Reinventing the wheel: The environmental geometallurgy matrix and its supporting tools

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ABSTRACT

The challenge remains for the mining industry to identify the mechanisms by which to cost effectively forecast and manage geoenvironmental risks at the earliest possible stage in a mine's life. If adequately performed, appropriate allocation of funds and environmental management strategies can be developed and embedded into the mine plan enabling better closure outcomes. Whilst the metalliferous mining industry is cognisant of this, another major challenge is finding the right tools to facilitate early stage waste characterisation. For example, chemical (i.e., static and kinetic) tests have dominated how AMD properties have been measured since the late 1970s, but with AMD remaining an ongoing global issue (even at young mines), there is a necessity for innovation. With an explosion of new tools and technologies for ore characterisation, there has never been a more opportunistic time to follow an *environmental geometallurgy matrix* approach whereby the geoenvironmental toolbox is used for waste characterisation. The toolkit includes application of hyperspectral technologies to derive geoenvironmental domaining index and automated acid rock drainage index values, improved used of handheld tools and chemical tests, data mining, and finding new applications for μCT and 3D XRF drill core scanners. This paper focusses on demonstrating applications of hyperspectral datasets as the metalliferous mining industry trend is currently towards collecting these data during early life-of-mine stages. As we approach the next decade, the industry has the unique opportunity to adopt the environmental geometallurgy matrix and embed the use of the geoenvironmental toolbox into their operations to improve risk management.

INTRODUCTION

The process of mining is not only concerned with commodity extraction, but also moving and managing waste. Whilst many mining innovations have been implemented in recent years in terms of deposit characterisation (e.g., 3D mapping technology), ore extraction (e.g., Copper NuWave™, automation, use of renewable energy, excavator redesigns) and mineral processing (e.g., Toowong Process; MacDonald et al., 2018), the approach to managing waste rock material has remained comparatively primitive. Globally, up to 30 Gt of waste material per annum is removed, handled and placed into final repositories or landforms, based on engineering design criteria informed by geochemical parameters, where it remains indefinitely unless another use for it is identified. If inadequately managed, waste materials can pose a range of physical (i.e., dam failures) and chemical (i.e., acid and metalliferous drainage; AMD) geoenvironmental risks. Thus, the metalliferous mining industry is at a crossroads. Continue to exclusively use established AMD prediction tools, developed and established in the 1970s for the coal mining industry (Sobek et al., 1978) or evaluate new technologies and introduce them into a revised AMD prediction framework to supplement data collected by established methods. If the 'geometallurgy matrix' proposed by the AMIRA P843 GeM Project is adapted, our approach to mine waste characterisation can be rethought as shown in Figure 1 introducing the '*Environmental Geometallurgy Matrix*'. This aims to provide an improved, systematic framework for geoenvironmental characterisation. The matrix requires a large number of samples to be assessed at Level 1 to ensure that the deposit heterogeneity and resulting geoenvironmental characteristics are adequately assessed, with these data providing guidance for Level 2 sampling. At Level 2, established acid-base-accounting tools are used (with new methodologies i.e., improved net acid generation testing proposed by Parbhakar-Fox et al. 2018a to be used). These data enable the selection of samples for long-term kinetic tests at Level 3 with new designs used (e.g., advanced customisable leach cells; O'Kane Consulting) in conjunction with a pre-screening protocol (i.e., grade-by-size AMD mineral analysis, biokinetic testing and accelerated oxidation static tests) to be undertaken before their commencement. All these data ultimately feed into the waste block for the operations with the final landform or repository designed at Level 4.

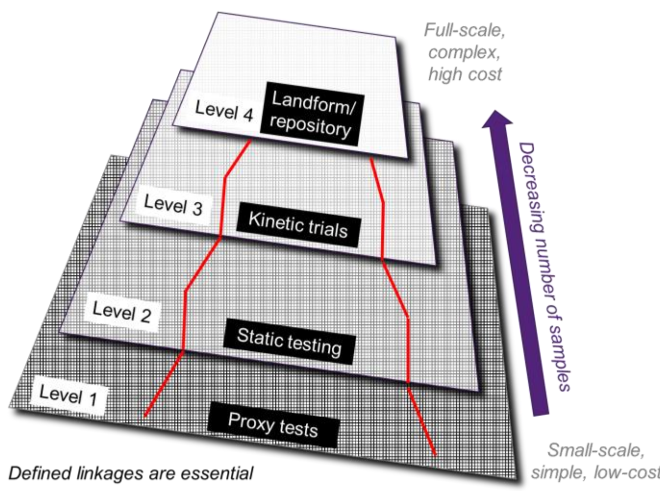

Figure 1. The Environmental Geometallurgy Matrix for geoenvironmental characterisation.

Ideally, the metalliferous mining industry needs to have a field-appropriate mine waste characterisation/AMD prediction toolbox (i.e., Level 1 tests) that allows the collection of useful data more time-efficiently and cost-effectively. If such tests can be readily performed at mine sites (either in the Coreshed, field lab or dedicated on-site automated mineralogy facility), then samples for detailed AMD test work at Level 2 can be better chosen. This paper focuses on providing an overview of Level 1 proxy tests.

ARD PREDICTION TOOLBOX

A description of the tools contained in the toolbox is given in Table 1. These methods have been tested using drill core and waste materials collected from several Australian mine sites in both Tasmania and Queensland.

Table 1: Level 1 tools to be used in the Environmental Geometallurgy Matrix.

Tool	Purpose	Example(s)
Hyperspectral mineralogy data collected using: Hylogger (SWIR and TIR) Corescan (SWIR)	Perform geoenvironmental domaining using the geoenvironmental domaining index (GDI) or Hylogger geoenvironmental index (HyGi)	Parbhakar-Fox et al. (2018b) Jackson et al. (2018)
Handheld tools including: Acid rock drainage indexing (ARDI) Equotip/ sonic velocity device Portable XRF	Log drill core by an environmental code Measure mineral hardness to calculate modal mineralogy weathering index to screen against total sulphur and paste pH values Measure elemental signatures and identify neutralising and acid forming domains	Parbhakar-Fox et al. (2011) Parbhakar-Fox et al. (2013) Parbhakar-Fox and Lottermoser (2017) Cornelius et al. (2018) Jackson et al. (2019)
Simple chemical tests: Chemical staining Field pH	Using calcite and dolomite stains to define ANC zones (and assist with geoenvironmental logging) Measure paste pH (normal and accelerated) of drill core materials using the ASTM CaCl2 (2007) methodology	Parbhakar-Fox et al. (2015) Noble et al. (2016) Parbhakar-Fox et al. (2017a)
Automated mineralogy (XMOD or equivalent point count mineralogy data required)	Perform computed acid rock drainage (CARD) risk grade evaluations (relevant for post met-test work residues to determine the AMD potential of future tailings).	Parbhakar-Fox et al. (2017b) Brough et al. (2017)
Data mining	Calculate mineralogy and AMD potential from assay data Correlate deleterious element abundance with mineralogy Perform automated Acid rock drainage Index (A-ARDI) assessments on high-res imagery	Berry et al. (2015) Beavis et al. (2017) Parbhakar-Fox et al. (2018b) Cracknell et al. (2018) Jackson et al. (2019)
Next-gen technologies	Use µCT and XRF platforms to evaluate AMD minerals in 3D and undertake A-ARDI analyses Use handheld LIBS to predict the chemical signature of acid forming minerals.	Fox et al. (2017) Parbhakar-Fox and Fox (2018)

This reminder of this paper describes the application of one tool, hyperspectral drill core scanning platforms, and focusses on applications for neutralising potential domaining and acid rock drainage index assessments.

METHODOLOGY AND RESULTS

Hyperspectral mineralogy tools have broad applications across the life of mine including for geoenvironmental domaining of waste. They use visible near infrared (VNIR), shortwave infrared (SWIR) and long wave infrared (LWIR) detectors to rapidly assess the relative modal abundance of a broad range of mineral groups as documented in Linton et al. (2018). Most significantly for geoenvironmental characterisation, mineral groups with primary neutralising capacity such as carbonate-group minerals can be accurately identified and their relative abundance estimated (Fox et al., 2017; Parbhakar-Fox et al., 2018b). The Corescan Hyperspectral Core Imager Mark-III (HCI-3) system is one of many scanning tools being increasingly used by the mining industry. It collects red-green-blue (RGB) visible wavelength imagery, laser derived digital surface models (DSM), and VNIR to SWIR spectra across the surface of drill core. RGB imagery is collected at a pixel resolution of 60 μm and laser data is collected at a horizontal resolution of 200 μm with a vertical precision of 15 μm. VNIR-SWIR spectra are collected across wavelengths of 448 to 2500 nm using 514 bands with a spectral resolution of 4 nm at a spatial resolution of 250 or 500 μm (depending on which system has been used). The scanning capabilities and sensor array of the Corescan system allows for rapid, non-destructive imaging of drill core to produce continuous true-colour photographs and, after extensive semi-automated processing, VNIR-SWIR mineral classifications. Applications of Corescan data for geoenvironmental domaining purposes are summarised in the next sections.

Geoenvironmental domain indexing (GDI) assessments

The GDI uses unprocessed Corescan data and, based on the mineralogy assigned to each pixel, it calculates a GDI score based on the relative mineral abundance, relative reactivity and an acid forming or neutralising potential factor (Jackson et al., 2018). The final score is unitless, but, the higher the score, the higher the neutralising potential. Based on the sulphide recognition algorithm developed by Corescan, acid forming potential can also be assessed in the GDI thus, if a negative score is assigned than the sample is likely acid forming. The GDI was developed using drill core materials from two porphyry deposits (Jackson et al., 2018; Parbhakar-Fox and Fox. 2018). GDI scores were compared and validated against static chemical tests and bulk mineralogy assessments as shown in Figures 2 and 3, with these Level 2 data plotted in a new data visualisation dashboard tool. GDI scores enabled the domaining of waste rock, particularly when screened against total-sulphur values. This tested approach is regarded to be at technology readiness level 4/5 (lab-scale validation/ early proto-type). Applications for assessing column feed material prior to kinetic testing have also been investigated (Jackson, 2019, Unpublished).

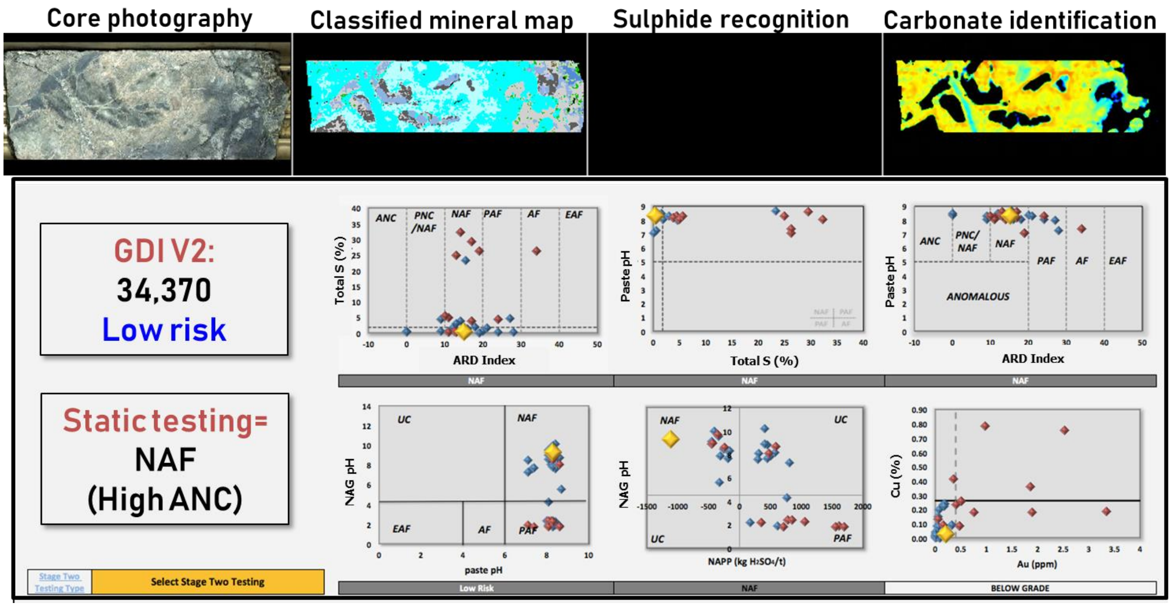

Figure 2 Geoenvironmental domaining index (GDI) output compared for the sample depicted by the yellow diamond (with corresponding data given to the left in the dashboard) classifying the sample as low risk (with a negligible neutralising potential and acid forming potential) confirming acid base accounting and mineralogical classifications as non-acid forming. Abbreviations: P- or A-NC- potential or acid neutralising capacity, (E)(P)AF- (extremely) (potentially) acid forming, NAF- non acid forming.

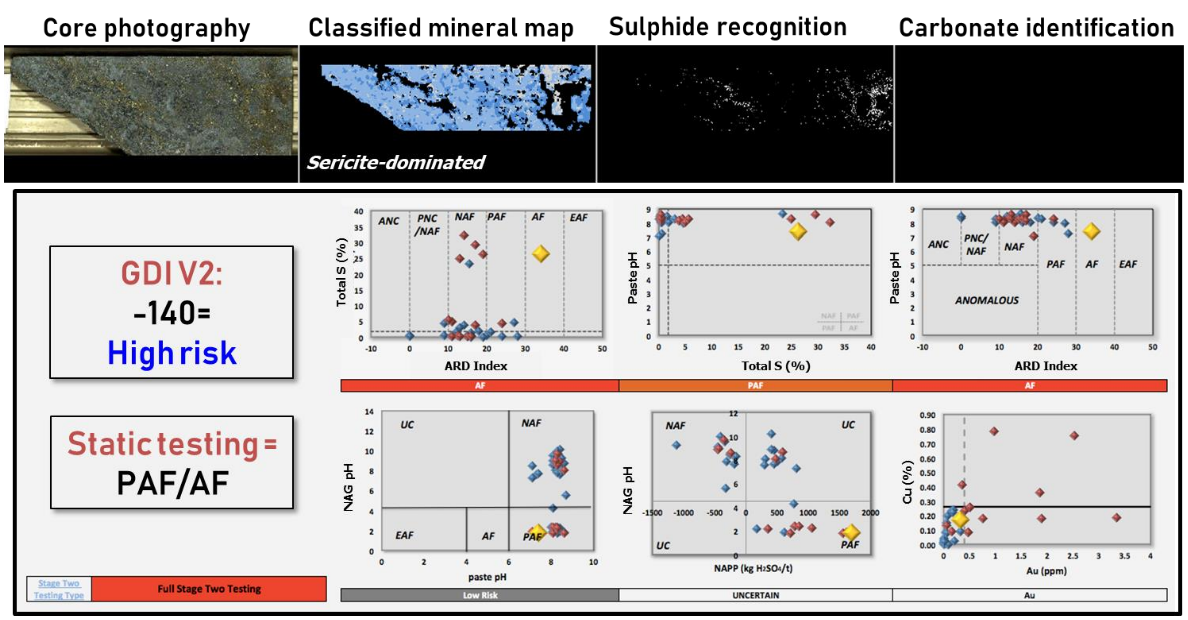

Figure 3 Geoenvironmental domaining index (GDI) output compared for the sample depicted by the yellow diamond (with corresponding data given to the left in the dashboard) classifying the sample as high risk (with a negligible neutralising potential and acid forming potential) confirming the majority of acid base accounting and mineralogical assessments. Abbreviations: P- or A-NC- potential or acid neutralising capacity, (E)(P)AF- (extremely) (potentially) acid forming, NAF- non acid forming.

Automated ARD indexing (A-ARDI)

To refine the estimate of acid forming capacity, the automated acid rock drainage index or A-ARDI was developed (Cracknell et al., 2018). The ARDI is derived from manual observations of, for example, hand samples or drill core and is based on the numerical ranking of five key indicators of acid-forming potential (A – sulphide content; B – sulphide alteration; C – sulphide morphology; D – primary neutraliser content; and E – sulphide mineral association) as detailed in Cornelius et al. (2018). However, such manual logging methods are subject to operator bias. Further, manual and analytical approaches are commonly limited by the amount of material (number of samples) that can be assessed due to time and financial constraints. To address this, the A-ARDI was developed using Corescan RGB true colour images, VNIR and SWIR mineral classifications. A-ARDI values are derived in four key stages:

- Identification of iron-sulphide minerals from the supervised classification of RGB image bands;
- Estimation of sulphide and neutraliser mineral (e.g., carbonate) concentrations from VNIR-SWIR mineral classifications;
- Characterisation of sulphide mineral geometries; and
- Quantification of sulphide mineral associations.

Cracknell et al. (2018) conducted A-ARDI development work using the same porphyry samples examined by Jackson et al. (2018) and compared visual ARDI scores against A-ARDI scores, static testing and bulk mineralogy results for validation. The majority of calculated A-ARDI values were within 10 points of the manually obtained values. For all drill core samples, the calculated sulphide% content was up to 40 % less than the visual estimate of sulphide%. This difference affects indicator A (sulphide content), indicator C (sulphide morphology) and indicator D (neutraliser%) calculations. Overall, the A-ARDI was regarded as more accurate than ARDI when validated against bulk mineralogy data. With a larger training set, the A-ARDI can be refined and fine-tuned for individual deposits. Ultimately, the A-ARDI presents a new opportunity for rapid, repeatable and accurate classifications of ARD potential using routinely collected digital drill core data, therefore maximising the value of data collecting during early life-of-mine stages, particularly if used in conjunction with the GDI.

CONCLUSIONS

With more demonstrated examples of hyperspectral data used for geoenvironmental forecasting refinement of the GDI algorithm will improve to a point where fewer Level 2 tests will need to be undertaken ultimately saving companies time and money (i.e., cost of acid base accounting, turn-around-time for results). This research represents a first-step towards realising the value of this type of data with others potential geoenvironmental data which could be collected including:

- Predicting the greenhouse gas consumption of mine tailings through characterisation of silicate mineralogy.
- Predicting the amenability for tailings filtration through examining the clay mineralogy as identified using hyperspectral IR technology.
- Determining the mineral weathering rate of waste rock materials based on an understanding of mineralogy and textural arrangement.
- Use hyperspectral IR technology to analyse existing mine waste materials, including spent heap leach materials, for identifying recycling and reuse options.

Further, with new image processing tools and smart technologies, the opportunity for 'app-based' ARDI assessments to support AMD forecasting is tangible, however, the metalliferous mining industry has to be responsive and facilitate these research endeavours as these disruptive technologies have potential to enact global change and improve environmental outcomes for all stakeholders.

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