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GEOSPECTRAL IMAGING

Hyperspectral Core Imaging for Geometallurgy

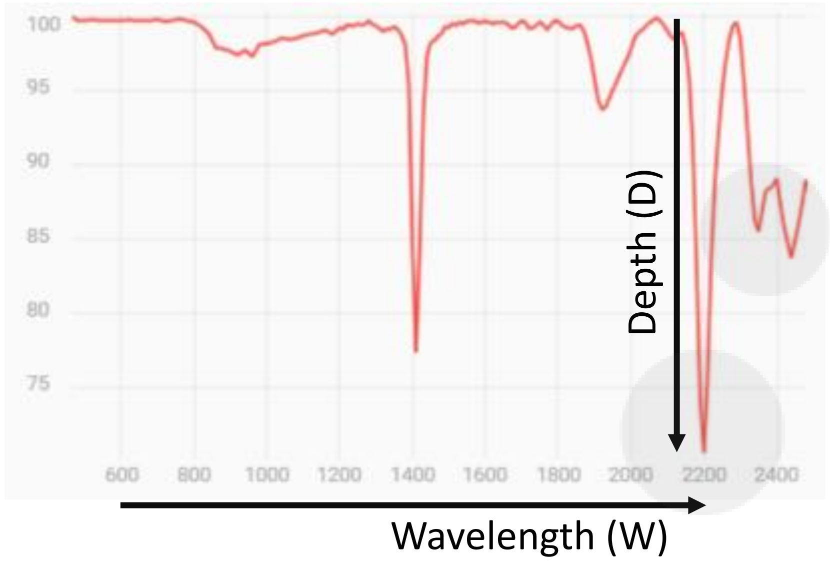
- Geometallurgy is the study of process plant performance that lies in the geology, mineralogy, texture and structure of the ore
- It is a predictive tool in that it provides advance information about the material/s to be processed, allowing for tuning of the plant to achieve optimal performance
- Thorough geometallurgical knowledge can be used to optimize mine planning and production schedules to return maximum value. It also provides a method beyond grade for ore control and waste delineation
- Ideally, geometallurgy is undertaken at the feasibility stage to provide information to both de-risk and optimize the feasibility study. It should continue through production for continuous improvement
- Geometallurgy provides critical information about the spatial variation of ore performance, something that is at best poorly captured by metallurgical testwork programs

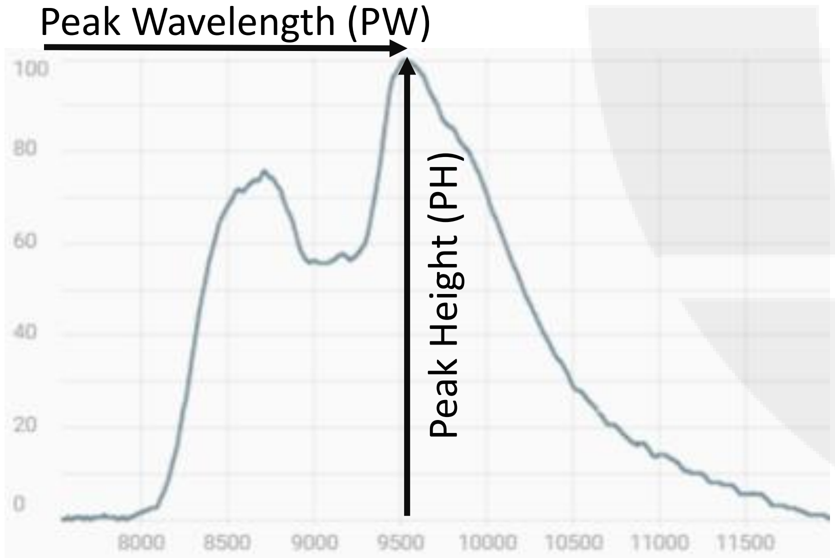
Introduction

Hyperspectral core imaging is of particular value given:

- It captures alteration mineralogy in situ and so textural relationships can be easily seen and mapped
- Since every pixel is imaged, quantitative counts of alteration minerals can be extracted (spectral modal mineralogy). The addition of the long-wave infrared adds anhydrous silicates, including quartz, feldspars, pyroxenes, olivines and calc-silicate minerals
- By extracting information related to absorptions (SWIR) or peaks (LWIR) the relative strength of spectral response provides a proxy for mineral abundance, and can be used as a correlation against metallurgical tests carried out in the laboratory
- Very importantly the dense data collected during imaging ensure data representivity, which is crucial for successful geometallurgical programs
- Importantly, sulphide minerals do not respond in either the VN-SWIR or LWIR. Therefore, geometallurgy for processing steps such as precious metal leaching are not solvable using core imaging and other data should be used (e.g. geochemistry)

Hyperspectral Core Imaging





- Hyperspectral data can be used to map mineral species and assemblages, this requires an interpretative step to produce mineral maps. These are a good first pass product, but as the interpretative stage generally requires yes/no answers we do lose critical quantitative information necessary for geometallurgy

- As a direct product, we can extract information about spectral features in each range as shown on the left. This does not require any interpretation, and is simply a record of each pixel spectrum expressed as a series of numbers (almost like a spectral assay). Ratios of specific features, and slopes across areas of the spectrum provide additional quantitative information

- These data can then be used to derive specific mineral products that record the strength of the spectral response (a proxy for abundance) and composition of the mineral phase/s – these are known as mineral indices, and should be constructed for all potentially problematic phases

- Textural measures related to mineral species can be extracted and domained, for example, whether a mineral phase occurs as disseminations, in veins etc.

- We would always advocate integrating spectral data with other datasets such as hardness measures, geochemistry, geophysical tools etc.

Hyperspectral Data for Geometallurgy

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- Problem minerals are those species that impact greatly on either comminution (throughput) or recovery
- Those that impact comminution include very hard phases that make ore difficult to crush and grind, especially in large tonnage low-grade deposits such as porphyries where economics require maintaining throughput
- Comminution may also be impacted by the presence of large amounts of clay (especially smectites), which can clog the circuit. For safety, identification of asbestos minerals is important
- Phyllosilicate minerals can impact flotation recovery, either directly by destabilizing the process or less directly by being entrained and reducing concentrate grade. Knowledge of the oxidation state of ore is important for flotation, where fresh hypogene ore minerals are generally preferred (examples in slides 6 and 7)
- Acid leach recovery requires knowledge of carbonate minerals, which preferentially consume acid and reduce recovery and/or increase costs
- Deportment of the economic element is important to know, as not all minerals will respond equally to the chosen recovery process as is shown in slides 7, 8 and 9

Problem Minerals

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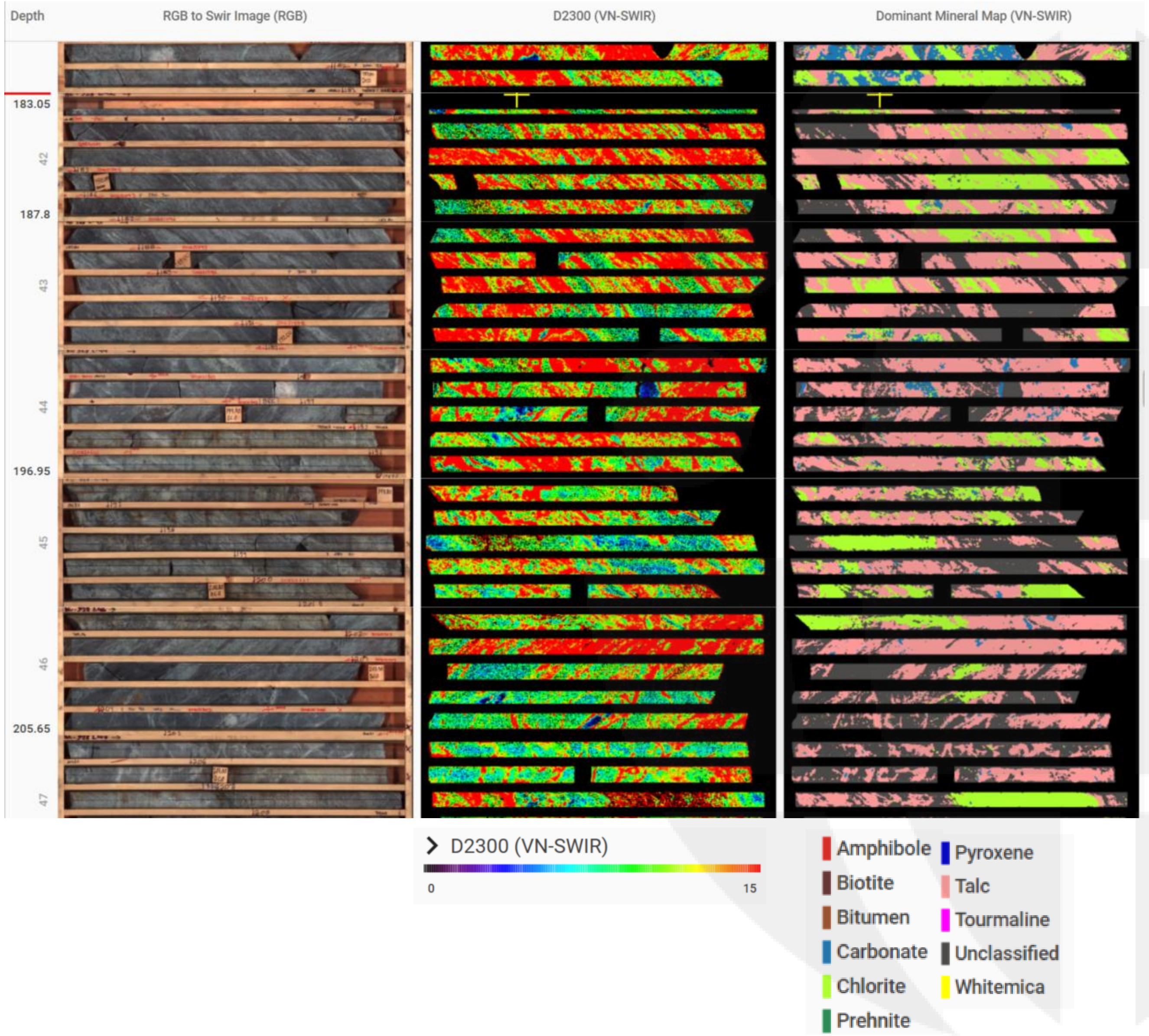

- Talc is a serial offender, especially where the recovery process involves flotation
- Talc will float, which reduces the grade of the concentrate but also destabilizes the froth and can cause over frothing which is both hazardous and expensive
- Mapping out talc zones, as shown in the example on the left, is therefore important. Talc responds well in both the SWIR and LWIR, in this example talc has been mapped and the depth of the main talc feature at 2300nm provides a guide to talc strength (and an abundance proxy)
- Forewarned is forearmed, and talc-rich zones can be dealt with by blending or reagent addition. The latter is an additional cost, so knowing when to add is obviously useful

Problem Mineralogy – Talc

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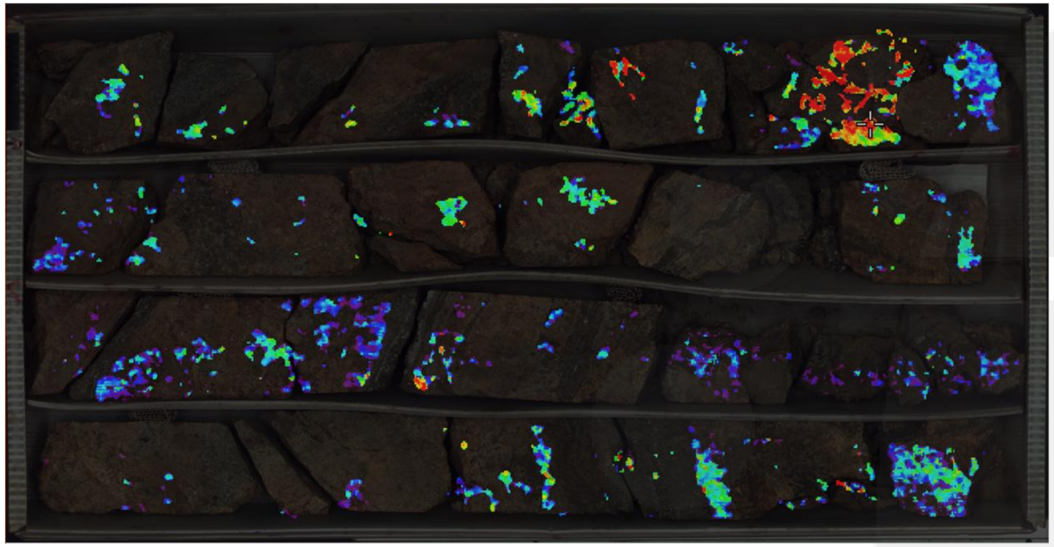
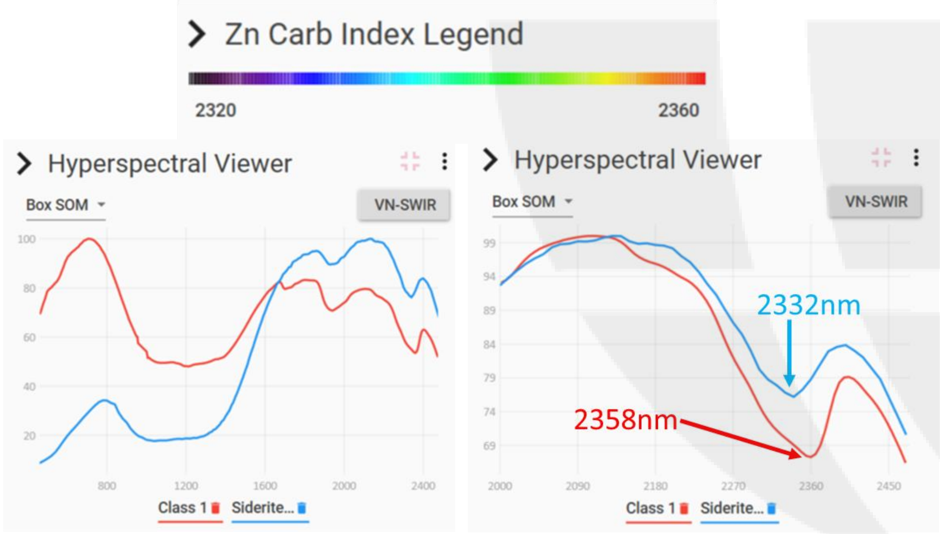


- Flotation circuits are set up for sulphide ores. When sulphides oxidize, the resultant minerals will not float and lead to reduced recovery especially in the mixed and hard to recognize transition zone between hypogene and supergene
- In this instance, the cause is subtle and a bit unexpected – oxidation has led to the formation of siderite, which, where associated with primary sphalerite, is producing a zinc-rich species
- This was picked out by variation in the position of the main siderite absorption, which as is shown by the blue library spectrum is normally at ~2330nm. The addition of Zn pushes this out to much longer wavelengths (closer to 2360nm)
- A mineral index was constructed for the sideritic pixels to track the absorption position, with the Zn-rich species easily picked out in warm colours



Problem Mineralogy – Sulphide Oxidation

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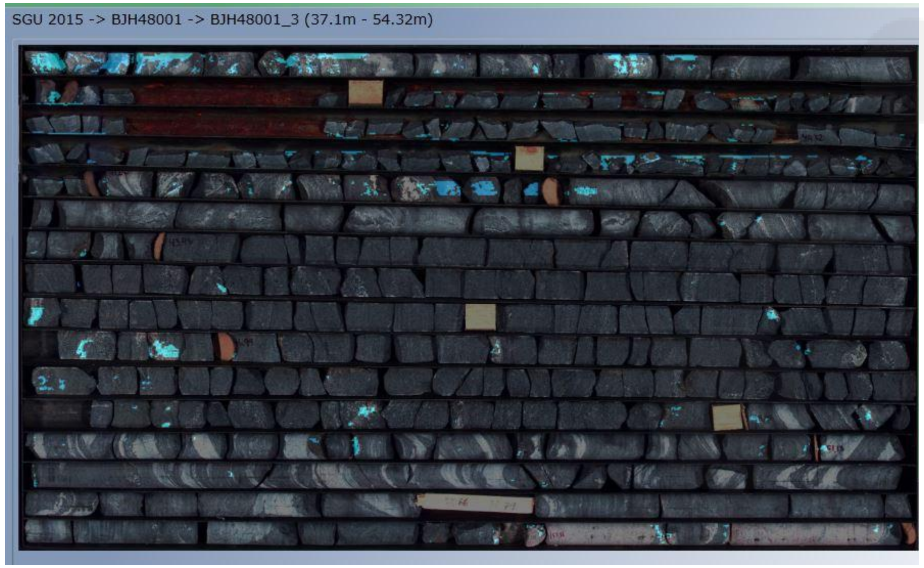

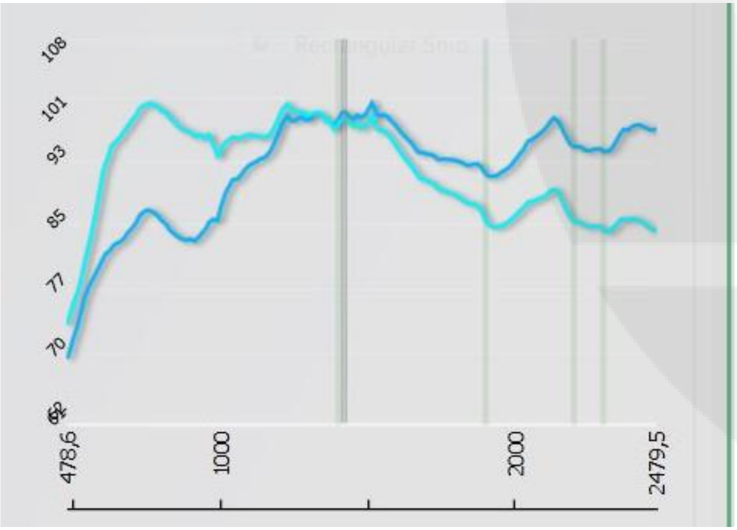

- A significant proportion of global iron production comes from magnetite-dominant deposits, especially the giant deposits in northern Sweden
- Magnetite is recovered from milled ore by magnetic separation, which will not capture other non-magnetic iron species
- In the example on the left, patchy haematite has formed via oxidation of magnetite. Haematite can be readily identified by the iron charge transfer absorption at ~870nm, as shown in the darker blue spectrum on the left
- The mineral map above left shows distribution of haematite in a core box as mapped using the spectral signature

Problem Mineralogy – Haematite

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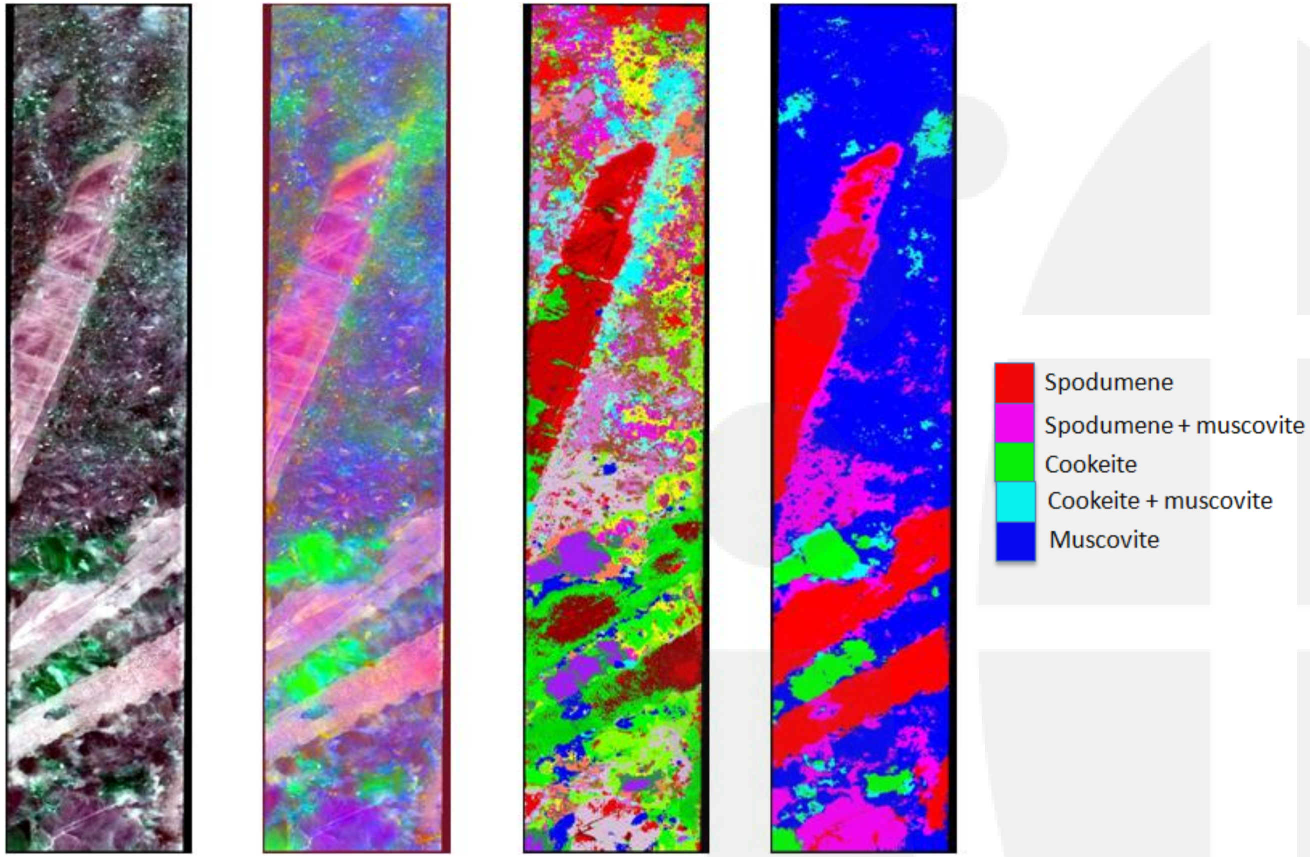

- In this example, the ore mineral in a Li pegmatite is spodumene
- Spodumene recovery can be either via dense media separation (essentially gravity) or froth flotation as in this case
- Zones of low Li recovery had been noted, with mica (lithian muscovite or lepidolite) suspected as the problem mineral
- However, analysis of micas showed them to be low in Li
- Imaging of core intervals identified the presence of cookeite, a Li-bearing chlorite which had not previously been recognized
- This mineral will not report to the concentrate, leading to low recovery

Problem Mineralogy – Cookeite

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- As opposed to mapping out a problem mineral or set of minerals, in this case we use all the spectral information that can be extracted as shown in slide 4

- This is almost a black box approach, ignoring any mineralogical interpretation process which may skew results

- The spectral data, either alone or more commonly in conjunction with other dense data that are collected at the scale of assay (such as geochemistry, hardness measurements, geophysics on core), are then mathematically correlated to the results of small-scale laboratory tests measuring metallurgical parameters (crusher index, sag power index, A*b hardness, ball mill index, batch flotation, leach recovery etc.)

- As the laboratory tests are quite expensive, they cannot be run on every assay sample – instead the derived correlations are used to predict metallurgical parameters creating a database of metallurgical properties at assay (grade) scale

- These can then be modelled and estimated in the same manner as grade information to produce a block model for each parameter

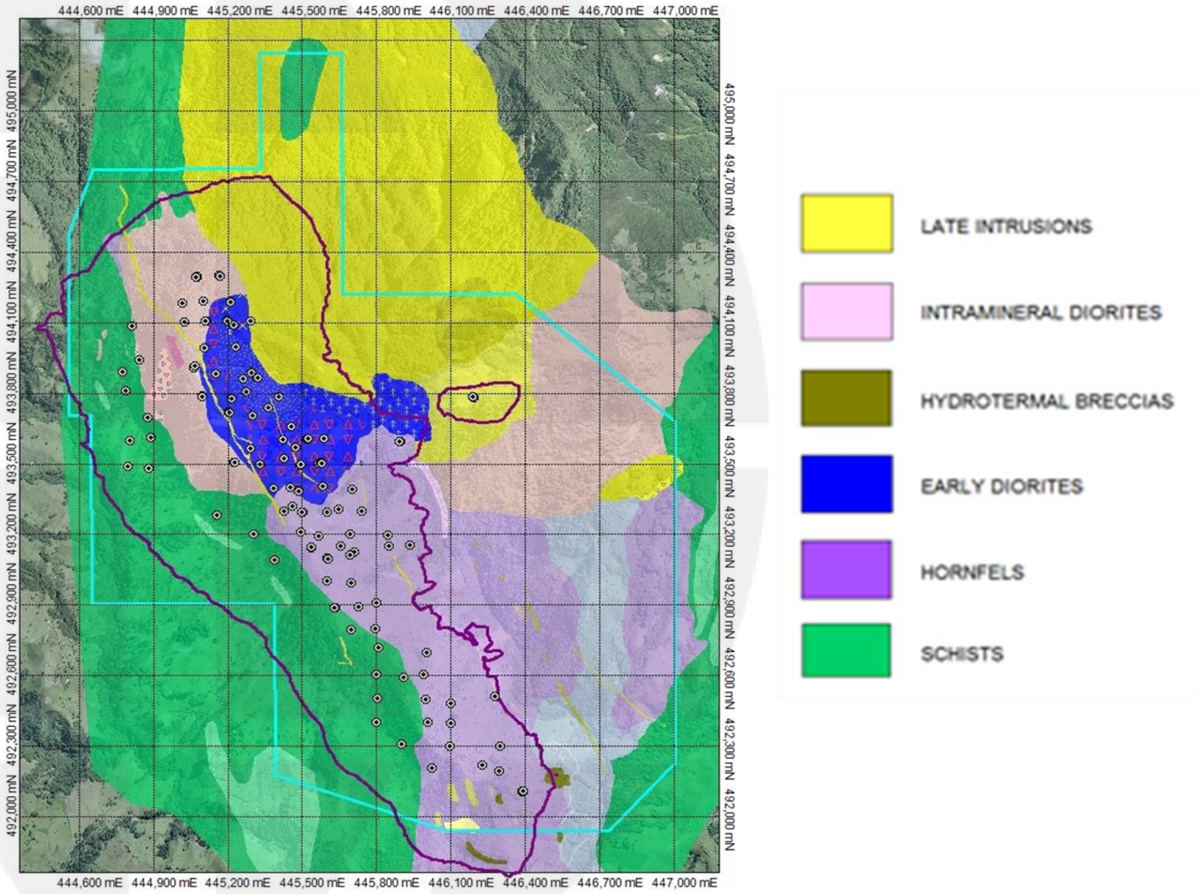
- These are then transformed to provide throughput and recovery per resource block, in essence providing processing cost at a much more granular scale than is normal. The resulting net value per block is used for planning and financial modelling

- The following slides show a case study of comminution at a porphyry project

Numerical Geometallurgy

The project:

- Big project – porphyry Au, 32Moz @ 0.8 g/ton
- Conventional metallurgical testwork suggests that ore hardness may be problematic – average A*b ~32, BMWi ~16.5
- PFS capex estimate is ~$6 billion, risk mitigation clearly required
- Large plant, dual-stream comminution – throughput target 65Mt p/a (~6200 tph)



Numerical Geometallurgy Case Study

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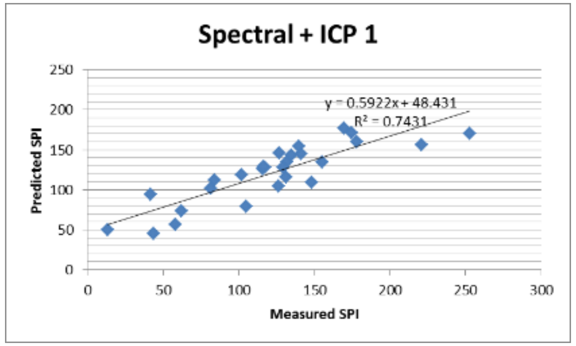
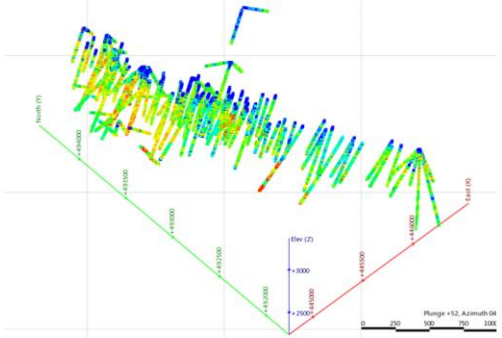
Available to use:

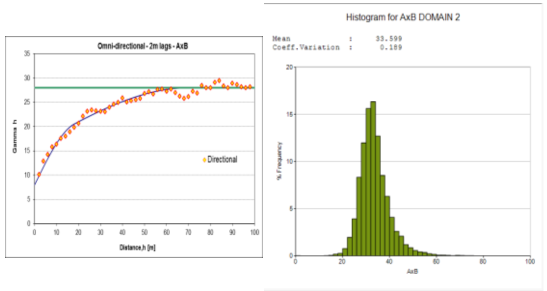
- 150000m of drilling, 2m assay sample spacing
- Full coverage with SWIR hyperspectral core imaging
- ~75000 ICP analyses (49 element, 4 acid digest)
- Magnetic susceptibility and sonic logger on all core
- Equotip hardness testing @ 2cm spacing
- 279 A*b hardness (Rotary Breakage Tester), 434 modified bond index, and 220 SAG power index tests collected (90% on 2m samples, 10% on 5-10 samples)



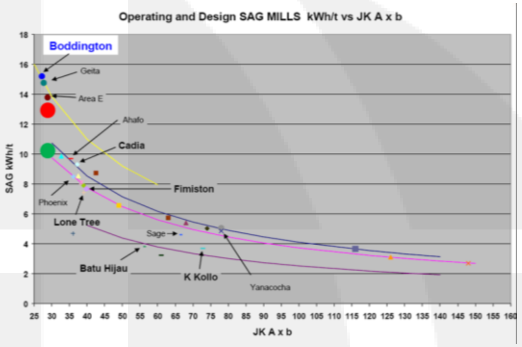
Step 1: correlation of hyperspectral + geochemistry with metallurgical parameters



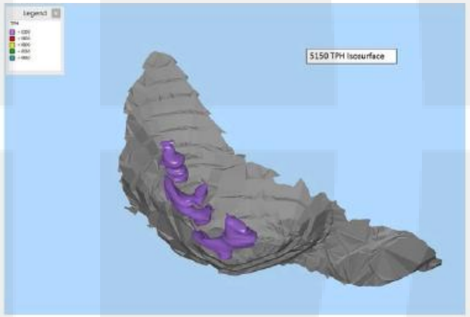
Step 2: 3-D modelling of predicted values for QA/QC



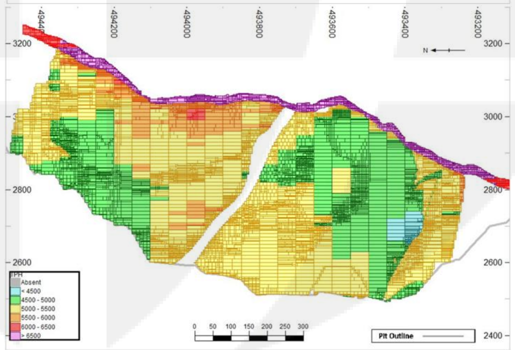
Step 3: estimation of predicted parameters into block model via ordinary kriging



Step 4: transformation to throughput using plant design and published performance of similar plants



Step 5: creation of 3-D wireframes of throughput cutoffs



Step 6: detailed study to identify geological drivers of throughput, assessment of PFS assumptions and viability

Numerical Geometallurgy Case Study

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Conclusions

- Hyperspectral core imaging is a powerful tool for geometallurgy. It provides a continuous visual and mineralogical record of the core, importantly capturing minerals and assemblages in situ and so providing textural context

- The data can be used to directly locate and map mineral phases that are known or suspected to be problematic during processing

- By extracting numerical information from the spectra, the data can also be correlated to metallurgical tests to build rich models of plant performance. These models provide performance information at the same scale as grade, and so allow for more robust cost calculation

- The resulting net values per resource block can be applied to financial modeling and mine planning to ensure optimization of a project

Conclusions