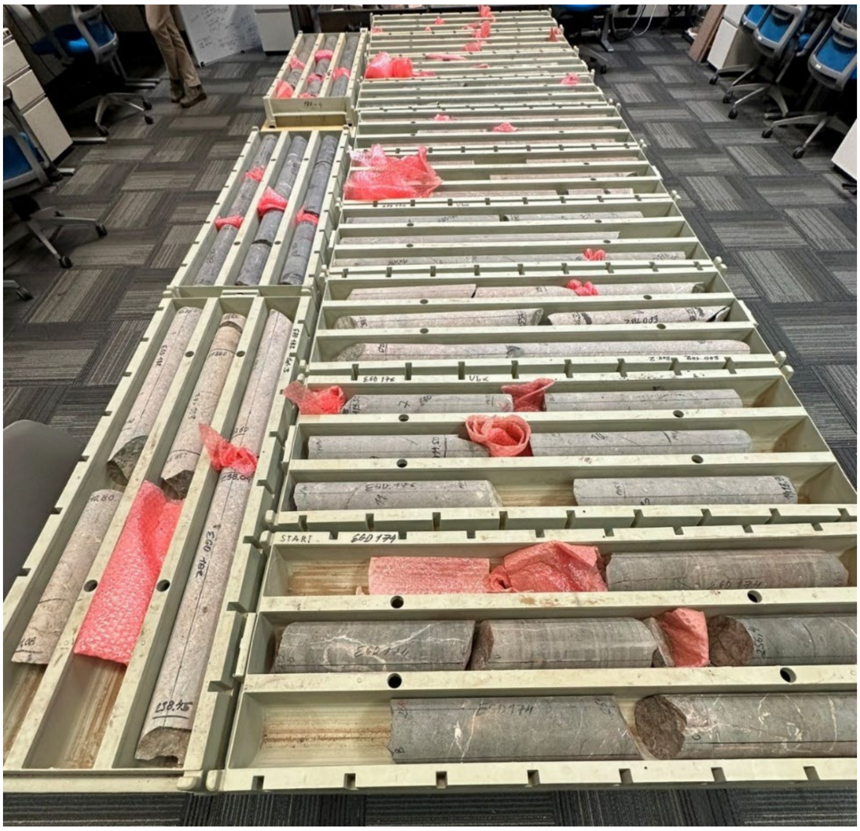


Figure 3 Oyu Tolgoi core samples (PQ3) laid out prior to logging for vein intensity

2.2 Conventional geotechnical testing

Conventional geotechnical testing – point load testing, indirect tensile strength testing (Brazilian test) and UCS testing – was conducted to provide comparative strength measurements.

2.2.1 Point load testing

Point load tests were conducted internally using axial loading in accordance with ASTM D5731 (ASTM International 2016). The mean point load strength index, IS50, for each borehole was calculated by excluding the two highest and two lowest values from datasets containing 10 or more valid tests and averaging the remaining results.

Figure 4 shows a PLT sample from EGD187 (PQ3) before and after testing.

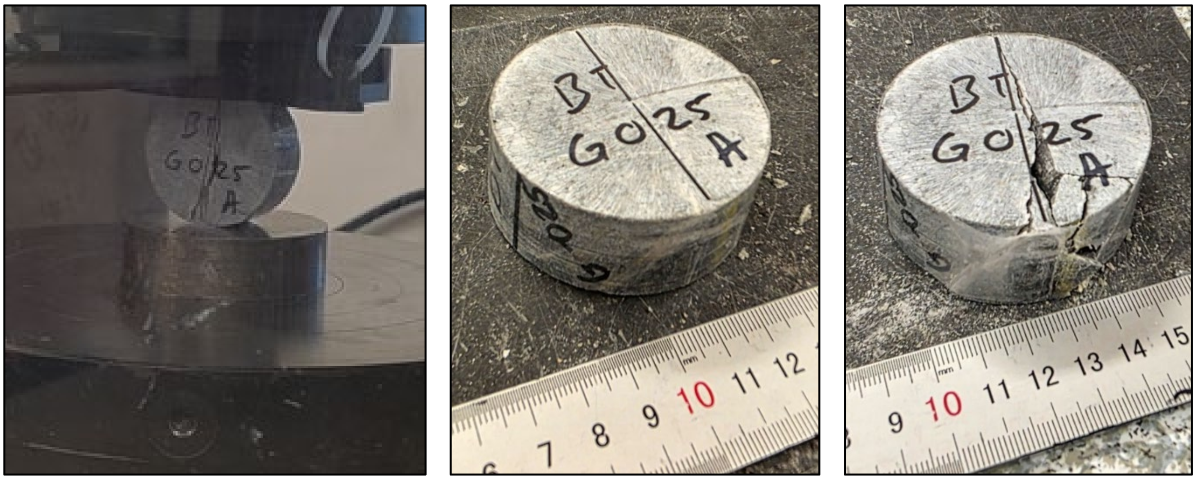
(a) (b)

Figure 4 Point load test sample from EGD187 (PQ3). (a) Before testing; (b) After testing

2.2.2 Indirect tensile strength testing (Brazilian test)

Indirect tensile strength testing was performed internally in accordance with ASTM D3967 (ASTM International 2023). The results of valid tests were averaged for each borehole to obtain representative tensile strength values.

Figure 5 shows the test set-up and a sample from UGD786 before and after testing.



(a) (b) (c)

Figure 5 Indirect tensile strength (Brazilian) test. (a) Test set-up; (b) Sample before testing; (c) Sample after testing (UGD786)

2.2.3 Unconfined compressive strength testing

UCS testing was conducted at an external laboratory in accordance with ASTM D7012 Method C (ASTM International 2014). The results of valid tests were averaged for each borehole to obtain representative UCS values. Densities reported from UCS testing were also compared with densities measured using the MPT.

Figure 6 shows a UCS sample from EGD187 (PQ3) before and after testing.

(a) (b)

Figure 6 Unconfined compressive strength test sample from EGD187 (PQ3). (a) Before testing; (b) After testing

2.3 MPT testing

MPT tests were conducted on half-core samples to generate MPT-predicted PLT IS50 values and to compare them with results from conventional geotechnical testing. No specific sample preparation is required for MPT testing, in contrast to PLT, indirect tensile and UCS tests, which require prepared samples.

Samples were fed through the machine, with high-resolution data collected along each core sample. As described in Section 1.1, the MPT also measures the size of each core piece automatically during testing. Combined with mass measurements, this enabled density to be calculated for each half-core piece and aggregated at the borehole scale. These density values were compared against measured densities from conventional testing for validation.

3 Results

3.1 Comparison of MPT-predicted strength with conventional geotechnical tests

Figures 7, 8 and 9 compare MPT-predicted PLT IS50 values with measured PLT IS50, UCS and indirect tensile strength (Brazilian test), respectively, at the borehole scale. Median MPT-predicted values and mean measured values from each borehole were used for the comparison.

Overall, the MPT-predicted PLT IS50 values for each borehole show a good level of agreement with measured PLT IS50 results (Figure 7), with an R^2 value of 0.80. The general trend indicates that the MPT captures relative variations in rock strength across the different boreholes. Some scatter is observed, particularly for two HQ3 boreholes (UGD786 and UGD824), which is expected given the limited number of conventional PLTs available for these boreholes (19 and 12 valid PLT measurements, respectively), as well as the inherent variability of the rock mass.

A similarly strong relationship is observed between MPT-predicted PLT IS50 and measured UCS values (Figure 8), with an R^2 value of 0.79. This suggests that MPT-derived strength values are consistent with compressive strength behaviour and can provide a reliable proxy for UCS at the borehole scale.

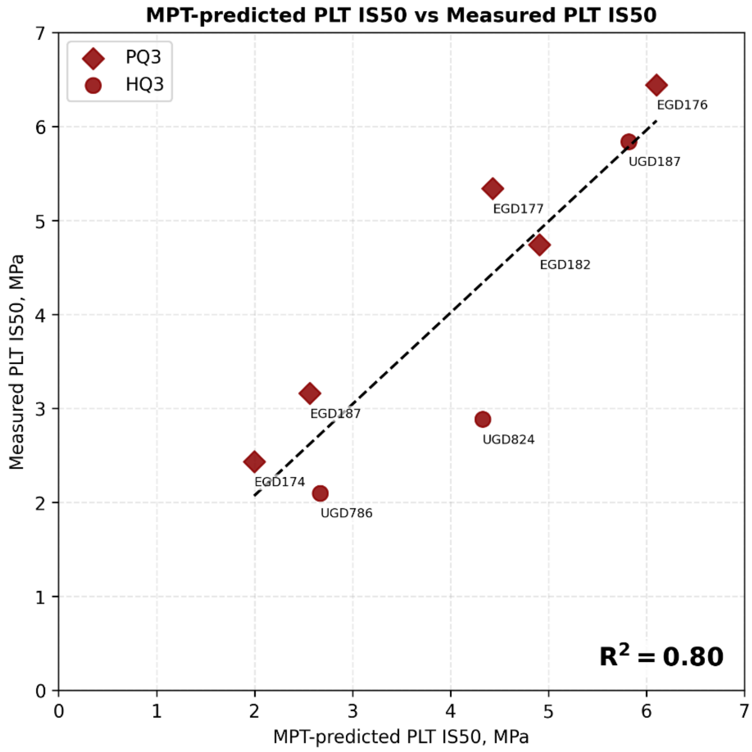


Figure 7 Comparison of Minpraxis Tester-predicted PLT IS50 and measured PLT IS50 at the borehole scale

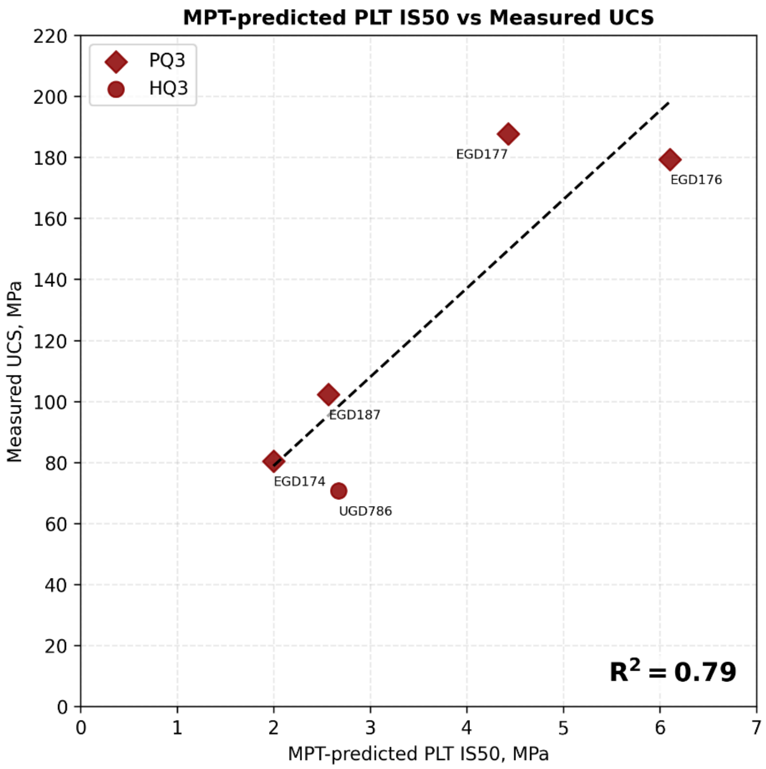


Figure 8 Comparison of Minpraxis Tester-predicted PLT IS50 and measured unconfined compressive strength at the borehole scale

The comparison between MPT-predicted PLT IS50 and indirect tensile strength (Figure 9) also shows a strong correlation (R^2 = 0.87). The results indicate that MPT measurements can capture trends in tensile strength, although some variability remains, particularly for UGD824.

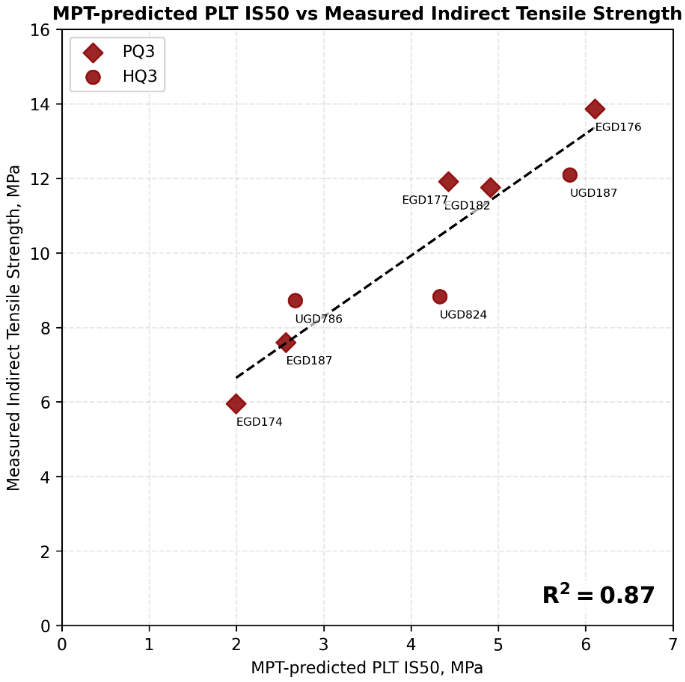


Figure 9 Comparison of Minpraxis Tester-predicted PLT IS50 and measured indirect tensile strength (Brazilian test) at the borehole scale

Across all comparisons, PQ3 and HQ3 samples generally follow similar trends, although some scatter is observed for two HQ3 boreholes. This may be related to differences in sample availability, test counts, local geological variability and the inherent variability that exists within the rock mass.

Overall, the results demonstrate that MPT-derived IS50 values are aligned with conventional geotechnical test results and can capture relative differences in rock strength across the tested intervals.

3.2 Influence of lithology and veining on strength measurements

Table 2 shows vein intensity and strength measurements for each borehole and lithology, including MPT-predicted PLT IS50, measured PLT IS50 and UCS values. These results are also shown in Figure 10.

Table 2 Vein intensity and strength measurements by borehole and lithology

Borehole ID	Lithology	Vein counts per metre		MPT-predicted PLT IS50 (MPa)			Measured PLT IS50 (MPa)		Measured UCS (MPa)	
		Mean	Std Dev	Mean	Median	Std Dev	Mean	Std Dev	Mean	Std Dev
EGD174	L	44.7	15.6	3.5	2.0	4.3	2.4	1.2	80.5	18.3
EGD176	Vbx	26.1	13.4	7.0	6.1	3.3	6.4	0.9	179.3	14.5
EGD177	Dac	27.1	15.3	4.9	4.4	2.4	5.3	1.5	187.8	39.3
EGD182	Qm	28.1	16.0	5.4	4.9	3.3	4.7	2.1	No tests	
EGD187	Bat	34.8	13.0	3.6	2.6	2.5	3.2	1.1	102.3	39.3
UGD187	AndT	25.4	18.9	7.2	5.8	5.1	5.8	2.5	No tests	
UGD786	Qmd	27.6	8.7	3.8	2.7	3.2	2.1	1.0	70.7	18.7
UGD824	Va	34.2	12.7	5.0	4.3	3.3	2.9	1.0	No tests	

Lithology abbreviations: L = Basaltic lava breccia; Vbx = Volcanic breccia; Dac = Dacite; Qm = Quartz monzonite; Bat = Basaltic andesitic tuff; AndT = Andesitic tuff; Qmd = Quartz monzodiorite; Va = Volcanic augite basalt

Figures 10 and 11 present the distribution of MPT-predicted PLT IS50, measured PLT IS50 and UCS values, together with vein intensity, across the main lithological units.

Strength values show clear variation with lithology. Lithologies such as Vbx (EGD176), Dac (EGD177) and Qm (EGD182) generally exhibit higher and more consistent strength values across all measurement methods. In contrast, lithologies such as L (EGD174), Va (UGD824) and Qmd (UGD786) show greater variability and, in some cases, lower strength values.

This variability is consistent with the observed vein intensity distribution (Figure 11). Lithologies with higher vein counts per metre, particularly L (EGD174), tend to exhibit lower and more variable strength values. In contrast, lithologies with lower vein intensity, such as Vbx, Dac, and Qm, generally show higher and more consistent strength.

These observations help explain some of the scatter observed in Section 3.1. Boreholes associated with higher vein intensity, including UGD824 and EGD174, show greater variability (EGD174) and deviation from the general strength trends (UGD824). In contrast, boreholes with lower vein intensity, such as EGD182, show more consistent agreement between MPT-derived values and conventional geotechnical test results.

Overall, the results indicate that MPT measurements capture lithology-related variability and structural effects on rock strength in a manner consistent with conventional testing, while providing higher-resolution data within each unit.

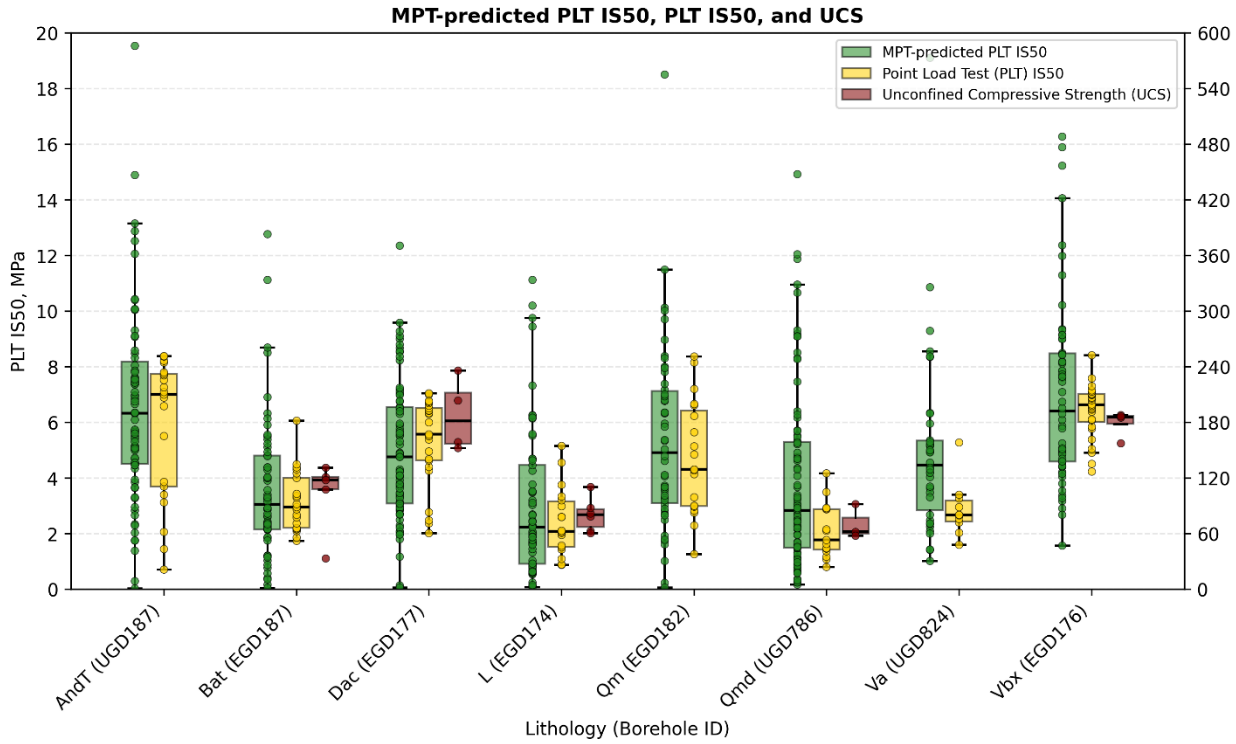


Figure 10 Distribution of Minpraxis Tester-predicted PLT IS50, measured PLT IS50 and UCS values by lithology (borehole IDs shown in parentheses)

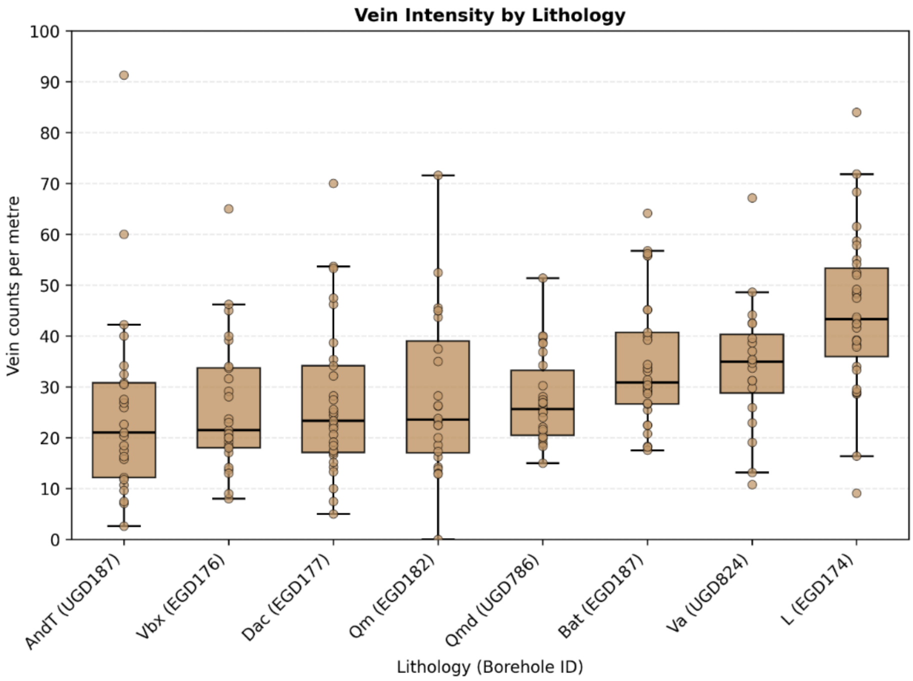


Figure 11 Vein intensity (vein counts per metre) by lithology (borehole IDs shown in parentheses)

3.3 Comparison of Minpraxis Tester-measured and laboratory-measured density

Figure 12 compares densities measured using the MPT with densities reported from laboratory UCS testing at the borehole scale.

Overall, a good level of agreement is observed between MPT-measured and laboratory-measured densities, with an R^2 value of 0.76. The results show that the automated size measurements combined with mass measurements used by the MPT provide reliable density estimates. Minor differences are observed for some boreholes, generally within 1–3%, which may be related to differences in sample selection, measurement methods and inherent variability within the core.

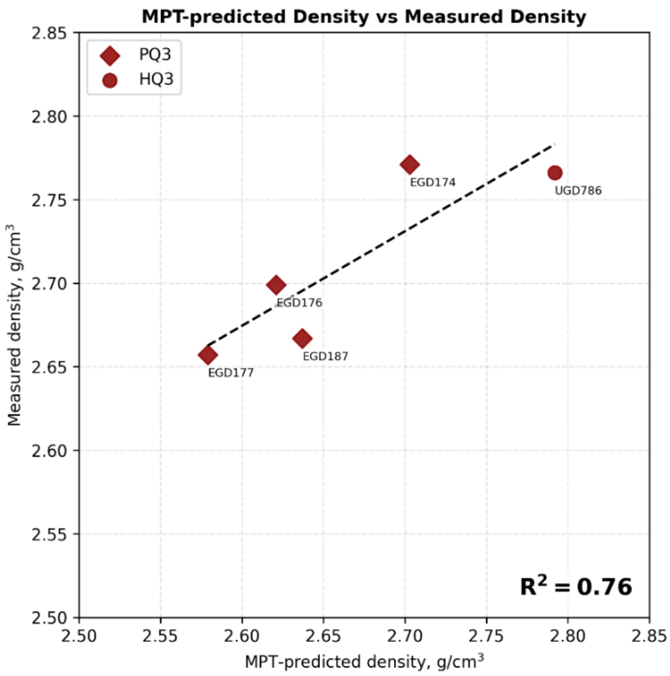


Figure 12 Comparison of Minpraxis Tester-measured and laboratory-measured density at the borehole scale

4 Conclusion

This study evaluated the use of the MPT for generating high-resolution strength and density measurements from drill core samples from the Oyu Tolgoi deposit.

The results show that MPT-predicted PLT IS50 values are aligned with conventional geotechnical test results (for point load strength, UCS and indirect tensile strength) and capture relative variations in rock strength across boreholes and lithologies. The agreement with UCS and indirect tensile strength is particularly strong, indicating that MPT-derived values can provide a reliable proxy for compressive and tensile strength at the borehole scale.

Analysis of strength and vein intensity by lithology shows that variations in rock strength are consistent with structural features such as veining. Lithologies with higher vein intensity tend to exhibit lower and more variable strength values, which also explains part of the scatter observed in comparisons with conventional test results. The MPT measurements capture these variations in a manner consistent with conventional geotechnical testing.

Density measurements obtained using the MPT show good agreement with laboratory-measured densities, with differences generally within ~3%, demonstrating the reliability of the automated size and mass-based density estimation approach.

Overall, the MPT provides a practical method for generating high-density geotechnical and geometallurgical data from core samples without additional sample preparation. The ability to capture continuous strength and density variability along core samples has the potential to improve orebody knowledge and support applications such as geotechnical block modelling and cave mine design. Future work is focused on quantifying the value of MPT-derived geotechnical data in operational caving workflows, particularly for preconditioning planning, hydraulic radius and drawpoint spacing decisions, and other elements of cave design.

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