Establishing the value of an integrated geochemistry-mineralogy-texture approach for acid rock drainage prediction

by

Anita Parbhakar-Fox
MSci. (Hons), Imperial College, London, UK

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Abstract

The total estimated cost for worldwide liability associated with current and future ARD (acid rock drainage) remediation is approximately US $100 billion (Tremblay and Hogan, 2001 in Hudson-Edwards et al., 2011). Such liabilities are partly due to the limitations of existing predictive protocols, highlighting the importance of using appropriate and accurate methodologies. Current protocols for ARD risk assessment follow the wheel approach (Morin and Hutt, 1998) or the AMIRA P387A Handbook (Smart et al., 2002). However, the accuracy of these protocols solely relies on geochemical tests and, there is a clear absence of detailed mineralogical and textural characterisation in the applied methodologies. Consequently, inappropriate decisions can be made, either by not allocating the necessary resources when the ARD risk is underestimated, or by wrongly not pursuing development when ARD risk overestimated. Therefore, an improved predictive methodology based on ARD characteristics must be developed and implemented at early-stages of the mine life cycle. Additionally, such a methodology should have applications at historic mine sites to identify acid forming samples and guide site rehabilitation strategies.

The potential for improvement in ARD prediction methodology needs to consider mineralogical and textural characteristics as well as geochemical analyses. Therefore, this thesis has developed an improved and integrated protocol for classifying solid mine waste in terms of acid forming potential. The geochemistry-mineralogy-texture, or GMT approach, consists of three stages which involve a parallel use of geochemical, mineralogical and textural analyses:

- **Stage-one**: Low-cost pre-screening geochemical, mineralogical and textural tests and evaluations are performed on the largest number of samples.
- **Stage-two**: Routine geochemical tests are performed on fewer samples, using more expensive tests.
- **Stage-three**: Advanced geochemical tests and microanalytical techniques are performed on well selected samples.

Results are cross-checked at the end of each stage to provide an accurate sample classification in terms of acid forming potential. The advantage of the proposed GMT methodology relative to those currently used (e.g., the wheel approach, AMIRA P387A Handbook) is its structured approach, as evaluations of problematic samples are focused upon, thereby increasing technical accuracy of predictions, and reducing total number of samples analysed by routine tests, and overall costs. The acid rock drainage index (ARDI) forms part of the GMT approach as a stage-one test, and was developed to evaluate intact rock texture in terms of five key parameters (A: sulphide contents; B: sulphide alteration; C: sulphide morphology; D: content of neutralising minerals; and E: sulphide mineral associations), which influence acid formation. The GMT approach was tested on waste material from the historic Croydon gold-lode mines, and drill
core samples from the operational Ernest Henry iron-oxide copper gold (IOCG) deposit, both located in Queensland, Australia. The geology (including style of mineralisation and texture) differed between the two sites, allowing for critical assessment of both the GMT approach and the ARDI.

A mesotextural classification method (using geological logging, field portable X-Ray fluorescence and short-wave Infrared techniques) for grouping waste materials was developed and tested at the historic Croydon-gold mining operations. Through undertaking mesotextural classification, ten groups (A to J) were identified, and systematically characterised by the GMT approach. At the end of stage-one, five groups (C: porphyritic rhyolite containing disseminated pyrite in quartz veins; E: porphyritic rhyolite containing disseminated pyrite in the groundmass; G: semi-massive quartz-sphalerite-galena-pyrite; H: massive arsenopyrite-quartz; and J: semi-massive quartz-pyrite) were identified as potentially acid forming and required stage-two testing. However, all samples were tested at stage-two to check the accuracy of stage-one results, and were in agreement thus validating stage-one classifications. Samples from mesotextural groups C, E, G, H and J were subjected to stage-three analyses which utilised advanced geochemical tests, and microtextural analyses (i.e., mineral liberation analysis, laser ablation-ICP-MS and scanning electron microscopy). Stage-three geochemical analyses demonstrated that NAG testing results on samples containing <0.3 wt. % sulphide were inaccurate (i.e., underestimated acid forming potential), with the multi-addition NAG test instead recommended for use. Microtextural studies indicated that trace element distribution; contents of micro-inclusions and mineral association were significant controls on sulphide oxidation. Final GMT approach classifications identified groups H and J as extremely acid forming; and groups E and G as potentially acid forming.

Croydon waste materials representative of mesotextural groups E, G, H and J were selected for thirty-week column leach kinetic testing following the recommendations of the GMT approach. Twelve columns were established, with two size fractions (-10 mm and -4 mm) prepared from each sample, to investigate the effects of grain size on pH, metal elution and secondary mineral precipitation. The mineralogy and microtexture of the column feed material were examined routinely (i.e., every five weeks) through quantitative X-Ray diffractometry, scanning electron microscopy and laser ablation ICP-MS studies. These data were directly compared with leachate chemistry (pH, EC, SO₄ and cation contents) to identify the controls on sulphide oxidation and trace element liberation. Material representative of mesotextural group H was the most acid forming, with lower pH values and higher cumulative mass release of elements calculated for the -4 mm fraction. Mineralogical data showed progressive replacement of arsenopyrite to trace element rich (i.e., Cu, Pb and Zn) scorodite. Pyrite in material representative of mesotextural groups E and J was As-rich, with greater quantities of pyrite weathering products (i.e., rhomboclase, jarosite, alunite) and textures identified over time. Generally, lower pH and higher dissolved metals and arsenic were measured in leachate from the -4 mm fraction. Values of pH were particularly sensitive to the development of fine hydrous ferric oxide coatings on pyrite in groups E and J. Galena was also identified in material representative of groups E and J and was observed to weather rapidly to anglesite over the duration of these tests. Whilst sphalerite present in material representative of mesotextural group G was Cd- and Fe-rich and contained Cu micro-inclusions (factors which increase
oxidation rate), overall it was the least weathered of the sulphides. However, the leachate pH values measured from group G indicated that this material is acid forming as a consequence of the oxidation of pyrite which was also identified in this group. The highest cumulative mass release of Zn relative to the other groups was measured from the -4 mm fraction. However, very low cumulative mass release rates of Cd were calculated from both grain size fractions. Kinetic test results confirmed that mesotextural groups G, H and J pose the greatest environmental risk in terms of ARD and potential metal/metalloid leaching. Consequently, a rehabilitation strategy focusing on individual segregation and treatment of material representative of groups G, H and J from non-acid forming mesotextural groups is recommended.

The application of geometallurgical techniques for predicting acid formation was demonstrated using samples from the Ernest Henry IOCG deposit. Samples from two drill holes were initially subjected to GMT analyses with results compared against geometallurgical data sets collected by mineral liberation analysis (MLA), HyLogger and EQUOtip. Modal mineralogy data collected by MLA allowed for the carbonate:sulphide ratio to be examined down hole as is required by stage-one of the GMT approach. Relative carbonate contents determined from the HyLogger allowed for acid neutralising capacity (ANC) values to be critically evaluated in terms of effective ANC. Finally, relationships between mineral hardness measured using EQUOtip and lag-time to acid formation were identified. This study identifies the potential for integrating geometallurgical techniques and data into the GMT approach, as a means of allowing for ARD characterisation to be routinely undertaken at the early stages of mine operations.

Results from the two case study sites (Croydon, Ernest Henry) demonstrate that the geochemistry-mineralogy-texture (GMT) approach represents a significant improvement to existing ARD predictive protocols (e.g., the wheel approach, AMIRA P387A Handbook), by providing a structured methodology to more efficiently identify problematic samples. Stage-one of the GMT approach allows best practice sample numbers to be realistically achieved through cost-effective pre-screening tests, thus improving ARD risk assessment. Furthermore, selection of samples for testing based on mesotextural grouping, rather than lithology, allows for deposit wide ARD domaining to be effectively undertaken, particularly when integrated with geometallurgical data. The presented methodology effectively integrates existing geochemical tests with novel mineralogical and textural characterisation techniques. This in turn leads to maximisation of knowledge, cost savings, and a more detailed characterisation of the most acid forming samples. Therefore, the GMT approach represents a fundamental step-change in how ARD should be predicted.
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