Practical geometallurgy – and let there be light

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ABSTRACT

Mining and processing operations that do not understand the characteristics of their deposits survive as did J R R Tolkien's Gollum; in the dark until a metallurgical crisis drags them out to search for a precious solution. Geometallurgy is about knowing metallurgical and production outcomes before ore is mined and processed and requires that the key drivers of these outcomes are attributes in the mine block model. Practical geometallurgy is the use of deposit geological 'style' characteristics and the common drivers of performance for that deposit style to generate these attributes. This allows the common features of the deposit with others of the same style with operating history to be 'banked' while focusing attention on differences discovered during a geometallurgical program. Mineralogy controls metallurgy, so a practical geometallurgy program is about measuring the important characteristics of the basis lithology, alteration, and weathering units in the deposit such as mineralogy, mineral associations, mineral liberation, and mineral texture before embarking on extensive and expensive metallurgical test programs. This paper describes the general outline of a practical geometallurgy program from sampling and retaining the characteristics of ore in 3D mineralised space to typical analysis and test programs and using the results of these programs to develop geometallurgical models to populate the block model. Geometallurgy case studies for some common deposit styles are included to give examples of the consistent drivers of performance inherent in each style.

INTRODUCTION

Geometallurgy is about knowing metallurgical and production outcomes before ore is mined and processed. To know these outcomes, the engineering block model (the mining version of the geology block model) must be populated with measured parameters or proxies (attributes) that allow prediction of metallurgical performance. Populating the engineering block model also eliminates time as a variable, allowing changes to the mine production schedule without impacting the predicted value of outcomes from processing an individual ore block.

Geometallurgy practice includes words like 'geology', and 'mining'. Hence there cannot be robust and practical geometallurgy outcomes without engaging the other two key disciplines for mineral processing operations – geology and mining.

Standardising geological and geotechnical measures and practices combined with setting up of a strategic geometallurgy program outline should commence before any holes are drilled, and certainly before samples are submitted for assay. Although it is better to be late starting a geometallurgy program than never, having an early outline in place will prevent re-work and missed key measures, and more importantly mitigate the fundamental business risk of not accurately predicting and achieving planned future production and costs. A common problem is that different disciplines will store their data in different software packages and in different locations – a geometallurgy program should have all data on a 'single tab' so that the assay, geology, geotechnical, mineralogy and metallurgy measures can all be provenanced back to a location in 3D mineralised space.

The geological style of deposit will focus the activities in a geometallurgy program plan and provide a reference case. A geometallurgy axiom is to 'bank the similarities, master the differences' as it is rare that a deposit style is unique. Geological differences or uncertainties of style may also not be geometallurgically important, for example Irish-type lead-zinc deposits and Mississippi Valley type lead-zinc deposits can be considered identical from a metallurgist's perspective.

Geotechnical measures of rock hardness taken during routine core logging can provide important information for geometallurgical ore hardness and comminution modelling. For example, measures such as rock quality designation (RQD) and Point Load Index (PLi) and other measures of rock competence are indicators of the rock's resistance to comminution (Morrell, personal communications, 2019).

Another geometallurgy axiom is to 'measure more, test less'. Measuring the geotechnical characteristics, mineralogy, mineral association, mineral liberation, and mineral texture up front allows benchmarking against other deposits of the same style and will highlight any potential differences or operating or metallurgical challenges. Testing then becomes confirmatory rather than exploratory, minimising the overall costs and time of a program. An analogy for proceeding directly to testing lacking these vital data is that it can create a 'results crime scene'; equivalent to having a body lying on the floor and no idea how it got there. You are then forced to put on a Sherlock Holmes hat and try to gather evidence which takes time and money, delays the program, and creates anxiety for project stakeholders because a metallurgical criminal is on the loose, and may never be caught. If the full characterisation measures are done upfront, to quote Captain Louis Renault in *Casablanca*, you can 'round up the usual suspects' preventing the 'results crime' from being committed.

Depending upon how common the deposit style, a suitable geometallurgy program plan can be developed well before a hole is drilled. For example, a geometallurgy plan including all the important assays, tests, and mineralogy measures for porphyry copper deposits, orogenic gold deposits, and sedimentary exhalative (SEDEX) lead-zinc deposits can be developed to a very high level of detail to capture the key drivers of metallurgical performance without even having a deposit.

From a processing perspective, deposits normally fit into one of two categories; throughput dominated, or metallurgy dominated, and a geometallurgy plan should recognise which of these categories the deposit under investigation is in. Porphyry copper deposits are a good example of throughput dominated – large and low-grade, achieving throughput is critical to the project economics, while volcanogenic massive sulfide (VMS) Cu-Au-Ag-Pb-Zn deposits are a good example of metallurgy dominated – achieving good recoveries into multiple concentrates of acceptable quality is critical. So the geometallurgy plan for a porphyry copper deposit must have comprehensive ore hardness characterisation, while the geometallurgy plan for a VMS will strongly focus on the variable mineralogy, mineral associations, and liberation size of the key minerals.

Including all the key geometallurgical measures and drivers as algorithm-based models of throughput and metallurgical performance into the block model is rarely an experience in achieving outstanding accuracy. Geometallurgy models are often performance trends due to compounding errors in sampling, measuring, and testing combined with the 'noisy' environment of process operations treating variable material. Therefore, care should be taken to avoid over-complicated models and making predictions over short time periods. The purpose of the geometallurgical models is important to understand – are they for life-of-mine, annual, quarterly, monthly production planning, or for short-term performance prediction? Models that don't capture the key drivers of performance or require constant 'tweaking' or that include variables that can't be attributes of the block model are not useful.

THE REFERENCE CASE

Most deposits are members of a geological style. It is rare that a deposit has truly unique geochemistry, rock types, and mineralogy. Some styles are very common, and this allows new deposits of the same style to be easily benchmarked against the large operating data set, with just the measures of mineralogy, mineral association, mineral liberation and texture able to provide a supportable estimate of likely metallurgical performance.

An example of deposit style benchmarking is presented in Figure 1, with a SEDEX Pb-Zn-Ag deposit under study compared with the Broken Hill, Mount Isa, and McArthur River SEDEX Pb-Zn-Ag deposits. The metallurgical performance of this deposit style is heavily influenced by the degree of metamorphism and the resultant textural complexity. Sphalerite, galena and pyrite grain sizes increase, the naturally hydrophilic carbonaceous gangue content decreases, and the spherical/framboidal form of pyrite which is finally intergrown with sphalerite is depleted with increasing degree of metamorphism. Figure 1 shows that the SEDEX under study is 'better' than McArthur River, but 'worse' than Mount Isa, and metallurgical performance (lead and zinc recoveries and concentrate grades) will be between these two.

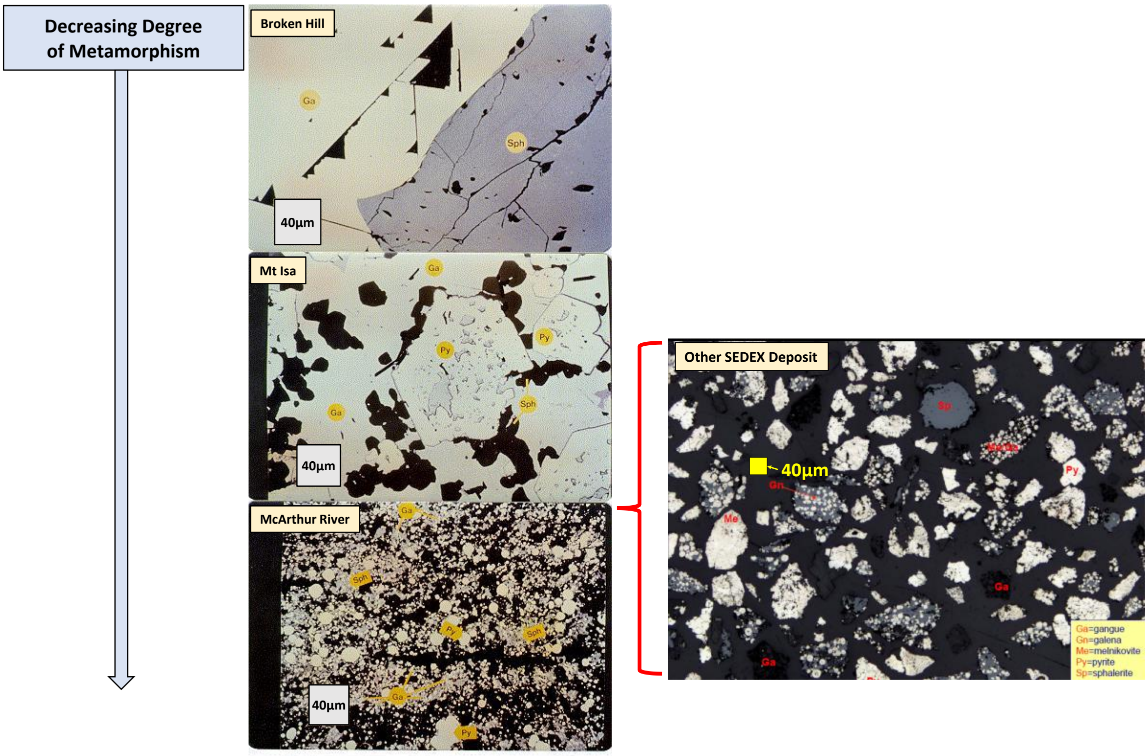

FIG 1 – Benchmarking of a SEDEX deposit against some well-established SEDEX operations.

A second example of deposit style benchmarking is shown in Figure 2 with copper sulfide mineral liberation at the optimum P_{80} primary grind size for a porphyry deposit of interest in comparison with 77 other porphyry deposits. The mean optimum P_{80} primary grind size for the 77 other deposits is 175 µm, while the deposit of interest is 150 µm. Even with the finer grind, copper sulfide mineral liberation is only 42 per cent against a mean of 52 per cent for the other 77 deposits.

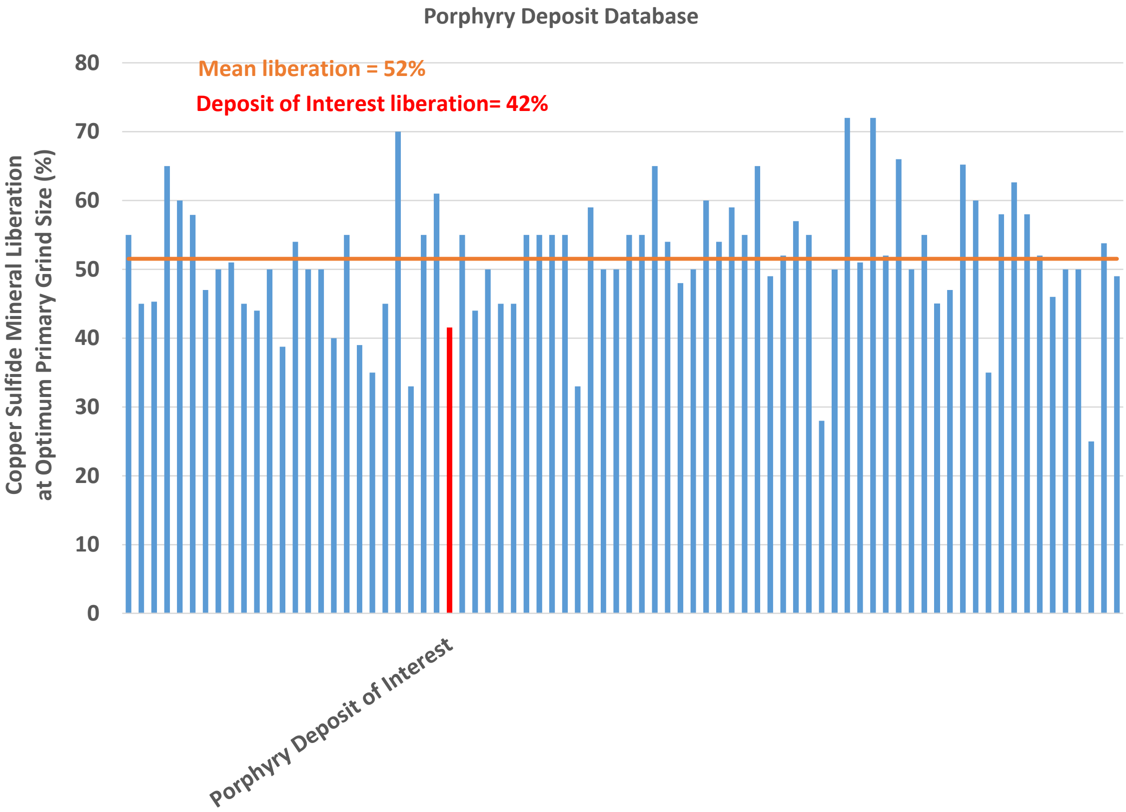

FIG 2 – Porphyry deposits copper sulfide mineral liberation at optimum primary grind size.

Figure 3 compares copper recovery into final concentrate for the same porphyry deposit of interest (head grade of 0.48 per cent Cu) and 25 other porphyry deposits of similar copper head grade (mean head grade of 0.48 per cent Cu, minimum 0.37 per cent Cu, maximum 0.66 per cent Cu). This shows the negative influence of the lower-than-average copper sulfide mineral liberation; copper recovery is almost 5 per cent lower. This copper recovery of course can be improved by finer primary grinding and regrinding. However, this is less economic and highlights the importance of measuring the key drivers of performance.

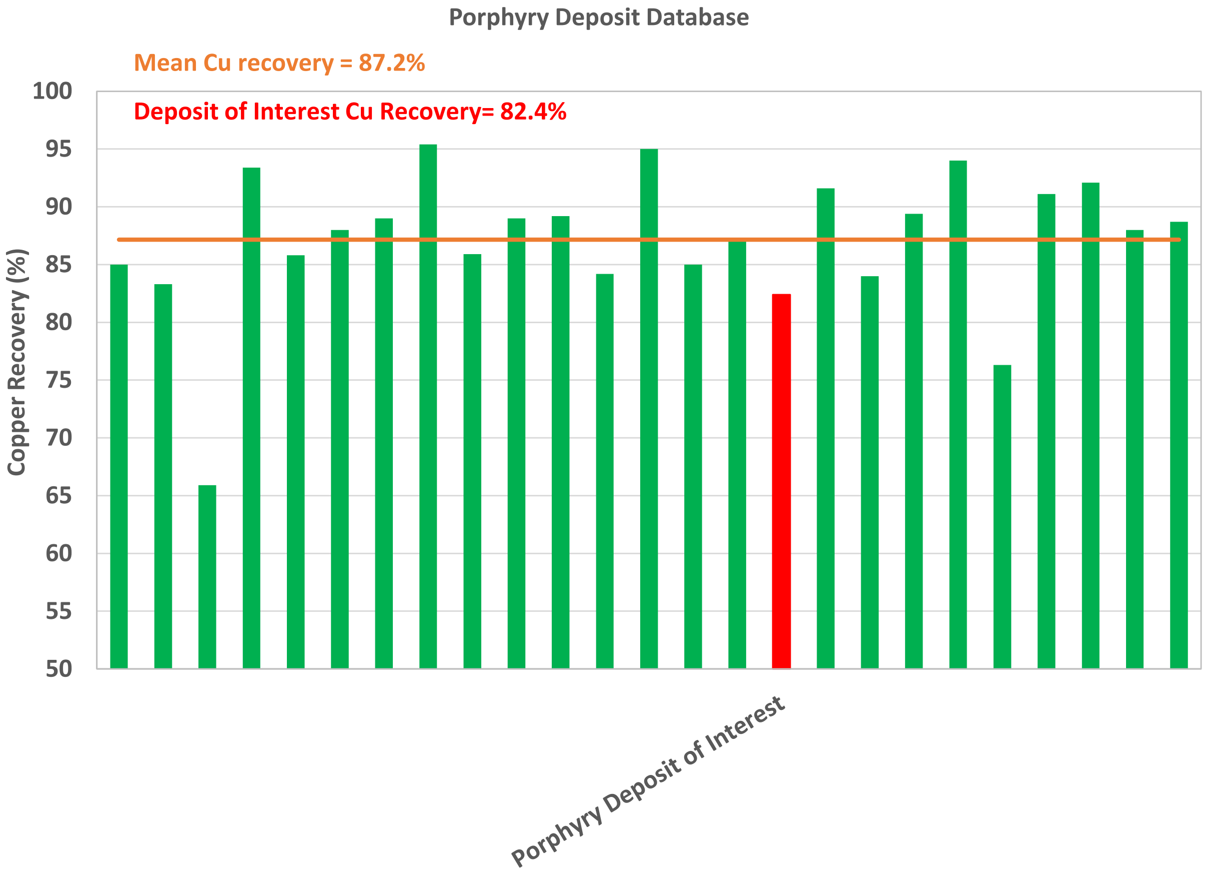

FIG 3 – Copper recovery comparison with similar head grade porphyry deposits.

A deposit style will have similar geochemistry to other deposits of the same style. This provides focus to the geology and geometallurgy program, and for defining the analytes required for assaying and the types of measures and tests required. Assay by acid digest and inductively coupled plasma mass spectrometry (ICP) will provide more than 30 elements, with the important elements and analytes for some common deposit styles presented in Table 1. The ICP suite selected may not provide some important analytes, and this has resulted in proceeding to operations with no real understanding of the distribution of minerals and elements that can have a devastating effect on product quality. For example, a Democratic Republic of the Congo copper-cobalt operation producing cobalt hydroxide was unable to sell batches of it due to a very high uranium content; this element had not been assayed in drill core (The Standard, 2019). Uranium and thorium are elements of potential interest in any sedimentary type of deposit. A second example; an iron-oxide copper-gold (IOCG) operation did not measure or model the fluorine content in the deposit, resulting in initial metallurgical test work producing flotation concentrates exceeding the fluorine acceptance limit of 1200 ppm. Although a correlation was found between the barium assay and the fluorine content, this was not sufficiently accurate to confidently assign fluorine values to the block model, so core samples had to be re-assayed for fluorine using the expensive specific ion method.

TABLE 1

Important analytes for some major deposit styles – analytes in **bold** are not measured in a 47 element 4-acid digest and ICP assay.

Deposit style	Important analytes	Important penalty/toxic analytes	Processing category
Porphyry Copper Deposit – Island Arc	Cu, Fe, S, **Au**, Ag, **Acid Soluble Cu**, **Cyanide Soluble Cu**,	As, Pb, Zn	Throughput dominated
Porphyry Copper Deposit – Cordilleran	Cu, Mo, Fe, S, **Au**, Ag, **Acid Soluble Cu**, **Cyanide Soluble Cu**	As, Pb, Zn	Throughput dominated
Iron Oxide Copper – Gold Deposit	Cu, Fe, S, Au, Ag	Bi, Pb, Zn, **F**, U	Throughput dominated
Volcanogenic Massive Sulfide	Cu, Pb, Zn, Au, Ag, Fe, S	As, Sb, **Hg**	Metallurgy dominated
SEDEX	Pb, Zn, Ag, Fe, S	**C(organic)**, **SiO_2**	Metallurgy dominated
Low – Intermediate Sulfidation Epithermal Gold-Silver	**Au**, Ag, S, **Cyanide Soluble Au and Ag**, **C(organic)**	**Hg**, Se	Throughput dominated
Orogenic/Archean Gold (Newmont Ltd, 2021)	**Au – fire assay, screen fire assay, NaCN soluble Au**, Ag	**S – total, sulfide, sulfate**. **C – carbonate, organic**, **preg-robbing capacity**, **Hg**	Throughput dominated

THE 'LAW' OF GEOMETALLURGICAL SAMPLING

Populating the block model with performance-predicting attributes or proxies requires that the metallurgically important characteristics (key drivers) of each block are first determined. Samples need to be provenanced to a location in 3D mineralised space, and the characteristics of that location applied to an ore block in the model. When starting a geometallurgy program, the key drivers are not defined and quantified, even if they may be recognised as likely to be key drivers. Samples are therefore required to retain these key drivers so that they may be measured.

Besides element grades which are always measured, these drivers may be included in the 'LAW' (lithology, alteration and weathering) characteristics of the material so these should form the boundary of geological discontinuities and of each sample. Material with identical lithology, alteration, and weathering characteristics and therefore similar geochemistry can be reasonably expected to behave the same regardless of its location, while crossing boundaries risks blending metallurgically different features. An example of a visually obvious geological boundary is presented in Figure 4, this boundary forms the sampling limit. Sampling across the boundary means that the characteristics of both become mixed, inseparable, and the key drivers of performance cannot be determined.

FIG 4 – Core photo showing a geological and sampling boundary.

Mixing samples to form composites of sufficient mass for testing must be done with extreme care, because as the old saying goes – one bad apple can spoil the whole barrel, and it is impossible to 'deconstruct' a composite back into its individual components. Compositing for metallurgical testing introduces time as a variable into 3D mineralised space, ie it assumes that this is how the material will be mined, blended, and processed. A credible mine production schedule is normally the last thing to evolve in the general sequence of study activities for the mining and processing of a deposit.

An example of the consequences of compositing occurred during a test program on a copper-lead-zinc VMS deposit when a sample with a significant talc content was included with other samples to make a master composite for flotation testing. The hydrophobic talc floated into the copper concentrate, making it impossible to produce a saleable copper product due to the low copper grade and high fluorine content. Ironically, the sample with talc came from outside the mine wireframe, thus creating a metallurgical 'problem' that did not even exist. An example of compositing disguising variability was from a low sulfidation epithermal gold-silver deposit, when approximately 80 samples with a 'similar' oxidation level were combined into a bulk composite for cyanide leach testing. The results disguised that the gold in some of the samples was very fine and poorly liberated at the primary grind size. During cyanide leaching operations, all was tragically revealed with long periods of gold recoveries less than 10 per cent when treating this material.

Samples are selected based on LAW geology logging, and even though automated scanning is becoming more common, most logging is still the result of visual inspection and manual measurements. These logging results are what will end up in the block model, so samples must align both spatially and with the LAW characteristics of each block within the block model.

COMMINUTION GEOMETALLURGY

Geotechnical measures of rock competency and hardness taken during core logging can provide important information for geometallurgical ore hardness and comminution modelling. For example, rock quality designation (RQD) and Point Load Index (PLi) and other measures of competence such as core recovery are all potential indicators of the rock's resistance to comminution (Morrell, personal communications, 2019). Some of these measure correlations are consistent across all deposits, for example PLi from testing of lump samples corrected to the 50 mm drill core reference dimension by multiplying the lump result by 1.54 (Morrell, personal communications, 2013) with the SMC test Drop Weight Index (DWi) is presented in Figure 5. Note that the correlation R^2 values range between 0.59 and 0.72 showing that the correlation is fairly weak, but with hundreds or thousands of PLi measures available compared with typically less than 100 SMC tests for a large deposit, ore hardness and resulting semi-autogenous grinding (SAG) mill throughput can be modelled with reasonable confidence. Having a PLi-based geometallurgical block model can also provide life-of-mine planning capability if core throughout the deposit has been routinely tested during logging; zones of high hardness can be delineated and tested in greater detail to help investment case development for future comminution equipment requirements.

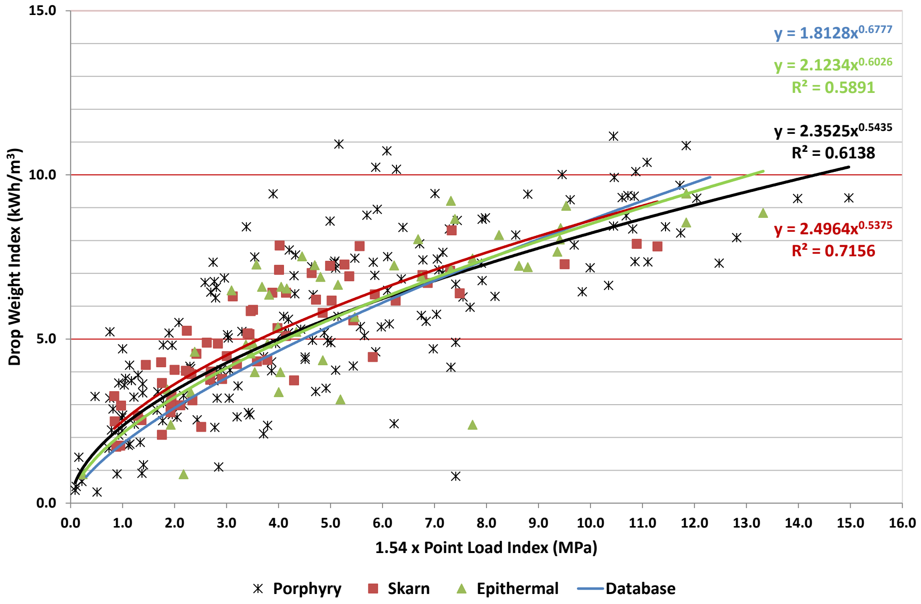

FIG 5 – PLi measures of lump material corrected to 50 mm reference dimension and correlation with SMC test DWi.

Other common and simple measures can also be used to give an indication of rock competency. Porphyry deposits form at depth with a vertical pressure and temperature gradient, which can lead to higher rock competency, hardness, and specific gravity at greater depths. For example, the mean measured DWi for each 25 m of depth interval below surface is presented in Figure 6 for a large copper-gold Island Arc porphyry deposit.

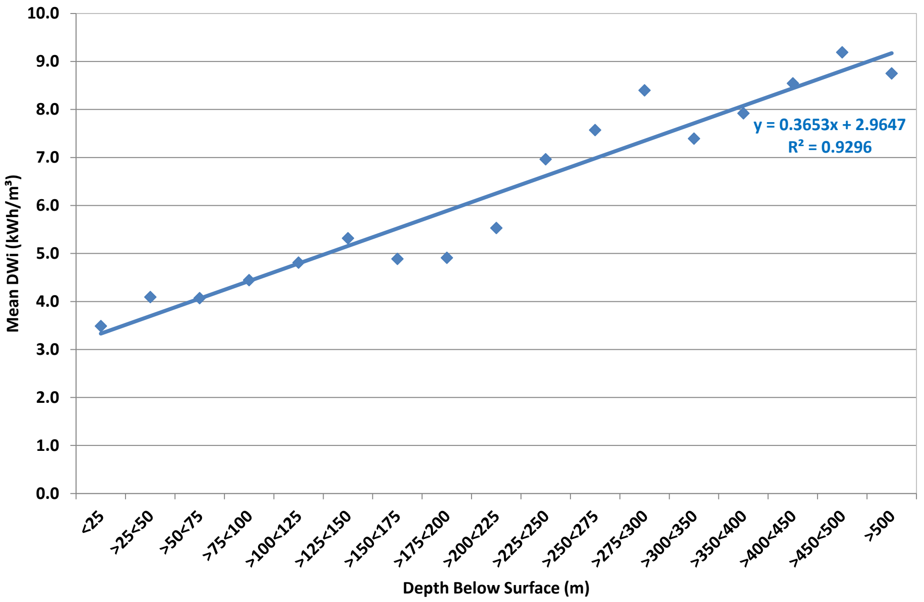

FIG 6 – SMC test DWi for 25 m depth intervals for a porphyry deposit.

Even simpler methods can be used successfully, for example a porphyry-skarn deposit treating three main rock types applied mill throughput values to each rock type with a self-learning empirical modelling method using the SAG mill as the analytical instrument, resulting in monthly throughput prediction errors falling to within ±1.5 per cent of actual (Carpenter and Saunders, 2017).

Bond Ball Mill Work Index (BWi) is often more closely related to individual mineral grain hardness than rock competency as shown in Figure 7 by the inconsistent association between mean DWi and

BWi (normalised to a 106 µm closing screen size) values across multiple deposit styles. The marker size indicates the number of test results for each deposit.

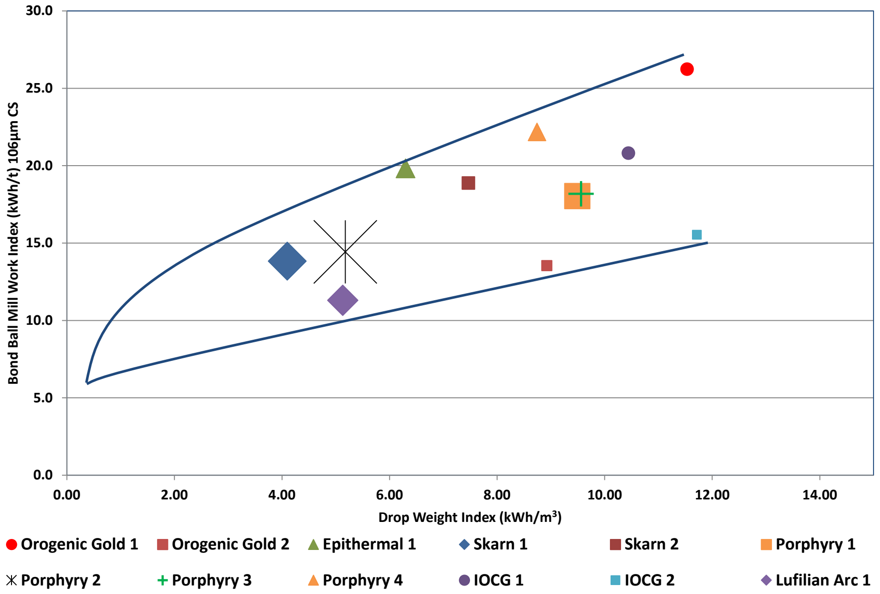

FIG 7 – BWi versus SMC test DWi for different deposit styles.

This mineral grain hardness relationship to BWi can be exploited for geometallurgical modelling. Intelligent use of multi-element data in the block model supported by Quantitative X-ray diffraction (QXRD) can predict rock type, and with other measures such as specific gravity can be used to estimate hardness (Li *et al,* 2021). An example of this is presented in Figure 8, with calcium and magnesium assays proxies for the carbonate minerals content of a Lufilian Arc sediment hosted stratabound copper-cobalt deposit. The majority of non-carbonate minerals in these deposits are harder silicates, so the carbonate content or the silicate content can provide reasonable hardness models.

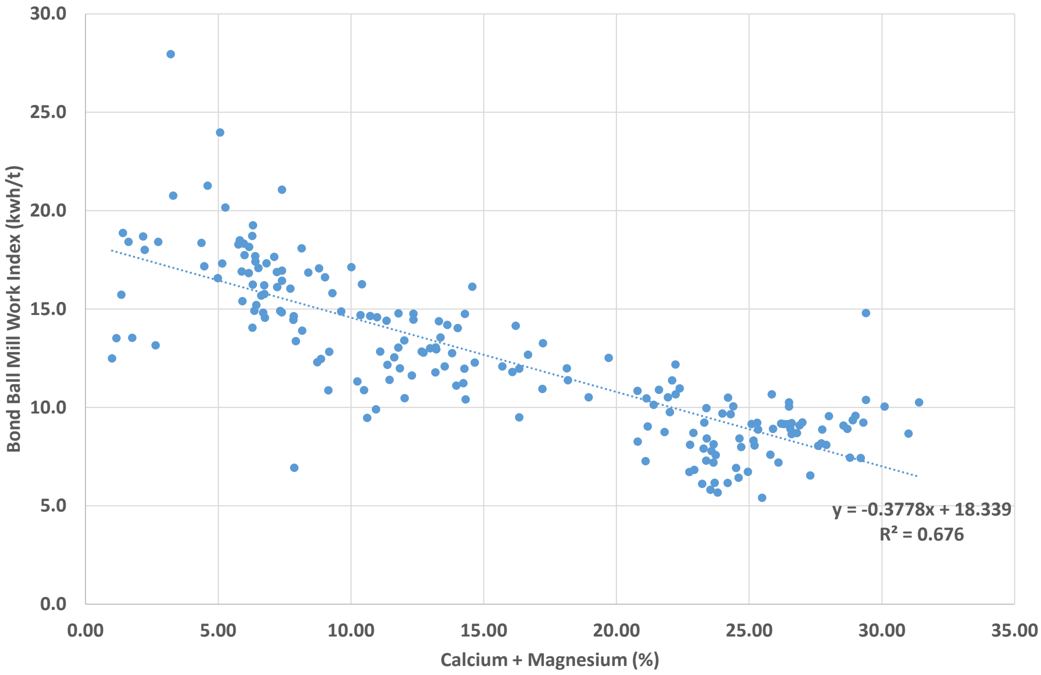

FIG 8 – BWi versus Calcium + Magnesium % for a Lufilian Arc copper-cobalt deposit.

Table 2 gives some typical measures that may be useful for ore hardness modelling and subsequent throughput modelling in combination with the grinding circuit design.

TABLE 2

Some typical ore hardness proxy measures.

Attribute	Model output	Comments
PLi	Axb, DWi	The relationship between PLi and DWi (kWh/m^3) is consistent for all deposit styles and can provide a lot of data points at low cost compared with comminution testing
RQD	Axb, DWi	RQD is a measured indicator of rock competency and may have a significant correlation with Axb and DWi
Specific gravity, depth from surface	Axb, DWi	Specific gravity can provide a correlation with mineralogy and usually increases with depth and can have a correlation with comminution parameters such as Axb, DWi, and BWi.
Lithology	Axb, DWi	A lithology (rock type) may be of consistent hardness and give an Axb, DWi, BWi or simple throughput value of acceptable accuracy for modelling
Silicate/carbonate grade	BWi	The combined silicate minerals content has been observed to be positively correlated with BWi at numerous sites, while carbonate content may be negatively correlated.
Sulfur grade	Axb, BWi	Massive sulfide deposits have been observed to have a strong correlation between assayed sulfur grade and BWi and Axb, with increasing sulfur grade resulting in decreasing BWi and Axb.

PROCESSING GEOMETALLURGY

The geometallurgy axioms of 'bank the similarities, master the differences' and 'measure more, test less' generally apply, but especially to processing geometallurgy. A failure to thoroughly understand the deposit mineralogy including the mineral associations, the minerals particle grain size and liberation size, and the minerals texture will risk getting poor metallurgical test results that just cannot be explained after test products are pulverised for assay. Pressure then comes on to 'fix the problem', impacting on study schedule and cost as repeating the sampling and analysis work is often the only possible solution.

A useful analogy for testing before characterising is going straight into surgery before having a check-up.

All samples should therefore be analysed and characterised before any testing is undertaken, with QXRD and QEMSCAN (the chosen discrimination mode is dependent upon mineralogy, grades, and processing requirements) and techniques such as semi-quantitative mineragraphy or Fourier Transform Infra-Red (FTIR) providing important measures. In combination with benchmarking results for the deposit style, the objective is to have good estimates of liberation for primary grind and regrind product sizes, and preliminary test conditions (chemistry, pH, redox, residence time, slurry density etc) available prior to the first test.

A list of mineralogy measuring techniques is provided in Table 3.

TABLE 3

Mineral analysis methods suitable for geometallurgy.

Method	Description	Detail
QEMSCAN®, MLA	Quantitative electron microscopy, mineral liberation analyser	Automated scanning electron microscopy for characterising minerals by type, association, texture, and size. Typically five modes with varying analysis detail: 1. BMA (bulk mineral analysis) which provides fast mineral identification and distribution and quantity. 2. BMAL (bulk mineral analysis with liberation) for mineral composition and estimate of the mineral liberation size. 3. Field image or MLA-XBSE which provides mineralogical and textural information from rock samples. 4. PMA (particle mineral analysis) which characterises the composition of discrete particles. 5. SMS/TMS (specific/trace mineral analysis) or MLA-SPL (sparse phase liberation) which looks in detail for selected minerals.
QXRD	Quantitative X-Ray Diffraction	Used for non-destructive mineral assaying and distribution. Limited capacity for low-level mineral detection and oxide gangue discrimination.
Sequential assay	Multiple wet chemistry methods	Sequential assaying uses a series of discrete assay steps to estimate quantities of different minerals of the same element, and weathering (oxidation) of minerals. Limitations are in discrimination in complex systems such as copper which may have over five mineral species present with two or more species assayed or partly assayed within one step.
Semi-Quantitative Mineragraphy		Optical microscopy and point counting supported by QXRD mineralogy, particularly useful for sulfide mineral characterisation.
FTIR, SWIR	Fourier-Transform and Short Wave Infrared spectroscopy	Uses reflected light spectra collected across the near, mid and far infra-red spectral ranges to detect and quantify oxide mineral content, particularly useful for certain mineral species such as swelling clays that are undefined by QXRD or QEMSCAN®.

Liberation is critical to economically optimise, but it is the most difficult deposit attribute to model (Preece, Robles and Salazar, 2023). Fortunately most deposits have a reasonably consistent mineral particle size range, but a site geometallurgy program must include measure of liberation of key minerals to ensure mineral particle size won't unexpectedly change and have either a detrimental effect on recovery or present an opportunity to relax grind size if liberation improves.

Once the characterisation is complete, metallurgical testing can commence as confirmation rather than as exploration, minimising the likelihood of surprises in test results. Tests have produced successful results at the first attempt after effective sample characterisation and alignment of test conditions with benchmarked operations treating the same deposit style.

The results of tests are then used to derive geometallurgical models, using the characteristics of the tested samples to determine what the key drivers of performance were. Some typical characteristics that are used for process geometallurgical modelling are presented in Table 4.

TABLE 4

Some typical process geometallurgy modelling measures.

Attribute	Model output	Comments
Head grade	Recovery	Very common driver of process recovery and always available as a block model attribute.
S/Me or Me/S ratio	Recovery/grade	Common in copper, lead and zinc (Me) sulfide flotation process modelling, where the S/Me or Me/S ratio is a proxy for the gangue sulfide/valuable sulfide ratio and gives an indication of position on the final grade-recovery curve.
Metal ratios	Recovery/grade	Certain metal ratios may be used as proxies for degree of weathering and metallurgical response, as some minerals are oxidised before others. For example, the Ag/Au ratio may be a proxy for weathering as silver is depleted while gold is not.
Specific mineral content	Recovery/grade	The presence of certain minerals can have a significant influence on metallurgical performance. If the mineral is associated with a certain lithology or alteration mode or if an element proxy can be found for the mineral (for example, fluorine in talc) it can be an attribute in the block model,
Alteration mode	Recovery/grade	Alteration mode describes a group of mineral types, some of which may be drivers of metallurgical performance. For example, advanced argillic altered material contains many minerals including phyllosilicates and clays that are detrimental to metallurgical and materials handling performance.
Ca, Mg, others	Recovery and acid consumption	Ca, Mg or other elements which are entirely contained in carbonate minerals can provide a proxy for metallurgical performance (carbonate minerals can ‘protect’ valuable sulfide minerals) and acid consumption in leaching operations.
CO_3, S	Acid generating/ neutralising capacity	Sulfur or sulfide sulfur assays and carbonate mineral assays can be used to classify waste rock and tailings as potentially acid forming or non-acid forming, and provide the likelihood of oxidation during stockpiling and storage.
Conductivity, natural pH, EDTA	Degree of oxidation	Not easily directly measurable on core during logging but can be measured during laboratory tests and on grade control samples to confirm oxidation/weathering state.

GEOMETALLURGICAL MODELLING

The modelling process begins with confirmation of the drivers of performance, and quantification of their influence on processing outcomes. Modelling is an iterative process, the preliminary models developed from the deposit studies must be updated as more data becomes available during operations. Every plant upgrade or process change will require a model review. Best practice is formal detailed annual models review and validation as part of life-of-mine planning and monthly geometallurgy models review as part of production reporting. Trends in performance can then be monitored and models adjusted before becoming unacceptably inaccurate and driving wrong operations behaviours, for example developing to and mining uneconomic material.

Some notes on geometallurgical modelling:

- Model variables must be attributes or attributes by proxy in the block model. Operating conditions such as throughput and grind size cannot be included in models unless they are attributes in the block model.
- Model variables and sign should be intuitive. For example, increasing head grade should give increasing recovery, and increasing acid soluble copper content as a percentage of total copper content should reduce sulfide flotation copper recovery.
- Model variables should be chased back to the mineral that is the driver to confirm and validate their value contribution. For example, if the aluminium assay value provides a good correlation with ore hardness, the aluminium containing mineral that contributes to the ore hardness value should be determined in case other aluminium containing minerals appear and confound the model hardness output.
- Minor element and minor mineral content correlation with model outputs need to be validated. For example, it is unlikely a mineral that is 1 per cent of the ore can have a significant effect on ore hardness.
- Having all characterisation and test data on a 'single tab' allows for fast and simple determination of likely drivers and modelling.
- Models are developed from test work which include drilling and sampling errors, test method errors (Angove and Dunne, 1997), and assay errors. Do not expect model accuracy (on a monthly basis) of better than ±5 per cent relative without a lot of work to characterise ore material and quantify operational variability. Very extensive work on throughput modelling at Minera Los Pelambres in Chile was required to improve monthly throughput estimate accuracy to a mean relative error of 3.0 per cent (Rodriguez *et al,* 2023).

CONCLUSIONS

Geometallurgy is about knowing metallurgical and production outcomes before ore is mined and processed. To know these outcomes, the block model must be populated with measured parameters or proxies (attributes) that allow prediction of throughput and metallurgical performance. Populating the block model also eliminates time as a variable, allowing changes to the mine schedule without impacting the value of outcomes from processing an ore block.

The geological style of a deposit will define the important activities required in a geometallurgy program plan. A geometallurgy axiom is to 'bank the similarities, master the differences' as it is rare that a deposit style is truly unique. Geological differences or uncertainties of style may also not be geometallurgically important.

The geotechnical measures of rock hardness taken during core logging can provide important information for geometallurgical ore hardness and comminution modelling. For example, measures such as rock quality designation (RQD) and Point Load Index (PLi) and other measures of rock competence are all indicators of the rock's resistance to comminution.

The geometallurgy axiom of 'measure more, test less', by measuring the characteristics of the deposit including geotechnical, mineralogy, mineral association, mineral liberation, and mineral texture up front allows benchmarking against other deposits of the same style. Testing then becomes confirmatory rather than exploratory, and the overall costs and time of a program are minimised.

Including all the key geometallurgical measures and drivers as algorithm models of throughput and metallurgical performance into the block model is rarely an experience in achieving outstanding accuracy. Geometallurgy models are often performance trends due to compounding errors in sampling, measuring, and testing combined with the 'noisy' environment of process operations treating variable material. Therefore care should be taken to avoid producing over-complicated models and attempting predictions over short time periods.

Geometallurgical practice and modelling is an iterative ongoing process, the preliminary models developed from the deposit studies must be updated as more data becomes available during operations, and every plant upgrade or process change will require regular model review. Best practice is formal detailed annual models review and validation as part of life-of-mine planning and monthly geometallurgy models review as part of production reporting so trends in performance can be monitored and adjusted before becoming unacceptably inaccurate.

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