Improving Orebody Knowledge with High-Resolution Rock Strength Characterization Using the Minpraxis Tester

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Abstract

The Minpraxis Tester (MPT) is a compression-breakage test device that treats half-core samples continuously length-wise, providing a high degree of rock characterization in comparison to conventional methods. Furthermore, it is able to extract this information while operating as a crusher when used in a conventional assay preparation workflow. This expands the characterized volume of a rock mass to include samples that were recovered for assay purposes, in other words resource core, and would otherwise not be measured with industry-standard methods. The additional resolution on a local-scale (order of 1cm) and the ability to test samples while preparing them for assay results in a significant increase (order of 500 times more) in characterization data over conventional methods.

The MPT device can also be used to test lump samples, which provides the capability to test core pieces that have broken apart during the drilling process as well as the ability to rapidly test lump pieces, such as those from grade control samples, to determine their crushability and grindability.

Outputs of the device can be successfully correlated to geotechnical and geo-metallurgical parameters, such as point load index (IS_{50}), drop weight-type indices and Bond ball mill work indices, which are measured while capturing the variability of strength within core sections or granular samples.

This paper presents results from a range of testing campaigns that were carried out using samples from various deposit-types to demonstrate the applicability of the MPT technology to predicting geotechnical and geo-metallurgical parameters.

Keywords

Comminution, geotechnical characterization, geometallurgical characterization, crushing indices, grinding indices

Introduction

The mining industry is challenged by having only 20 percent of mining operations perform within estimates outlined in feasibility studies (Dussud et al., 2019). A substantial proportion of underperforming mining operations trace back their failures to a lack of orebody knowledge. Orebody knowledge is fundamental to the design and operation of mining projects by providing valuable information for geological, mining, metallurgical, environmental, and economic decisions (Lakshmanan & Gorain, 2019; Jackson, 2017). Sample and data sources feeding into orebody knowledge are usually obtained from testing and analyses of drill core, geological mapping, and geophysical/chemical surveys.

During project assessment stages, drilling is the only practical access to the orebody and represents a tiny fraction of the volume to be mined and processed (<0.001%). Of the small quantity of available drill core, the majority is used for metal assay (i.e., resource core) while only a small proportion is used for testing to inform mine and plant design. Dunn's (2014) review of several projects revealed that, for scoping level studies, the percentage of geotechnical boreholes providing core samples for focused geotechnical testing in proportion to resource boreholes had a mean of 2.8%. For feasibility level studies, this percentage increased to a mean of 11.9%. These proportions vary based on the complexity of the ore body and the mining method used. Similarly, in the context of geometallurgy, metallurgical boreholes for generating test samples represent a small proportion of resource boreholes. Metallurgical testing is time-consuming (compared to the geochemical analyses that are performed meter by meter along core recovered from resource boreholes), generally resulting in only a few (<100) core samples of greater support (e.g., one observation per 10-meter interval in a geostatistical context) being subject to comminution and flotation tests (Hoffiman et al., 2022).

The industry trend towards developing spatially predictive 3D block models, which incorporate geotechnical and geo-metallurgical parameters, necessitates the use of sample characterization methods that can generate large volumes of data with appropriate composite sizes, unit costs, and turnaround times. There are many examples where efforts have been made through application of scanning methods to extend geotechnical and/or geometallurgical sample characterization to resource boreholes, such as the work of Harraden (2018), where the potential for using a Corescan hyperspectral drill core logger for geotechnical and geometallurgical applications was studied.

Comminution tests that are integral to routine assay sample preparation have also been proposed including the GeM Comminution index (Kojovic et al, 2010), which was based on constrained jaw crushing protocols linked to analysis of resultant size distributions. The authors noted that the JKTech Drop-Weight Test (Drop-Weight) A×b estimates exhibited a low level of correlation and suggested further steps to improve the model to address several limitations, such as difficulties with friable cores and samples with high clay content, and sensitivity of the method to variable feeding rates (choke vs trickle), crusher closed-side setting drift and variation in feed shapes. To improve on the GeM method, Couët et al. (2015), proposed a test which was based on the use of two stages of jaw crushing, followed by roll crushing with roll power being recorded by a power meter and size analysis of products. The authors found that the reliability of the test was limited due to the sensitivity of the results to drift in closed-side setting on the roll crusher that provided the main inputs to the predictive model.

The Minpraxis Tester (MPT) was developed to meet the demand for low-cost geotechnical and geo-metallurgical tests that can be applied to small sample volumes in large quantities, such as resource core (Nadolski, 2019 and Nadolski, 2020). The MPT can be used as a crusher in a typical assay preparation workflow while providing a high-resolution measurement of sample compressive strength. In the case of processing half-core, samples are processed lengthwise at a local-scale resolution in the order of 1cm. The MPT device can also be used to test individual lump samples, which provides the capability to test core pieces that have broken apart during the drilling process as well as the ability to rapidly test lump pieces, such as those from grade control samples. Overall, a two-fold increase in strength information is achieved for a rock mass: continuous high-resolution strength measurement and measurement of resource samples collected for metal assay (which would otherwise not be tested for strength and hardness characterization purposes).

A full-scale prototype of the Minpraxis Tester is shown in Figure 1. Key distinguishing features that best represent innovation are its high-resolution force sensor, large drivetrain allowing for controlled crushing, roller position sensors, high (50,000 Hz) data sampling rate and sensors for real-time gap measurement. A hydraulic system is used to apply compressive forces to samples as they are being drawn in between the rolls, while the high-resolution force sensor measures the resistance of the sample to the force being applied. The hydraulic system was specified to ensure that the pressing force is sufficiently high to avoid gap expansion during sample processing. Roll gap sensors are used to confirm that the operational gap has not changed, however their primary purpose is to aid in gap adjustment for machine setup.

Coupled with a core feeder tube, the MPT unit measure is able to test half-core samples lengthwise. Through application of relatively slow (~0.4 m/s) roller operation and by use of roller position sensors, strength information is able to be related to a location on the original core-piece. Sensor readings, including force, are captured at a rate of 50,0000 Hz. In the case of lump tests, where a group (~40 particles) are fed to the crusher, the individual strength of the particles is measured so that the variability within a group is captured.

As part of the technology roadmap, the full-scale MPT prototype was used with samples provided from supporting mining companies to demonstrate applicability of the device for characterizing a range of sample types (core and lump) according to their geotechnical strength, crushability and grindability. A summary of key specifications of the MPT prototype is shown in Table 1.

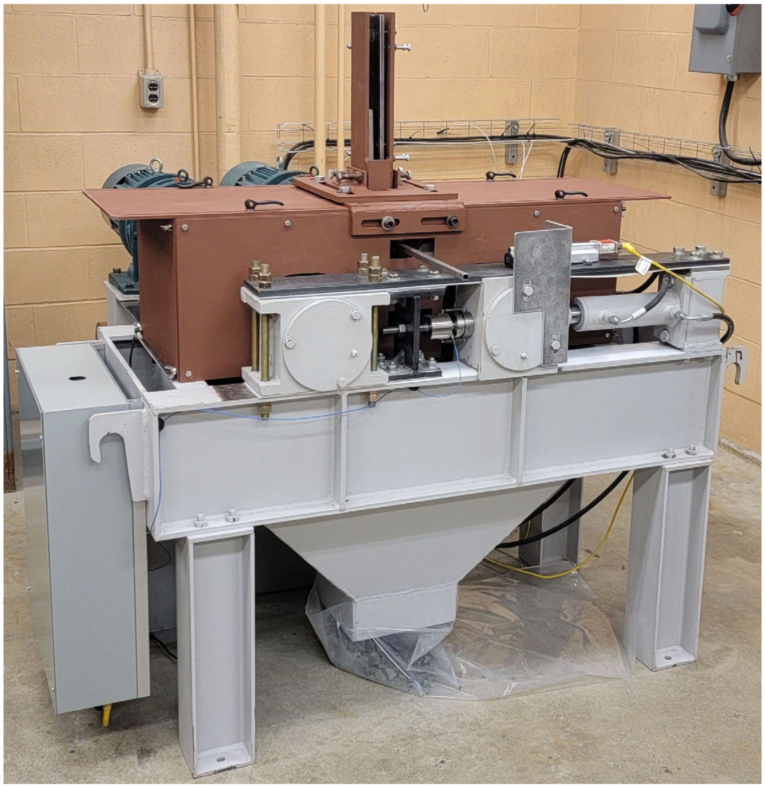

Figure 1—MPT prototype at the University of British Columbia

Table 1—MPT prototype specifications

Parameter	Value
Roll diameter	400 mm
Roll gap range	0 to +60 mm
Roll speed range	0 to 0.55 m/s
Drive train motor power	8 kW (2 x 4kW motors)
Data sampling rate, Hz	50,000

An example of an MPT compressive force response is shown in Figure 2. When processing half-core samples, force output data is categorized (e.g. binned) into slices, each representing ~1 cm along the sample length. In the case of lump tests, a shorter force response is usually observed. From the abundance of recorded data per sample piece, including force response and roller position, metrics representing compressive strength and energy input can be determined and compared to conventional geotechnical and metallurgical test responses for the same sample types (or representative splits).

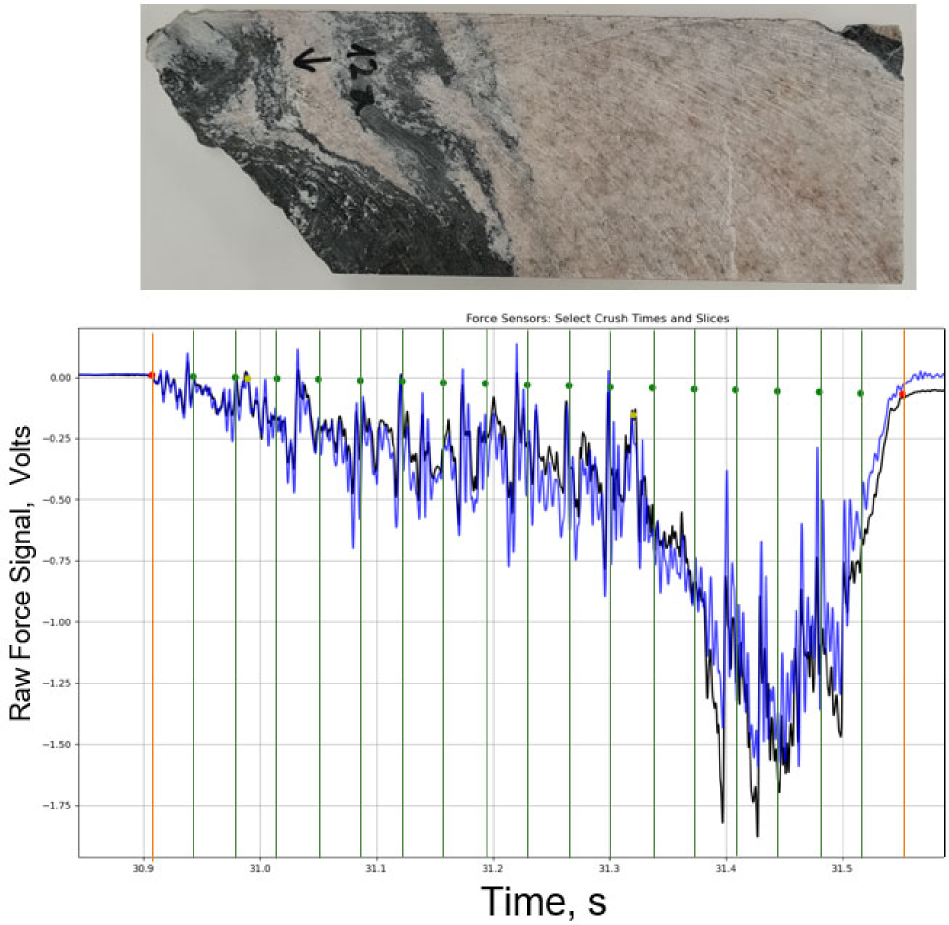

Figure 2—Example of MPT compressive force outputs for a half-core sample

Applicability of the MPT to geotechnical strength characterization

Understanding the spatial variation in rock mass strength is critical to many aspects of geotechnical mine design, including excavation and ground support design (Pierce, 2022). Geotechnical strength testing using Point Load and UCS approaches is usually carried out at large drill core intervals of approximately 5 to 10 meters and requires full diametral core. Together with the University of British Columbia (UBC) and sponsoring mining companies, Minpraxis carried out a number of geotechnical testing programs to demonstrate applicability of the device to geotechnical strength characterization. Since the MPT is currently setup to accept half-core specimens, Şahin et al's (2020) half-core point load methodology was carried out for the cases where sample runs were only available in half-core form. Otherwise, the American Society for Testing and Materials (2017) and International Society for Rock Mechanics (Franklin, 1985) point load testing methods were followed to calculate point load Is(50) values, which is the size corrected point load strength index, Is(D), of a rock specimen that would have been measured by a diametral test with a diameter of 50 mm.

A large testing campaign was carried out for HQ half-core samples from a volcanic-hosted massive sulfide deposit. The sample included 51 geo-groups, with each geo-group consisting of approximately 11 metres of continuous half-core, for a total of 550 metres of half-core. Samples were sourced from various boreholes and represented different stages of the projected mine life. For each geo-group, 20 point load tests were carried out using samples taken every ~0.5 metres of core run. To calculate the average point load strength of each geo-group, the two highest and two lowest point load values were eliminated from the set of valid test results, as per ASTM, 2017c. The means of the point load test results were calculated and compared to the MPT outputs for the remaining samples within each geo-group.

Following core logging and MPT and point load testing, HQ half-core samples were measured and processed with the MPT at a gap setting such that the ratio of sample thickness to roll gap (gap ratio) was 1.2. Based on the measured force and cross-sectional area of the sample, the maximum IS50 value occurring at 1-cm intervals was determined. For each geo-group, the 70th percentile of IS50 values for the ~11 metre core runs (i.e., the 70th percentile of approximately, 1,100 IS50 values of similar length-weighting) showed a strong correlation to the mean point load strength for the corresponding group. A comparison of the means of each method are shown in Figure 3, while Figure 4 compares the distributions of results.

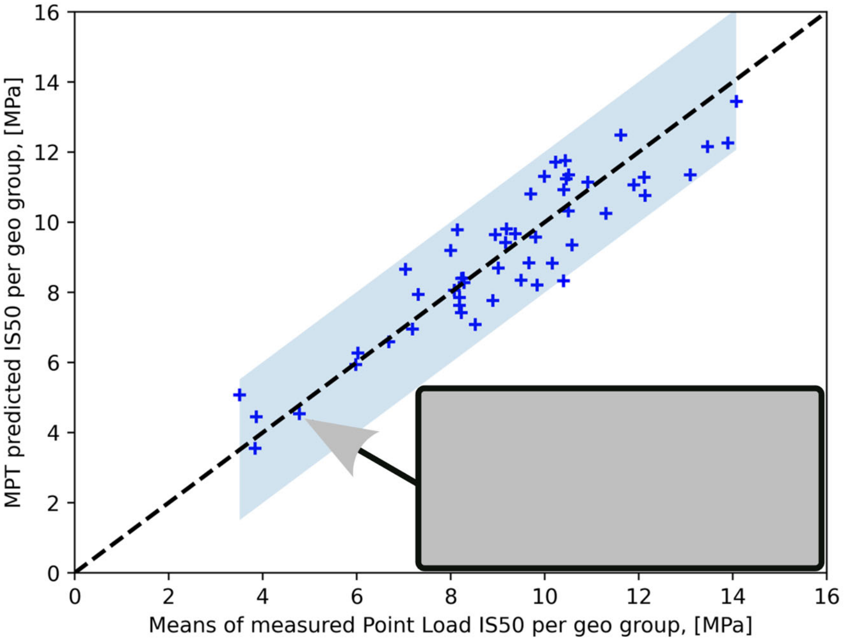

Figure 3—Comparison of MPT predicted and measured Point Load IS50 values for 51 geo groups. Shaded areas show the 90% prediction intervals. The distribution of MPT measurements is shown for one geo-group

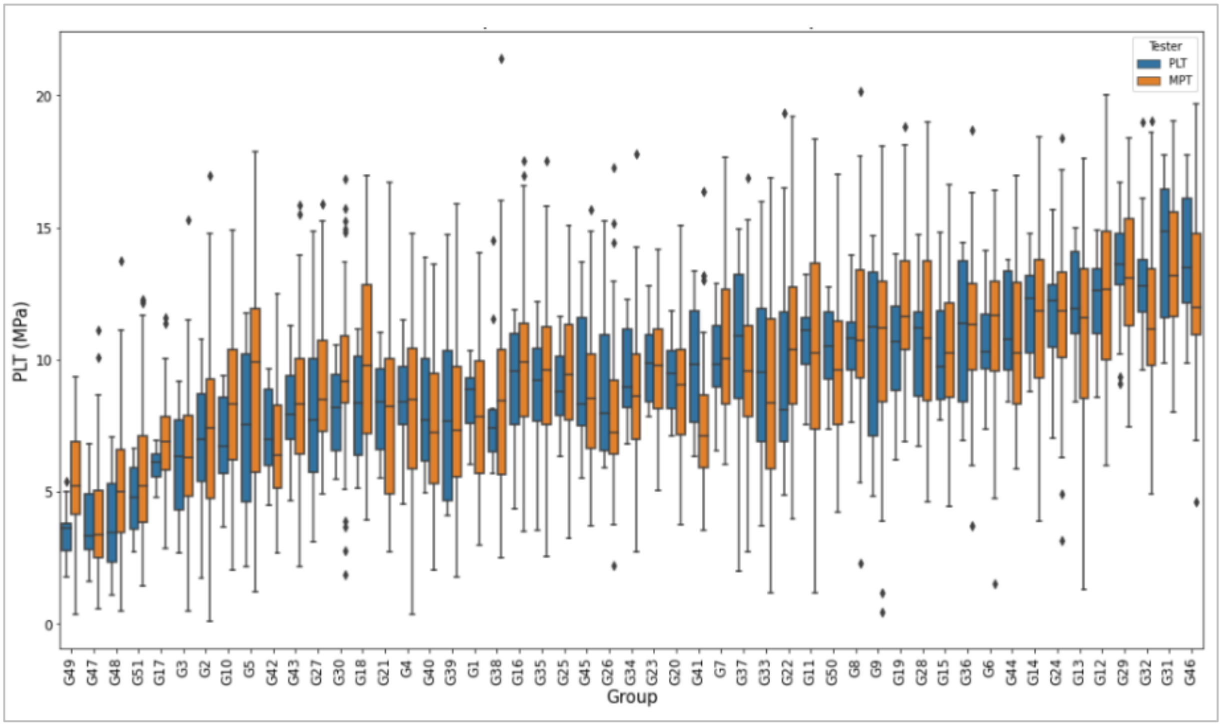

Figure 4—Comparison of MPT predicted and measured Point Load IS(50) values for 51 geo-groups

In addition to generating additional data to tie into geotechnical block modelling, the sampling resolution of the MPT has implications to the margin of error associated with strength variation. A study for a copper porphyry deposit in British Columbia showed that the reduction in error margin for the mean of point load strength reduced by 76% for a ~15-metre downhole section (at a confidence interval of 90%), shown in Figure 5.

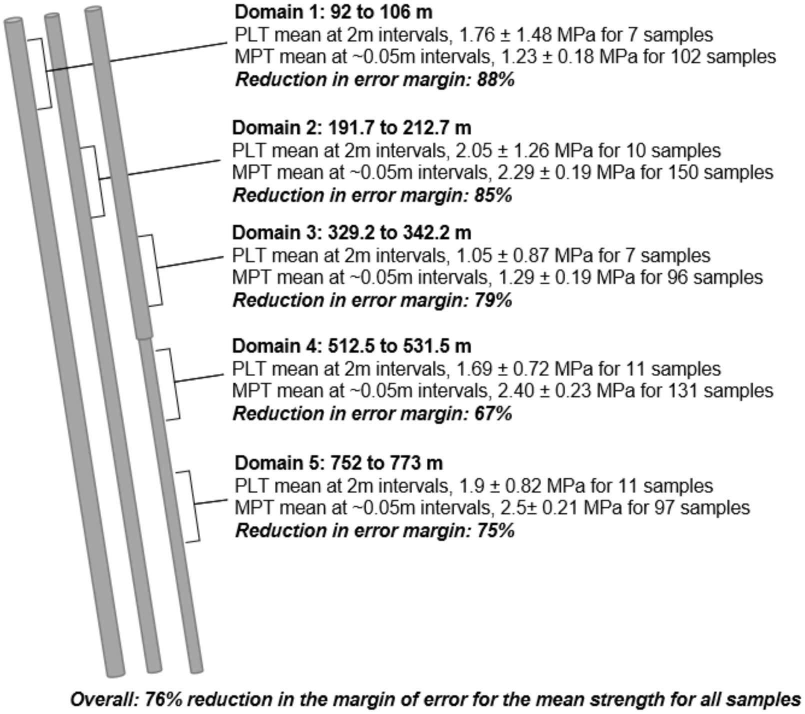

Figure 5—Point load results for three boreholes for a copper porphyry. An example of the change in the reduction in error due to the abundance of MPT measurements. Error margins are relevant to a nominated confidence level of 90%

More work is being done towards further validation of the MPT with geotechnical strength tests requiring full diametral core such as the Brazilian tensile test, UCS and axial/diametral point load tests.

Applicability of the MPT to crushing and grinding indices

Results from the MPT device when processing half-core and lump samples were compared to crushing and grinding indices to assess application of the technology for focused characterization work or as an assay preparation crusher for resource core or ore control samples.

MPT HALF-CORE PROCESSING AND SMC (DROPWEIGHT) VALUES

For the previously mentioned 550 metre testing campaign, MPT products were sized and used for SMC tests, a test that makes use of the JK Drop Weight Test device, at a commercial laboratory. Products from each ~11 metre geo-group were combined and sieved so that representative -22.4, + 19 mm sample could be subjected for SMC testing.

To generate drop weight-type outputs, a different form of predictive model (than used for predicting point load strength) was required using results from MPT half-core testing. An output of the MPT device is the integral of the force and time curve, which has been found to strongly relate to roll energy input (due to the roll gap and roll speed remaining constant). Specific energy input can therefore be represented to a reasonable extent by the force-time integral divided by sample mass. This parameter is found to be relevant to crushing indices such as drop weight when used in an appropriate model.

For the 51 geo-groups of VHMS material, MPT processing at the gap ratio of 1.2, as described in the geotechnical section, was used to build predictive models for DropWeight Index (DWI), in units of kilowatt hours per cubic metre (kWh/m^3) and Axb, which is the product of two unitless parameters that describe product fineness (t10) in relation to specific energy (kWh/t). The MPT model outputs were found to align well to the measured drop weight results, a comparison is shown in Figure 6.

The 51 geo-groups had a significant variation in specific gravity, which may explain the discrepancy in model fit between the two figures, where a tighter predictive interval is apparent for Axb than DWI (which is volume-based). Overall, results were considered to confirm suitability of the MPT device for generation of drop weight-type outputs when processing half-core. Further investigation would be necessary to quantify the contribution of sample shape (half-core for MPT vs crushed product for drop weight sample) and size (~30 mm thick half-core for MPT vs ~20.6 mm for drop weight sample) to the observed error, as they are believed to be contributing factors.

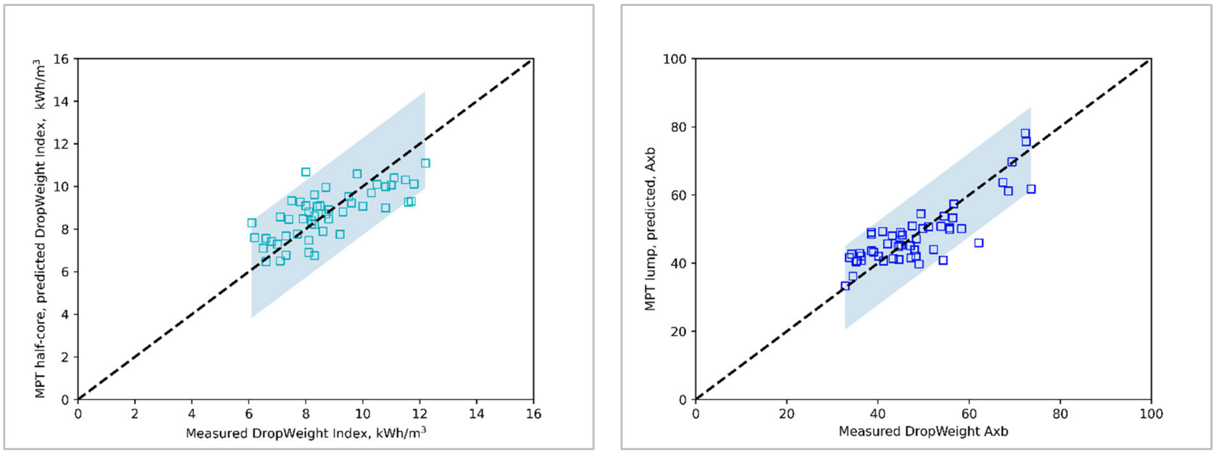

Figure 6—Comparison of MPT half-core outputs and measured drop weight Index (left) and drop weight Axb (right) values for 51 geo groups. Shaded areas show the 90% prediction intervals

As mentioned in the geotechnical section, the MPT outputs also provide the variability in strength for the ~11 metre continuous sections. Due to the resolution of MPT measurements, drop weight predictions can be compiled to a finer interval size, as used for resource core assay composites, (e.g., 1 metre) to support integration with geostatistical methods for geometallurgical block modeling.

MPT LUMP SAMPLE PROCESSING

To investigate the applicability of the MPT for rapid testing of lump samples, such as ore control samples, focused test work has been carried out on samples from over seven deposits. The current lump test methodology involves sieving of samples into narrow size fractions ranging from -13.2, +11 mm to -31.5, +26.5 mm. Each test uses 40 particles, tested individually, at the same machine settings for gap and roll speed. Product size distributions are not measured.

For each particle, the force response curve is measured and energy input is calculated from the force in relation to roll position, as described by Nadolski, 2019. In this way, the strength of individual particles can be measured to capture the variability within a sample group, as shown in Figure 7. For example, the figure shows that samples taken from the same deposit had significantly different force responses. The distribution of hardness for sample #1 is right-skewed, while sample #2 exhibits a more normal distribution. It is envisaged that the distribution of hardness within mill feed has implications to mill performance, such as the pebble recycle rate in SAG – Ball Mill – Crushing (SABC) circuit.

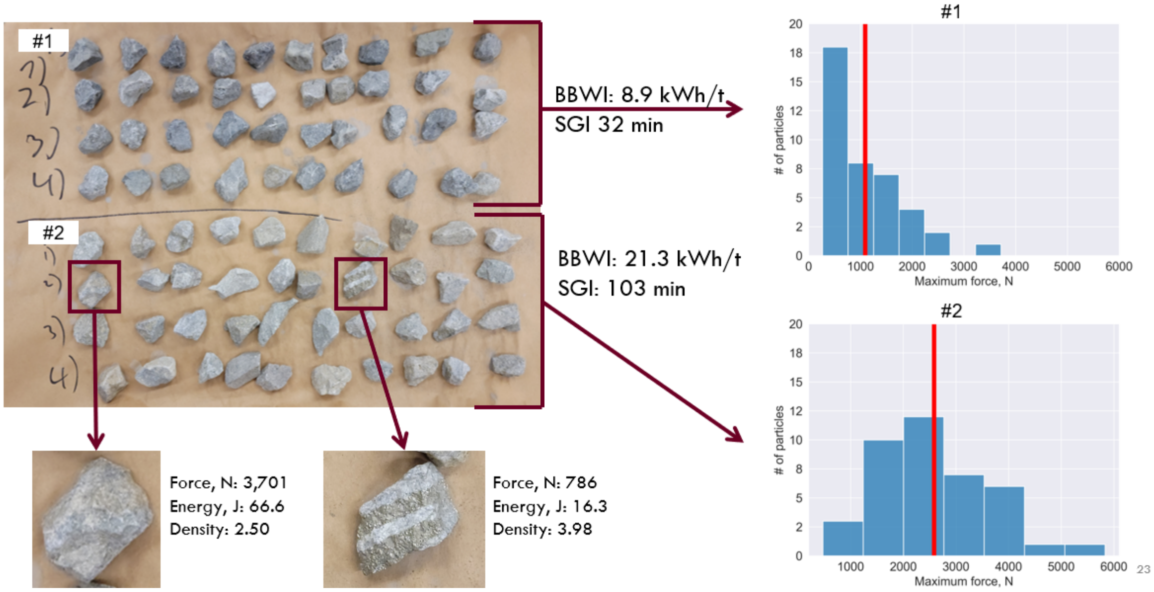

Figure 7—Capturing the variability of particle strength within samples

Outputs from MPT lump testing using a feed size of -22.4 +19 mm and a roll gap of 12.9 mm were compared to SMC test results for 51 geo-groups. 40 particles from each geo-group were tested individually and compared to DWI and Axb results, as reported by the SMC test for splits of the same size fraction. A predictive model based on MPT force and particle mass was used, presented in Figure 8.

Once the samples were prepared into the target size fraction, processing with the MPT required approximately 2-minutes of operator time per sample. Product samples were not sieved for size distribution. Data analysis was carried out with manual confirmation of test start and end times. Recently the data analysis package has been upgraded to automate analysis and summarization of test outputs. At the time of writing, the automated algorithm is being validated.

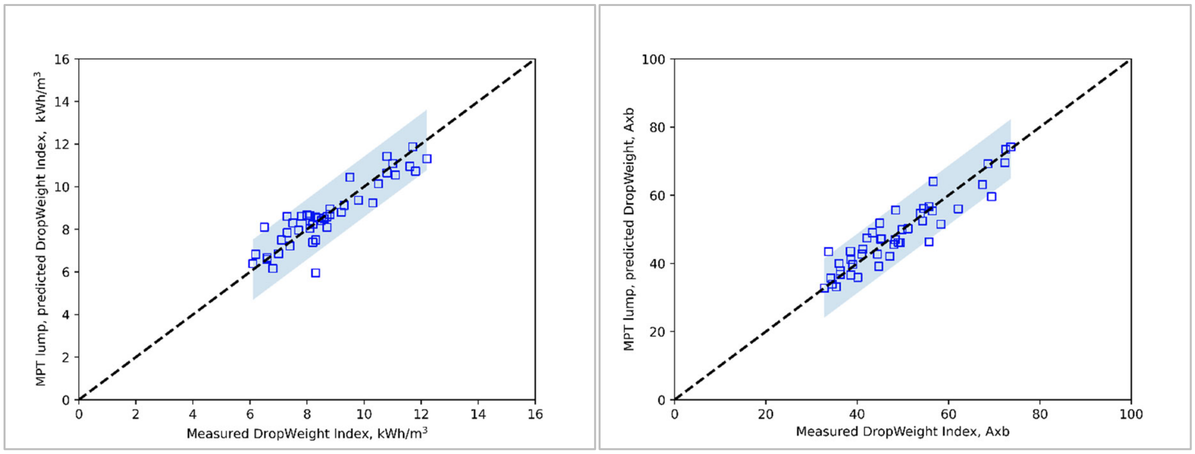

Figure 8—Comparison of MPT lump outputs and measured Drop Weight Index values (from SMC testing) for 51 geo groups of one deposit. Shaded areas show the 90% prediction intervals

For the VHMS testing program, the boreholes from which the samples originated were de-surveyed to determine the 3-D coordinates for each piece of core. A spatial representation of the estimated DWI results for each individual piece is shown in Figure 9. The figure demonstrates the potential for observing the spatial variation in rock strength and comminution parameters within a project area. Characterization of all the intervals within the presented boreholes is feasible, and it is expected that incorporating the added information into the overall orebody knowledge would be valuable for design and planning.

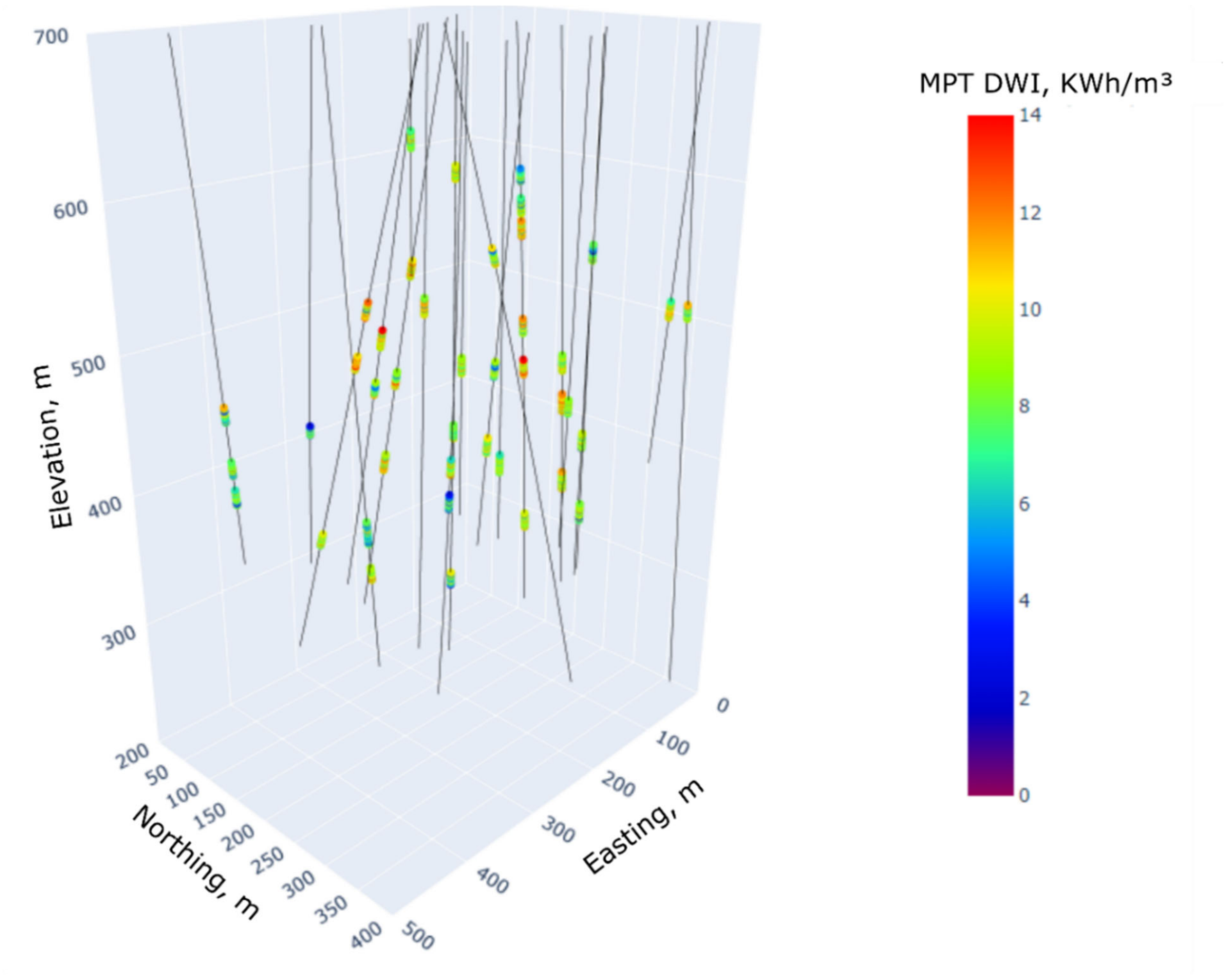

Figure 9—Spatial distribution of MPT processed samples
(Northing and Easting adjusted to preserve project anonymity)

A universal MPT lump model was applied to results from 112 samples that had corresponding DWI and Axb values. The sample set contained material from seven different deposits and a range of sample sizes (-11, +13.2 mm to -31.5, +26.5 mm). The universal model, based on the measured force and particle mass, was used for the range of particle sizes within the data set. A gap ratio of 1.6 was used for the tests. Results showing the performance of the model are presented in Figure 10.

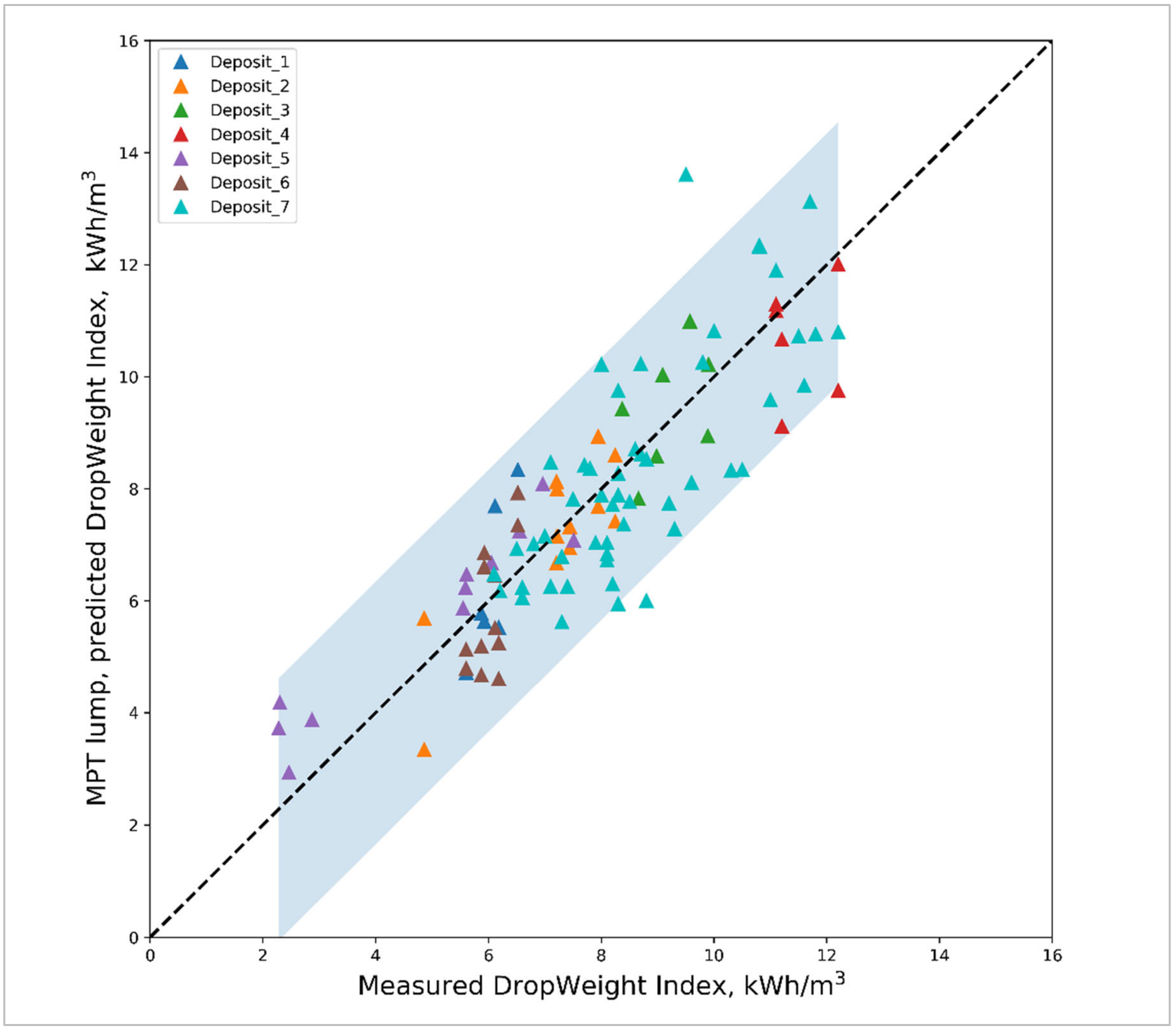

Figure 10—Comparison of MPT lump outputs and measured DWI values for seven different deposits. Shaded areas show the 90% prediction intervals

Discussion and Conclusions

Validation test campaigns with the Minpraxis full-scale prototype showed significant potential for generating geotechnical and metallurgical (comminution) data. In the case of geotechnical strength characterization, good correlations were found with MPT half-core results and point load strength for 51 geo-groups from the VHMS deposit. Additionally, the abundance of data and ability to test rubbly pieces of core samples, which do not meet point load test specifications, has significant implications to rock mass characterization. Hoek (2008) comments that conventional geotechnical testing methods are only applied to intact specimens that survive the collection and preparation process. Therefore, conventional strength testing results represent a highly biased sample set that suggest greater competency than is actually present within the rock mass. Additionally, feeding of the MPT tester is more consistent than standard point load methods, which are susceptible to operator bias (e.g., the placement of point load platens on or away from discrete rock features can vary operator to operator).

Geotechnical strength testing using Point Load (and UCS) approaches is usually carried out at large drill core intervals of approximately 2 to 10 meters. Comparatively, the MPT prototype is providing data at least every cm of roll movement. Further work is being done to quantify the practical resolution of strength measurement while considering sample edge effects. The potential for improving the size of a dataset is considerable, even with a conservative assumption that at least every half-core piece is characterized with the MPT. This is due to the technology offering two distinct advantages:

1. A finer interval of strength testing, which can increase the amount of data captured along a core run by approximately 50 times (compared to conventional methods);
2. The ability to characterize resource core that would otherwise not be tested with conventional geotechnical approaches, potentially increasing the dataset size approximately 10 times (for a generalized case where only ~10% of boreholes are geotechnical boreholes).

Taken together, these advantages can result in an overall increase in the size of the geotechnical dataset by 500 times, providing a valuable input for generation of geotechnical block models that accurately represent the spatial variation within a project area of a deposit.

The benefits in data abundance, described for the geotechnical application, are similar for the case where geometallurgical indices are being generated. In addition to the discussed benefits associated with characterizing resource core, the ability of the MPT device to rapidly test lump samples (such as those being crushed to determine ore control grades) and capture the variability in strength within the samples themselves provides new information that can be used to better design and operate crushing and grinding plants.

Other comminution indices, such as SAG Grindability Index (SGI) and Bond ball mill work index have also been the focus of comparative studies. Force responses were found to be a reliable indicator of SGI hardness for samples for a copper porphyry deposit. In the case of building predictive models for Bond ball mill work index (using MPT outputs), reasonable correlations have been found with a fine MPT test methodology using a gap size of 2.8 mm. However, it is expected that better correlations will be found with revised methodologies where a comminution duty that is more similar to that of the Bond ball mill test (e.g., a reduction from a feed top size of 3,350 µm to an 80% passing size of 150µm product size) is used as the basis of the MPT test.

In summary, the MPT device generates both geotechnical and geometallurgical outputs that can be valuable for improving orebody knowledge. It provides opportunity to substantially increase the information gained from available samples at different stages of project progression while in the case of MPT application at operating mines, there is a wide range of opportunities including implementation into an assay preparation laboratory for characterization of ore control samples.

A new field-deployable MPT device with design improvements is currently being manufactured for demonstration of the technology at mine sites, exploration sites and commercial laboratories for progression along the technology roadmap. The new MPT model is also being designed to achieve a higher precision on gap settings and force responses while improving user operability for high volume testing.

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