Mine Closure 2016 – AB Fourie and M Tibbett (eds)

https://papers.acg.uwa.edu.au/p/1608_48_Pearce/

A risk-based approach using process flow diagrams for operational waste rock classification — case studies

S Pearce *O'Kane Consultants, UK*

J Warner *G-Resources, Indonesia*

E Sinclair *Bathurst Resources Limited, New Zealand*

J Pearce *O'Kane Consultants, Australia*

W Olds *O'Kane Consultants, New Zealand*

P Weber *O'Kane Consultants, New Zealand*

Abstract

Acid and metalliferous drainage (AMD) management plans are generally developed as part of a site's closure plan to inhibit or mitigate the generation and release of AMD for sites with problematic materials. They are typically constructed around a body of knowledge involving multiple geoscience and environmental disciplines. However, despite the volume and degree of scientific investigations completed, if the waste rock classification system and therefore AMD management plan developed is not practical and does not take into consideration other site drivers such as production, its successful implementation and adoption is unlikely. A common weakness of AMD plans developed based on industry best practice is that they often fail the practicality test, as the characterisation process produces ambiguous outcomes such as the classification of material as uncertain with respect to acid generating potential.

As part of optimising the characterisation process, a site specific waste rock classification process flow diagram approach is discussed herein. The development and use of a process flow diagram to optimise the testing regime opposed to a traditional matrix-style system can reduce the number of tests required, the cost of testing, and the time required to make informed classification decisions. However, to be confident in the use of a process flow method for waste rock classification requires detailed knowledge of site geology and geochemistry; and the completion of a suitable sampling program, incorporating acid base accounting (ABA) before the development of a process flow method.

A flow process often only requires basic parameters for the classification of a block of waste, arriving at the parameter boundary values that incorporate the results of several detailed second and third geochemical testing phases. The use of acid buffering characteristic curves, kinetic net acid generation tests and large scale site column tests allow the consideration of kinetic factors for a risk-based operational waste rock classification that differentiates between different degrees of potentially acid forming (PAF) materials. This differentiation allows more control over AMD management and subsequently reduces closure risk.

At the Martabe Gold Mine, Sumatra, following a detailed ABA classification program, a process flow methodology and specialised rapid field testing program for geochemical classification of waste rock was developed as a tool for the operational management of overburden. This is used as a quality control or verification phase for confirmation of the geochemical waste rock block model, and ensures that waste rock is correctly identified in the field and handled as per the management plan. Application of this approach is discussed in this paper.

At the Escarpment Coal Mine, West Coast, New Zealand, a new process flow method for geochemical classification is being trialled. Results indicate that classification by a process flow method results in far fewer samples being classified as uncertain compared to the current resource consent matrix-style classification. Results presented in this paper indicate that ABA data and field column leach trials validate this approach.

1 Introduction

Mining operations typically require geochemical classification of waste rock in the planning and operational phases, to determine the potential for acid and metalliferous drainage (AMD) as part of mine closure business risk management and in order to receive regulatory approval for mining. A substantial sampling and testing regime is usually required for the mining operation to demonstrate confidence in the waste classification and management method proposed as part of mine operations and closure planning. Over estimation of AMD risks may prevent projects from starting due to high capital expenditure and operational costs for treatment; while underestimation may result in unanticipated treatment costs and legacy issues for the project at closure. It is important therefore that the best estimate of AMD potential is provided so that suitable management measures, such as engineered covers and treatment systems, can be designed to address the likely scale of environmental issues during operation and closure, and meet the approval of regulators and the community (Olds et al. 2015).

AMD management plans are generally developed to inhibit or mitigate the generation and release of predicted AMD during operations and closure. They are typically constructed around a body of knowledge built on extensive investigations involving multiple geoscience and environmental disciplines. However, despite the volume and degree of scientific investigations completed, if the AMD management plan is not practical and does not take into consideration other site drivers such as production, its successful implementation and adoption is unlikely.

Where AMD management plans require laboratory testing of materials for classification purposes and subsequent materials placement, substitution with field testing procedures has the advantage of minimising disruption to production through delays in materials movement. Having the capacity to test a block of waste as it is excavated and then direct the waste to the appropriate location based on field testing results can substantially reduce the time interval between excavation and placement.

The purpose of developing field testing programs are to develop a simple site based testing procedure for the geochemical classification of waste rock with respect to its acid-base characteristics, based on the principles of acid-base accounting (ABA).

A risk-based process flow method for waste rock classification has been developed for two mining operations and is discussed in this paper.

2 Classification methods

2.1 Acid base accounting

Geochemical classification of waste rock overburden involves a variety of ABA techniques. The industry standard approach is to determine the net acid production potential (NAPP) (AMIRA 2002). The NAPP is the difference between (a) the acid neutralisation capacity (ANC), which typically represents carbonate minerals that can be determined by titration methods and is expressed as kg H_2SO_4/t equivalent, and (b) the maximum potential acidity (MPA) where MPA = wt% total S × 30.6 and is expressed as kg H_2SO_4/t equivalent. The factor of 30.6 used to calculate MPA is determined by the stoichiometry and molar mass of pyrite oxidation in the presence of oxygen and water producing ferric hydroxide compounds.

Total sulphur is typically used for the calculation of MPA in the absence of sulphur speciation data, however, sulphide content (sulphide sulphur) is also frequently determined for MPA calculations as sulphides are considered to be the main acid forming sulphur species. A negative NAPP indicates that the sample has a net neutralising capacity and a positive NAPP indicates the sample has a net acid-generating capacity.

$$NAPP = MPA - ANC \quad (1)$$

The ANC of a mine waste is determined by treating the sample with a known excess of hydrochloric acid and back-titrating the unconsumed acid with sodium hydroxide. The principal neutralising minerals in most geological materials are calcium and magnesium carbonates. Additional neutralising minerals accounted for in the determination of ANC include basic silicates such as calcic feldspars, olivine, amphiboles, and biotite. However, due to their generally slower dissolution rates, their contribution to the overall ANC is generally considered to be small under ambient conditions. Felsic silicates, such as sodic and potassic feldspars, muscovite, most clay minerals, and quartz, do not contribute significantly to the ANC.

Net acid generation (NAG) testing involves the digestion of a pulverised sample (2.5 g) with 250 mL of 15% hydrogen peroxide, which is then allowed to react to completion before measuring the pH of the NAG liquor. The NAG liquor is then titrated with NaOH to pH 4.5 and 7. Acidity measured (expressed in kg H_2SO_4/t) by the titration to pH 4.5 is due to free hydrogen ion, as well as acidity from aluminium and iron (AMIRA 2002). Additional acidity measured by the titration to pH 7 can be attributed to metal hydrolysis reactions such as copper and zinc (AMIRA 2002). The NAG test is based on the principle that a strong oxidising agent (hydrogen peroxide) accelerates oxidation of any sulphide minerals. As the sample is oxidised and releases potential and stored acidity, acid neutralisation reactions also occur in tandem. If the sample contains sufficient ANC material, the alkalinity of the samples will not be depleted and the NAG pH will be circum-neutral to alkaline. If ANC is insufficient to neutralise acid released, the NAG pH will drop below 4.5 and the sample will have a positive net acidity.

Paste pH is determined by mixing 1 part of pulverised rock (<75 µm) and 2 parts of deionised water, followed by pH measurement of the paste as per the AMIRA (2002) method. Paste pH is a very simple test but can provide an indication of the immediate acid-base nature of the sample. If the pH is less than 5.5, it suggests the sample contains stored acidity in the form of acidic oxidation products such as melanterite and jarosite type minerals; the lower the pH the greater the stored acidity content. Samples having a low paste pH are nearly always considered potentially acid forming (PAF) as the immediate acid generating reactions outweigh any immediate acid neutralising reactions generated from fast dissolving minerals such as carbonates. Further discussion on stored acidity is provided by Weber et al. (2015).

2.2 Conventional AMD classification

The established approach to classifying mine waste rock is to use a simple combination of ABA tests, such as NAPP and the NAG acidity of the sample (AMIRA 2002), to provide two methods to assess whether the sample is PAF or non-acid forming (NAF) (Olds et al. 2015).

The classification method developed by AMIRA International is one example of an industry accepted method which plots NAG pH versus NAPP (AMIRA 2002). If there is good correlation between NAG pH and NAPP then a clear classification process can be developed identifying NAF and PAF samples. However, often uncertain (UC) classification can occur, as identified on Figure 1(a).

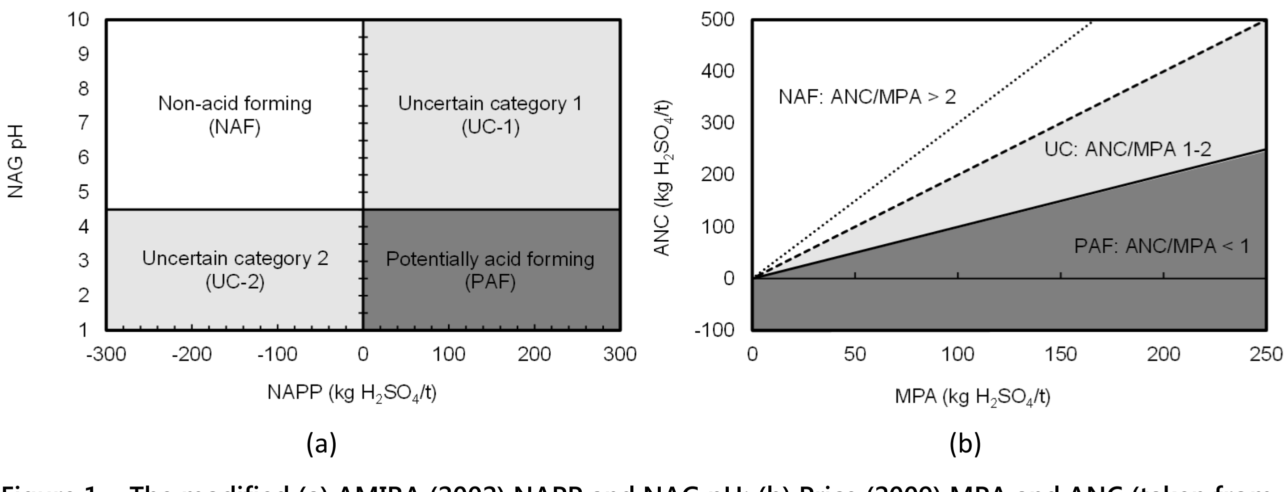


Figure 1 The modified (a) AMIRA (2002) NAPP and NAG pH; (b) Price (2009) MPA and ANC (taken from Olds et al. 2015)

A classification system more common to the northern hemisphere is one presented in the Mine Environment Neutral Drainage Program (MEND) guidelines (Price 2009) which utilises the ANC/MPA ratio (Figure 1(b)). Terminology used in the MEND classification system differs from that used in the AMIRA guidelines. The neutralisation potential ratio (NPR) referenced in the MEND classification system is equivalent to the ANC/MPA ratio that is generally used in Australasia. Typically, material with an ANC/MPA ratio greater than two are classified as NAF material, while material with a ratio less than one are classified as PAF material. If the ANC/MPA is between one and two the sample classification is uncertain.

Populating these classification schemes can be expensive and time-consuming when applied as a blanket approach to classification. It can also lead to a large proportion of samples with conflicting results or incorrect classification of samples (Olds et al. 2015). The most significant drawback to these schemes is that they inherently fail the practicality test for application on sites as the results produced are ambiguous. Large numbers of samples often report in the uncertain category which is not helpful for waste management planning and AMD risk assessment purposes.

2.3 Process flow diagram approach

A process flow diagram approach was developed for two sites to optimise the testing regime as opposed to a traditional matrix-style system. This approach is designed to reduce the number of tests required, the cost of testing, and the time required to make informed classification decisions. A flow process often only requires basic parameters for the classification of a block of waste, arriving at the parameter boundary values that incorporate the results of several detailed second and third geochemical testing phases. The use of tests such as acid buffering characteristic curves, kinetic net acid generation tests and large scale site column tests allow the consideration of kinetic factors for a risk-based operational waste rock classification that differentiates between different degrees of PAF materials. This differentiation allows more control over AMD management and subsequently reduces closure risk.

3 Case studies

Two case studies where process flow methodologies have been developed to improve waste rock geochemical classification are discussed: the Martabe Gold and Silver Mine and the Escarpment coal mine.

3.1 Martabe, Indonesia

The Martabe Gold Mine is located in the sub-district of Batangtoru, North Sumatra. It is owned and operated by G-Resources Group Limited, a mining company publicly listed on the Hong Kong Stock Exchange. Production at the Martabe Gold Mine commenced in July 2012 and mine life is a minimum of 10 years based on current ore reserves. The mining operations include an open pit and an integrated tailings storage facility which is a valley-fill containment structure where the embankment also functions as the site's waste rock dump. There is currently one active pit but over time additional pits will be developed.

Like many mines in the tropics, the site is in close proximity to local communities and high biodiversity value tropical forest. The waterways that drain the site are used as sources of water for washing and cooking and so are important to the communities. The success of the Martabe Gold Mine depends heavily on the company maintaining its social licence to operate and a key contributor to this is environmental performance.

The deposit is a high sulphidation epithermal deposit with fairly complex local geology that contains a package of altered volcanics. Generally mineralised quartz veins (that contain high grade sulphide ore) cut through a package of volcanics that include various altered breccias and more competent andesite rock. Alteration types include shallow oxide materials, argillic, advanced argillic, and silicified material (mainly at depth). Acid generating minerals identified from mineralogical analyses and ABA undertaken during the geochemical assessment program were pyrite, jarosite and alunite. Other influential minerals, with respect to ABA interpretations, were gypsum, calcite and ankerite (the latter being calcium carbonate based buffering minerals).

3.1.1 AMD management plan

A detailed AMD management plan has been developed by G-Resources for the Martabe Gold and Silver Mine. The plan provides:

- A concise summary of technical work undertaken by G-Resources to understand the geochemistry of the Martabe group of deposits in regards to AMD.
- Technical guidance for specific aspects of waste rock management during the development and operational phases.
- An overall framework for the management of waste materials during the construction of the tailings storage facility.

The waste rock management strategy at the Martabe Gold Mine has been progressively developed over a number of years taking into account the results of several major technical studies, ongoing refinement of waste models and waste schedules, and operational experience. Characterisation of waste rock into standard categories based on geochemical testing is integral to this strategy and will be conducted throughout life-of-mine.

3.1.2 Geochemical classification program

G-Resources has developed a significant database through geochemical characterisation of the waste rock at the Martabe mine site such that it is not only in-line with industry best practice but exceeds it. Several sources of geochemical data were available to develop the risk-based waste rock classification process flow method for operational use in characterising blocks of waste rock (Table 1).

Table 1 Geochemical data sources used for development of waste classification process flow diagram

Geochemical data source	Samples
Resource assay database	>10,000 datapoints for total sulphur, sulphide sulphur, and calcium content, base metals (As, Cu etc).
Phase 1 geochemical testing	Hundreds of samples analysed for acid ABA (sulphur speciation and ANC), NAG, and paste pH.
Phase 2 detailed testing	Range of detailed laboratory analyses, including total elemental analysis, (stored) acidic salt analysis, mineralogical analysis, static leach testing, kinetic NAG testing (KNAG), and acid buffering characteristic curves.
Large scale leach columns	In operation at site for >10 years and are thought to provide some of the longest running kinetic datasets in the industry.

Data collected from the geochemical testing program generally shows samples contain a proportion of stored acidity. This is likely, in part, to be due to aging of the sample prior to analysis and may not be a true representation of the fresh rock in the field following blasting and excavation. However, it does provide a good indication of the potential weathering (oxidation) effects, if the materials are left exposed to oxygen and moisture. Paste pH values suggest the presence of water soluble acid salts such as melanterite and adsorbed/readily available H^+ acid. The higher paste pH values greater than pH 7 for waste rock suggests there are some samples that have high initial ANC, greater than the initial acid generating reactions in the sample, and relate to the presence of significant calcium carbonate minerals.

NAG pH, NAG acidity, and NAPP confirm that some waste rock is PAF, although there are a large number of NAF samples as indicated by negative NAPP values. ANC data indicated that some samples have a high capacity to neutralise acid generation (>40 kg H_2SO_4/t equivalent). Effective neutralising capacities (ENC) determined by acid buffering characteristic curves (ABCCs) showed that, generally, ENC was greater than 70% of ANC for these higher ANC bearing samples.

3.1.3 Field testing process flow method

The waste classification process flow method was designed with the functionality to utilise simple tests that can be collected rapidly to reduce operational delays. A key point to consider is that although the process flow method only incorporates basic parameters for classification process it utilises the knowledge gained from the previous detailed geochemical data sources. The use of such data allows the consideration of kinetic factors for a risk-based waste rock classification process that differentiates between the various PAF materials.

The initial process flow method developed uses three standard parameters (paste pH, NAG pH, and NAPP), which require laboratory analysis and up to seven days for results to be available. To minimise operational delays by reducing lab turn-around times for ABA data, the laboratory methods were substituted for quicker field compatible methods.

The AMIRA paste pH method (AMIRA 2002) was adapted to a field pH method, and the field oxidation pH method was adapted from the 'Acid Sulfate Soils Laboratory Methods Guidelines' (Ahern et al. 2004) to replace the NAG test. Routine assay analysis already implemented in grade control processes, namely sulphur and calcium, were substituted for the determination of MPA and ANC for NAPP calculations. A process flow method was created to explain this approach and the subsequent geochemical classification (Figure 2).

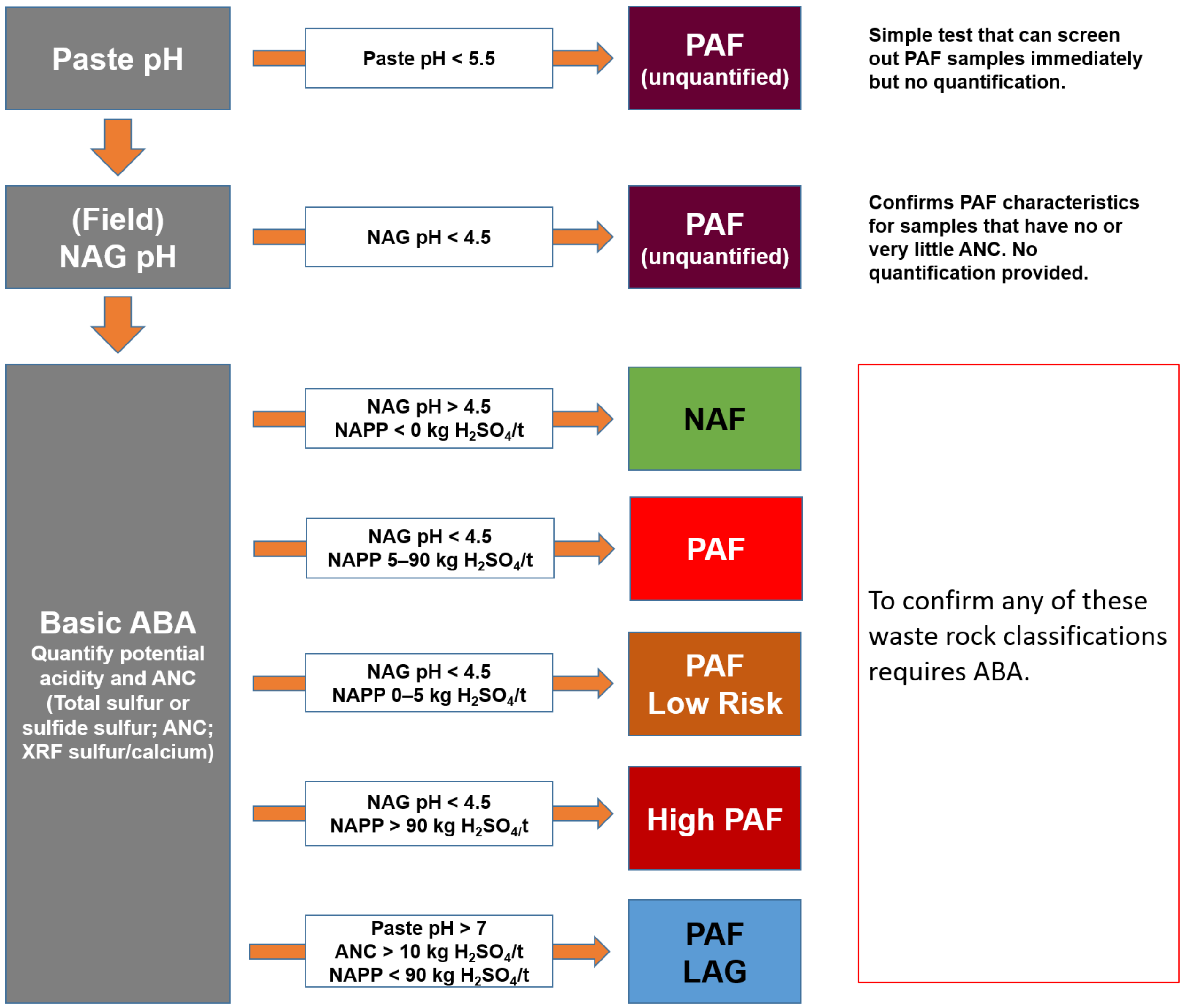
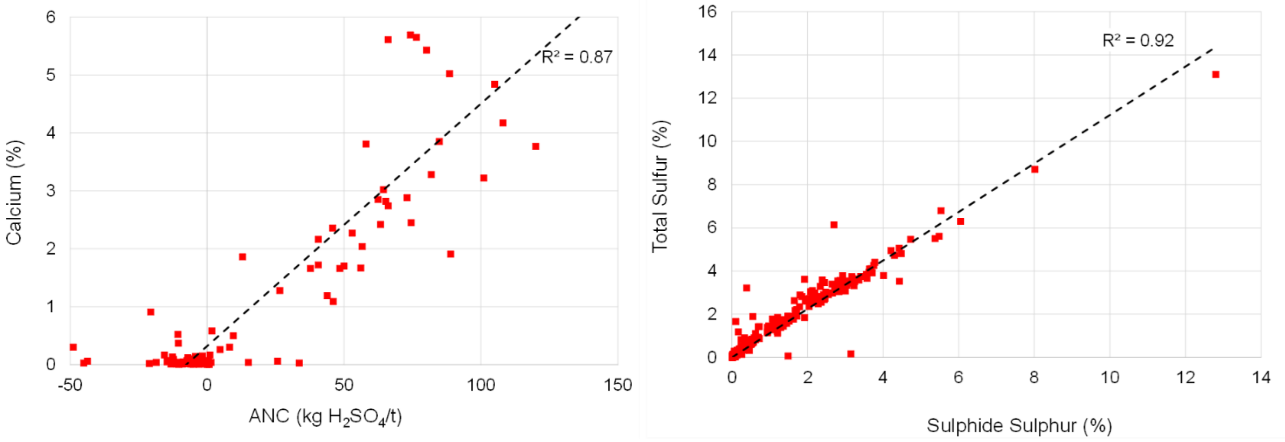


Figure 2 Initial process flow method for onsite waste classification at Martabe Gold Mine

Field pH and field NAG pH results can be applied directly to the waste classification system without any data manipulation.

The results from earlier geochemical testing showed that sulphur and calcium data collected either with a field portable x-ray fluoresce (XRF) or through routine assay analyses for grade control, provided good proxies for MPA and ANC (Figure 3). MPA is calculated from sulphur and it is assumed that all calcium is present as calcite; 0.4 wt% calcium is approximately equivalent to an ANC of 10 kg H_2SO_4/t. NAPP was calculated from these parameters.

The calcium data in the assay database was compared, where available, to measured ANC to provide an indication of the reliability of using calcium (determined by XRF) as a surrogate for ANC by titration. Results are presented in Figure 3 and show a reasonable trend (R^2 = 0.87), although a number of outliers are present. Further validation of this step is required to confirm the approach.



(a) (b)

Figure 3 (a) Total sulphur versus sulphide sulphur; (b) ANC versus wt% Ca

The waste rock classifications can be briefly defined as:

- NAF: waste rock is classified as NAF if the field pH and field NAG pH results are greater than 5.5 and 4.5 respectively, and if its NAPP is negative (i.e. ANC exceeds MPA).
- PAF: waste rock is classified as PAF if it has a positive NAPP and NAG pH below 4.5. Classification is then split into four sub-categories: PAF, PAF – Low Risk, High PAF, and PAF – LAG, as per Figure 2 depending on the magnitude of NAG pH and NAPP.
- PAF: Low Risk: materials with acidic field oxidation pH results (<4.5) and a slightly positive NAPP (0–5 kg H_2SO_4/t). These materials require less strict handling and management requirements compared to the materials classified as PAF and High PAF.
- PAF: High grade: materials with acidic field oxidation pH results (<4.5) and a highly positive NAPP (>90 kg H_2SO_4/t). Data analysis in combination with the waste rock schedule indicates that although the volume of PAF – High Risk is small, it represents a large proportion of the total potential acidity load for the site and thus requires robust management techniques to minimise AMD from the rock.
- PAF: LAG: test work indicates that a paste pH of greater than 7 and ANC greater than 10 kg H_2SO_4/t may indicate a lag to acid onset for materials with a NAPP less than 90 kg H_2SO_4/t. Materials are likely to have a time lag to acid onset and thus provide an opportunity to prioritise the management of PAF waste rock. Detailed geochemical data indicates that PAF – LAG waste rock can be left exposed for a reasonable time before any cover is required, unlike PAF and High PAF rock which has no time to acid onset.

3.1.4 Validation of field testing methods

A detailed QA/QC procedure was incorporated into the AMD management plan for the following key purposes:

- To continually assess the appropriateness of the modified field testing methods in representing the associated standard laboratory methods.
- To improve the efficiency of the field testing procedures and decrease their time dependence for site personnel by potentially reducing time required to accurately perform the field methods.
- To include robust duplicate testing procedures both at site and using a third party commercial laboratory to ensure data obtained is suitable for AMD management purposes.

Initially, an intensive testing regime for the calibration of the waste rock classification system is being implemented. Should consistency be observed in the test results, the frequency can be potentially reduced.

Duplicates (1 in 20) are sent to a commercial laboratory for AMIRA (2002) methods paste pH, NAG pH and ANC to confirm the appropriateness of the field pH and field oxidation methods as well as confirm the relationship between ANC and wt% calcium. It is also recommended that duplicates are sent for ABCC testing, as per the AMIRA (2002) method.

The initial measurement of the field pH and field oxidation pH at multiple testing durations is used to optimise the time dependence of the methods. For example, the duration of the field pH test may be significantly reduced compared to that given in AMIRA (2002), which is 12 hours.

3.1.5 Refinement of process flow method — resource block model pre-classification

To build on the initial waste rock classification process flow diagram, G-Resources incorporated a pre-classification process flow method (Figure 4) into their resource block modelling. This utilised assay data and lithological codes to classify waste into the five classifications presented in Figure 2. These classifications are then confirmed at the grade control stage using the process flow method presented in Figure 2. Therefore, this introduces the potential to reduce the dependence on high volume laboratory analysis following blasting and again reducing operational costs.

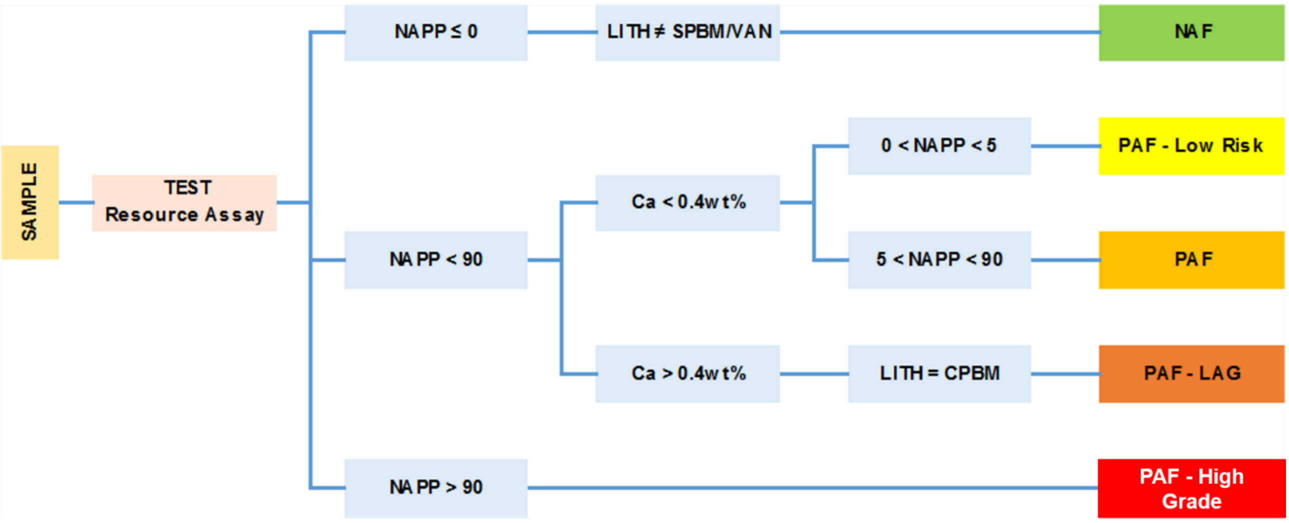


Figure 4 Pre-classification process flow method incorporated into resource block model. NAPP is calculated from sulphur and calcium assay results

The pre-classification process flow method is based on conventional NAPP from assay data contained within the drill hole database using the MPA derived from wt% sulphur (as total sulphur or sulphide), and the ANC based on the wt% calcium (assumed to be calcite). Although, NAPP is the primary assessment criteria, in absence of calcium data for NAPP calculation, a sulphur cut off value was also provided.

3.1.6 Potential operational cost savings

By implementing the process flow method at the grade control stage and successfully substituting laboratory analysis for field based methods, significant operational cost savings can be realised. Assuming between 300 and 500 samples are collected and analysed per month as part of the process flow method at the grade control stage, the following indicative laboratory costs are applicable for matrix-style method:

- Total sulphur (induction furnace): AUD 6,000 to 10,000.
- ANC (titration): AUD 7,500 to 12,500.
- Paste pH (AMIRA 2002): AUD 4,500 to AUD 7,500.
- NAG pH (AMIRA 2002): AUD 10,500 to AUD 17,500.

This equates to a potential cost to operations of between AUD 28,500 and AUD 47,500 per month. By implementing the process flow method at the grade control stage, which would utilise grade control assay data (sulphur and calcium) with field testing of pH and NAG pH, operational costs could be reduced in excess of 80%.

3.2 Escarpment Coal Mine, New Zealand

The Escarpment Mine, located on the West Coast of the South Island of New Zealand, is located approximately 13 km northeast of Westport. The mine occurs within the Brunner Coal Measures which are often deficient in carbonate minerals such that the oxidation of pyrite typically leads to the rapid formation of AMD.

3.2.1 Current Resource Consent waste rock classification system

Bathurst Resources Limited (BRL) currently clarify waste rock in line with their Resource Consent conditions which allows for classification of waste rock as NAF, low risk, and PAF (Table 2). The classification of waste rock by BRL is carried out through geochemical sampling and analysis of overburden, which facilitates the determination of the acid generating potential of waste rock. Once classified, waste rock is then managed to minimise acidity generation, for example by disposing PAF material at the core of the waste rock dump and restricting cover system construction materials to NAF waste rock only.

Table 2 Current Resource Consent classification by geochemistry for the Escarpment Coal Mine

Classification	Paste pH	NAG pH	NAPP acidity (kg H_2SO_4/t)
NAF	>4.5	>4.5	<0
Low risk	>4.5	>4.5	<5
PAF	<4.5	<4.5	>2

Currently BRL undertake a matrix-style classification approach for waste rock (Table 2) which is based on the AMIRA classification system, although a NAPP acidity of greater than 0 kg H_2SO_4/t is used for PAF classification based on recommendations by the Escarpment Peer Review Panel. Under this matrix-style approach (NAPP versus NAG pH), a significant number of samples from the Escarpment Mine are classified as uncertain (Figure 5).

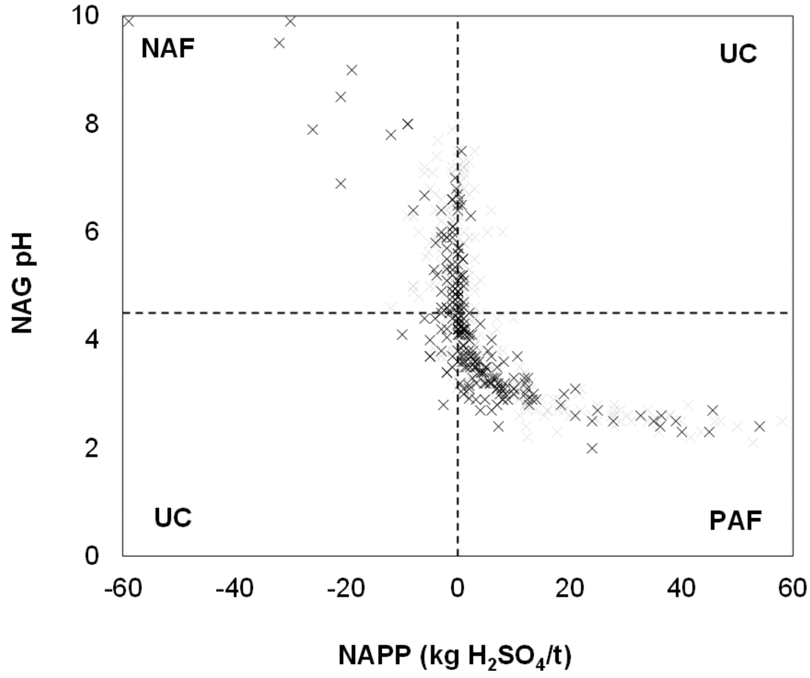


Figure 5 NAPP versus NAG pH for rock samples from the Escarpment Mine project

3.2.2 Process flow classification

A revised process flow method for geochemical classification has been developed for the Escarpment Mine (Figure 6). This approach limits the amount of testing on samples that are clearly PAF and NAF, allowing the operator to focus on the more difficult to classify, low risk materials. The end point of each branch of the process flow method is a classification rather than a set of data from which a classification is derived (Olds et al. 2015).

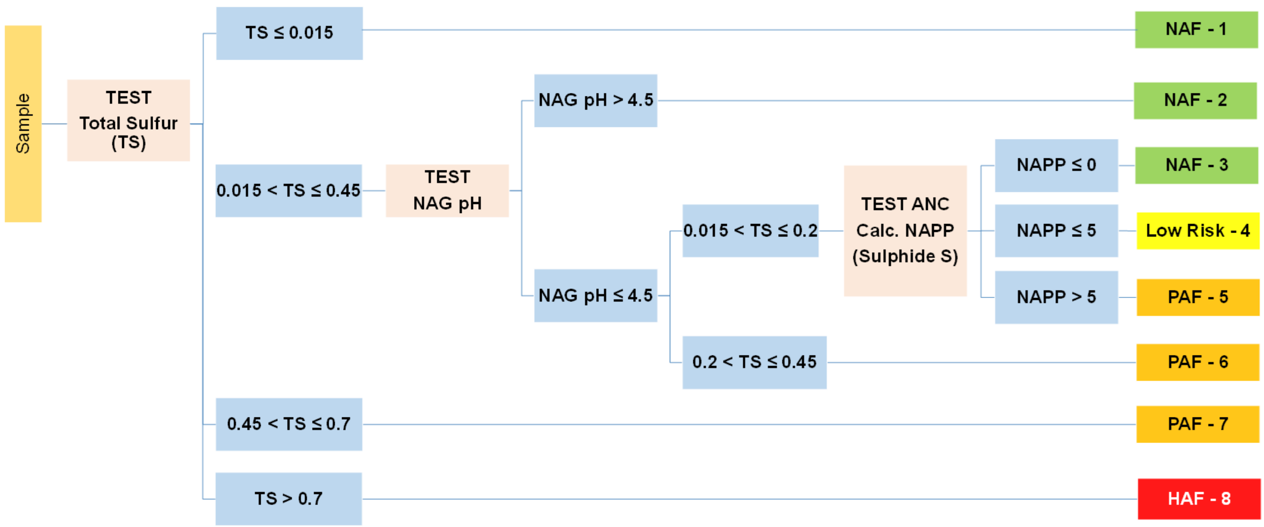


Figure 6 Process flow method for classification of Escarpment Mine waste rock. Sulphur values are wt%

As highlighted in earlier sections, a thorough understanding of site geochemistry is required prior to the development of a meaningful process flow method. For example, Figure 6 shows that any materials with total sulphur higher than 0.45 wt% have been classified as PAF without any further testing requirements. The Escarpment Mine ABA database shows that for the vast majority of samples the ANC is much less than 10 kg H_2SO_4/t (equivalent to approximately 0.33 wt% total sulphur), validating the assumption that ANC is negligible (in terms of classification) in samples with high sulphur content.

The Escarpment Mine process flow method is an iterative process with subsequent stages of testing being governed by the results of the previous stages of testing. The process flow method removes the uncertainty field from the matrix-style classification system. The only samples with potential for an uncertain classification occur where analytical data were missing, however, it remains relatively resilient to incomplete datasets. For example, samples that are high acid forming (HAF) can be classified if only total sulphur data are available (and they meet the HAF criteria), unlike a matrix system which requires multiple parameters for classification.

3.2.3 Classification results

BRL have compiled a geochemical testing database consisting of 726 samples. The database contains results from a range of typical tests including acid base accounting (ABA) testing including ANC, sulphur speciation (total sulphur and sulphide sulphur), NAG, and paste pH.

Under the traditional matrix-style classification system, the current Resource Consent AMD classification process results in 41% of samples being classified as uncertain (Figure 7(a)). An additional 23% had insufficient data for classification under the current Resource Consent system. Uncertain results typically lead to requirements for further test work to confirm geochemical classification, possibly delaying operations.

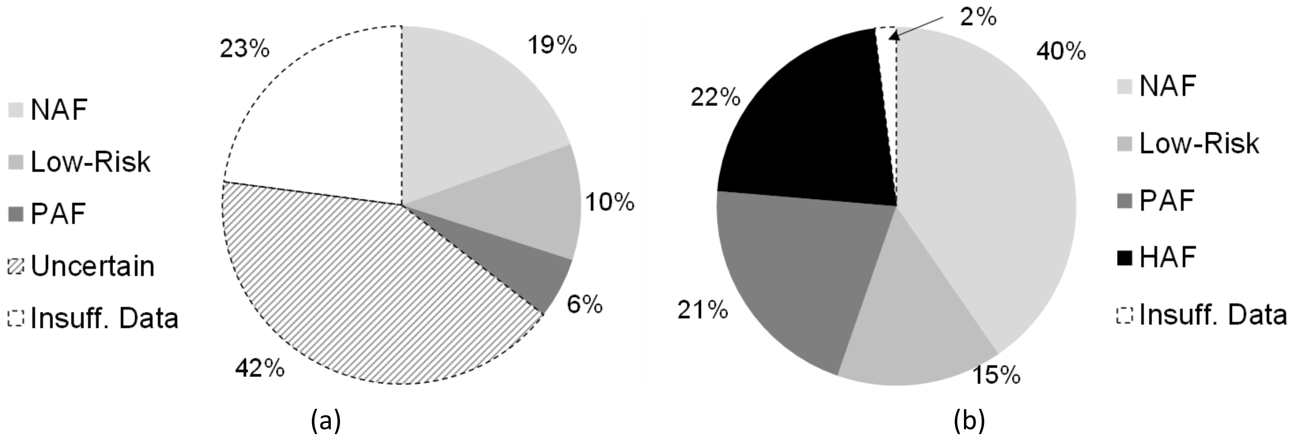


Figure 7 Comparison of waste rock classification by the (a) matrix-style; (b) process flow methods (taken from Olds et al. 2015)

As presented in Figure 7, the utilisation of the process flow method removes the possibility of uncertain classifications as the end point of each branch of the flow method is a classification. Therefore, with the exception of 2% of samples that had incomplete datasets, all other samples were classified using the process flow method (Figure 7(b)).

A key advantage to the process flow method, in addition to the removal of potential uncertain classifications, is the reduction in individual analyses required. Using the ABA dataset of 726 samples as an example, approximately 1,800 individual ABA analyses were completed for the matrix-style method. Applying the process flow method to the same dataset reduces the amount of individual analyses to a total 1,130. This equates to a total of 7 and 1.6 required tests, for the application of the matrix-style and process flow method respectively, highlighting the higher efficiently of the process flow method for waste rock classification.

3.2.4 Operational cost savings

Analysis of general laboratory costs for 726 samples indicates that approximately AUD 84,000 was spent to classify 35% of waste rock samples using the matrix-style classification. With the process flow classification approach a total of AUD 44,000 was required for analysis to classify 98% of samples, which is approximately a 50% decrease in laboratory costs for a 180% increase in successful classification.

This work confirms that the site specific process flow method is robust. Further work is required to understand the benefits of utilising paste pH, assessment of stored acidity, and any refinements that can be made to the current process flow.

4 Conclusion

At the Martabe Gold and Silver Mine, process flow methods have been developed as part of their AMD management plan for the efficient and thorough classification of waste rock. The pre-classification process flow method is incorporated into the resource block model and takes advantage of lithological data, as well as sulphur and calcium data, to classify waste into five classes. A second process flow method is then implemented at the grade control stage to validate the resource block model. The second process flow method substitutes laboratory testing for field based tests and utilises grade control assay data to reduce operational delays associated with laboratory analysis time requirements. It also results in a decrease in operational costs associated with waste classification at grade control stage of in excess of 80%.

The Escarpment Mine process flow method for waste rock classification, as applied to the existing ABA data, is shown to eliminate uncertain samples from the classification process which previously accounted for 41% of all classification outcomes. This resulted in a 98% successful classification rate for the Escarpment Mine ABA database. The application of the process flow method also decreases the operational cost associated with laboratory analysis by up to 50%. The ability to focus time and resources on classification of difficult to define materials increases confidence in the overall geochemical classification process. With the process flow method there was a 38% reduction in testing from the previous matrix classification method, reducing the cost of geochemical analyses.

Process flow methods are best designed after an initial general ABA testing phase such that site knowledge can be incorporated into the process flow. Both G-Resources and Bathurst Resources Limited have undertaken such an approach. However, site based validation of the any process flow method is also required for confidence by the operators and stakeholders and may help fine-tune the process flow classification. At the Martabe Gold and Silver Mine, the process flow method is being used to confirm the initial waste rock block model and is in itself a quality control step.

References

Ahern, CR, McElnea, AE & Sullivan, LA 2004, *Acid Sulfate Soils Laboratory Methods Guidelines*, Queensland Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland.

AMIRA 2002, *ARD Test Handbook - Project P387A Prediction and Kinetic Control of Acid Mine Drainage*, AMIRA International Limited, Melbourne.

Olds, WE, Bird, B, Pearce, JI, Sinclair, E, Orr, M & Weber, PA 2015, 'Geochemical Classification of Waste Rock using Process Flow Diagrams', in *The Proceedings of the 2015 AusIMM New Zealand Branch Annual Conference*, Australian Institute of Mining and Metallurgy, Dunedin, pp. 307–308.

Price, W 2009, *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials*, Mine Environment Neutral Drainage (MEND) Program, Smithers, British Columbia.

Weber, PA, Olds, WE, Bird, B & Pearce, JI 2015, Forecasting long term water quality at closure for current mining operations, *The Proceedings of the 2015 AusIMM New Zealand Branch Annual Conference*, Australian Institute of Mining and Metallurgy, Dunedin, pp. 495–505.