Geochemical classification of waste rock using process flow diagrams

W.E. Olds[1], B. Bird[2], J.I. Pearce[3], E. Sinclair[4], M. Orr[5] and P.A. Weber[1]

1 O'Kane Consultants (NZ) Ltd, Castle Hill Village, New Zealand. pweber@okc-sk.com
2 O'Kane Consultants (Australia) Pty Ltd, Belmont, NSW, Australia. bbird@okc-sk.com
3 O'Kane Consultants (Australia) Pty Ltd, Perth, Australia. jpearce@okc-sk.com
4 Bathurst Resources Limited, Westport, New Zealand. ESinclair@bathurstresources.co.nz
5 G Resources, Martabe Mine Site, Sumatra. Matthew.Orr@G-Resources.net

Abstract

Traditional geochemical classification of waste rock involves a range of acid base accounting (ABA) tests, which can be exhaustive and sometimes unnecessary. The established approach to classifying mine waste rock is to use a simple combination of acid base accounting tests, such as NAPP and NAG, to provide two methods to assess whether the sample is acid forming or not. This matrix-style classification system, which is often a requirement of consent conditions, is expensive and time consuming when applied as a blanket approach to classification. It can lead to a large proportion of samples with conflicting results or incorrect classification of samples.

An alternative waste rock geochemical classification methodology is to use a process flow diagram to optimise the testing regime. This can reduce the number of tests required, the cost of testing, and the time required to make informed classification decisions. To be confident in the use of a process flow methodology for waste rock classification requires detailed knowledge of site geology and geochemistry; and the completion of a suitable sampling programme, incorporating acid-base accounting before the development of a process flow methodology.

At the Escarpment Coal Mine, West Coast, New Zealand, a new process flow methodology for geochemical classification is being trialled. Results indicate that classification by a process flow methodology 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.

At the Martabe Gold Mine, Sumatra, following a detailed ABA classification programme, a process flow methodology for geochemical classification of waste rock was developed as a tool for the operational management of overburden. This has become a quality control 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. Findings of the revised classification method are discussed in this paper.

Keywords: Acid and metalliferous drainage, waste rock classification, geochemistry, acid base accounting.

Introduction

To obtain regulatory consent for a mining project to proceed, there is typically a requirement for geochemical classification of the overburden in the planning and operational phases, to determine the potential for acid and metalliferous drainage; and to understand the kinetics of the geochemical reactions. This is undertaken by a variety of laboratory and field based geochemical tests. If the classification process identifies the potential for AMD, additional work may be required to prevent, minimise and potentially treat AMD after operation begins. These geochemical tests are often collectively used for acid base accounting (ABA) purposes.

There needs to be confidence in the relative accuracy of the classification method used for an operation. Over estimation of AMD may prevent projects from starting due to high capex and opex costs for treatment; underestimation may result in unanticipated treatment costs and legacy issues for the project. It is important 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, and meet the approval of regulators and the community.

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

Classification methods

Acid base accounting

Geochemical classification of waste rock overburden involves a variety of ABA techniques. The industry standard approach includes the determination of the net acid production potential (NAPP) (Equation 1). This is the difference between the acid neutralisation capacity (ANC) and the maximum potential acidity (MPA). Sulfur is typically determined through analysis of total sulfur. However, sulfide sulfur is also frequently determined for NAPP calculations as they are considered to be the main acid forming sulfur 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.

$$\text{NAPP} = \text{MPA} - \text{ANC} \quad (1)$$

The ANC of a sample is often determined by aggressive Sobek-type tests (e.g. Sobek et al., 1978; AMIRA, 2002) using low pH (< 2) digestion to dissolve carbonates and reactive silicate minerals to determine the amount of acid consumed by the sample.

The net acid generation (NAG) test typically involves the addition of 250 mL of 15% unstabilized H_2O_2 to 2.5 g of rock to encourage the oxidation of any sulfide minerals present. Any subsequent acid produced will react with any carbonates (and reactive silicate minerals) present to generate a final NAG pH reflective of the final acid-base characteristics of the sample. Samples with low pH values are back-titrated to pH 4.5 and then 7.0 to determine the NAG acidity (kg H_2SO_4/t or kg $CaCO_3$/t). Samples that have a final NAG pH > 4.5 are non-acid forming, although the amount of excess ANC is not quantified by this method (AMIRA, 2002).

Paste pH is determined by mixing 1 part of pulverized rock (< 75 µm) and 2 parts of deionized water, followed by pH measurement of the paste as per the AMIRA (2002) methodology. 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 neutralizing reactions generated from fast dissolving minerals such as carbonates. Further discussion on stored acidity is provided by Weber et al. (2015).

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 (e.g. AMIRA, 2002), to provide two methods to assess whether the sample is PAF or non-acid forming (NAF).

One approach for AMD sample classification is to plot NAG pH versus NAPP (e.g. 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 Fig. 1A.

The Mine Environment Neutral Drainage Program (MEND) guidelines (Price, 2009) utilise the ANC/MPA ratio (Fig. 1B). Typically material with an ANC/MPA < 2 ratio are classified as non-acid forming material while ANC/MPA < 1 indicates potentially acid generating material. If the ANC/MPA is between 1 and 2 the sample classification is uncertain, possibly PAF if ANC is insufficiently reactive or is depleted at a faster rate than sulfide oxidation and subsequent acid generation.

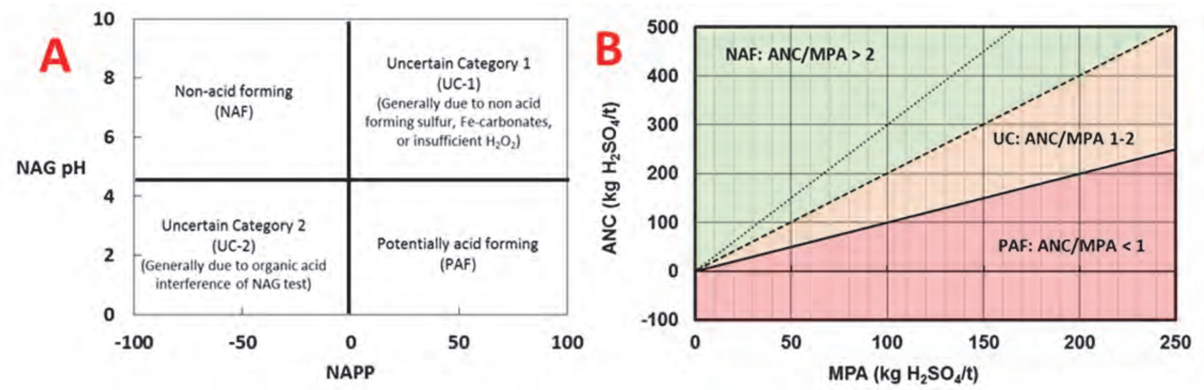

Figure 1. The modified (A) AMIRA (2002) NAPP and NAG pH and (B) Price (2009) MPA and ANC.

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.

Case studies

Two case studies where process flow methodologies have been developed to improve waste rock geochemical classification are discussed; the Escarpment Coal Mine and the Martabe gold and silver mine.

Escarpment Coal Mine, New Zealand

The Escarpment Mine, located on the West Coast of the South Island of New Zealand, is 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 acid mine drainage (AMD).

Current consent classification system

Bathurst Resources Limited (BRL) are required to carry out geochemical sampling and analysis of overburden to determine the acid generating potential of waste rock. Testing results in classification of the waste rock based on risk of generating acidity. 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. The current Resource Consent conditions allow for classification of waste rock as non-acid forming (NAF), low risk (LR), and potentially acid-forming (PAF) based on the criteria shown in Table 1.

Table 1. Current Resource Consent classification by geochemistry for the Escarpment Coal Mine.

Classification	Paste pH	NAG pH	NAPP Acidity (kg $CaCO_3$ eq./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 1), although currently a NAPP acidity of > 0 kg $CaCO_3$ eq./t is used for PAF classification based on recommendations by the Escarpment Peer Review Panel. Using the AMIRA NAPP versus NAG pH classification approach (as shown in Fig. 1A), a significant number of samples from the Escarpment Mine are classified as uncertain (Fig. 2).

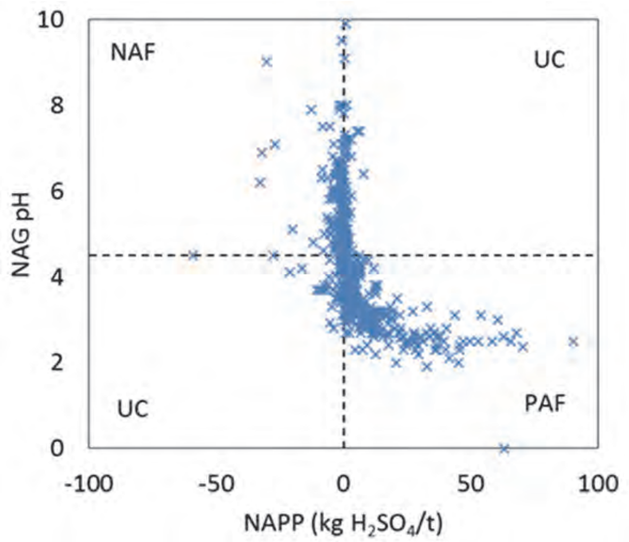

Figure 2. NAPP versus NAG pH for rock samples from the Escarpment Mine project.

Process flow classification

A revised process flow methodology for geochemical classification has been developed for the Escarpment Mine (Fig. 3). 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 methodology is a classification rather than a set of data from which a classification is derived.

A thorough understanding of site geochemistry is required before adopting this type of classification method. For example, any materials with total sulfur > 0.45 wt% (14 kg H_2SO_4 eq./t) have been classified as PAF without any further testing. The Escarpment Mine ABA database shows that for the vast majority of samples the ANC is much less than 10 kg H_2SO_4 eq./t, validating the assumption that ANC is negligible (in terms of classification) in samples with high sulfur content.

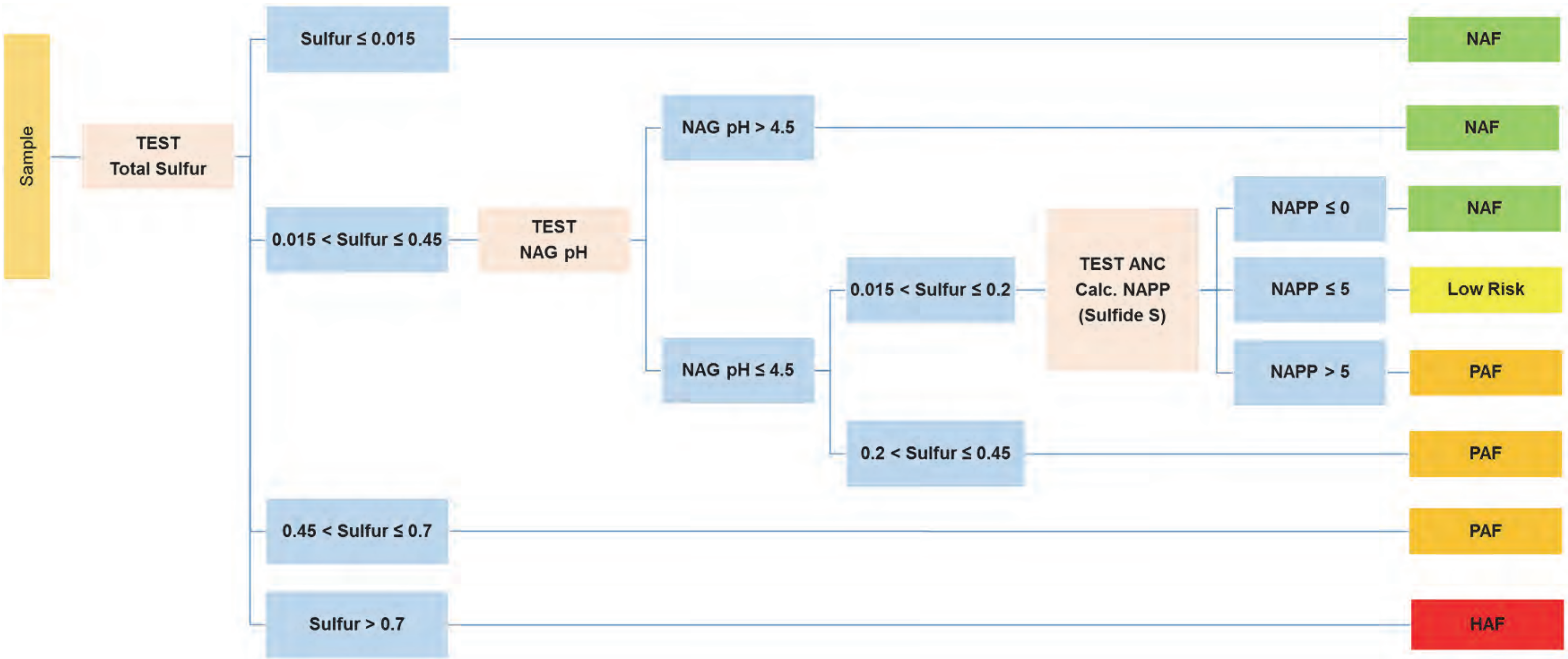

Figure 3. Escarpment Mine waste rock geochemical classification process flow methodology. Sulfur values are wt%.

The Escarpment Mine process flow methodology is an iterative process. Initially all samples are tested for total sulfur. Any samples with total sulfur less than 0.015 wt% are immediately classified as NAF while samples with between 0.45 and 0.7 wt%, and over 0.7 wt% are classified PAF and high acid forming (HAF), respectively. The remaining samples (total sulfur between 0.015 and 0.45 wt%) are then analysed for NAG pH. Samples with a NAG pH of greater than 4.5 are considered NAF while further classification of samples with NAG pH less than or equal to 4.5 is undertaken in conjunction with the original total sulfur content. Material with a total sulfur content between 0.2 and 0.45 wt% are classified PAF while samples with total sulfur between 0.015 and 0.2 wt% are tested for ANC. These samples are finally classified based on NAPP using sulfide sulfur content (rather than total sulfur) into NAF (NAPP $\leq$ 0 kg $CaCO_3$ eq./t), Low Risk (NAPP $\leq$ 5 kg $CaCO_3$ eq./t), and PAF (NAPP > 5 kg $CaCO_3$ eq./t).

Further work is being undertaken to consider any benefits of including paste pH into the process flow methodology. As it does not quantify PAF nor confirm NAF samples it may have limited value.

The process flow methodology 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 HAF are able to be classified if only total sulfur data are available (and they meet the HAF criteria) unlike a matrix system which requires multiple parameters for classification.

Classification results

BRL have compiled a geochemical testing database consisting of over 700 samples. The majority of these samples have been subjected to acid base accounting (ABA) testing including ANC, Total S, Sulfide S, NAG, NAG pH, and paste pH.

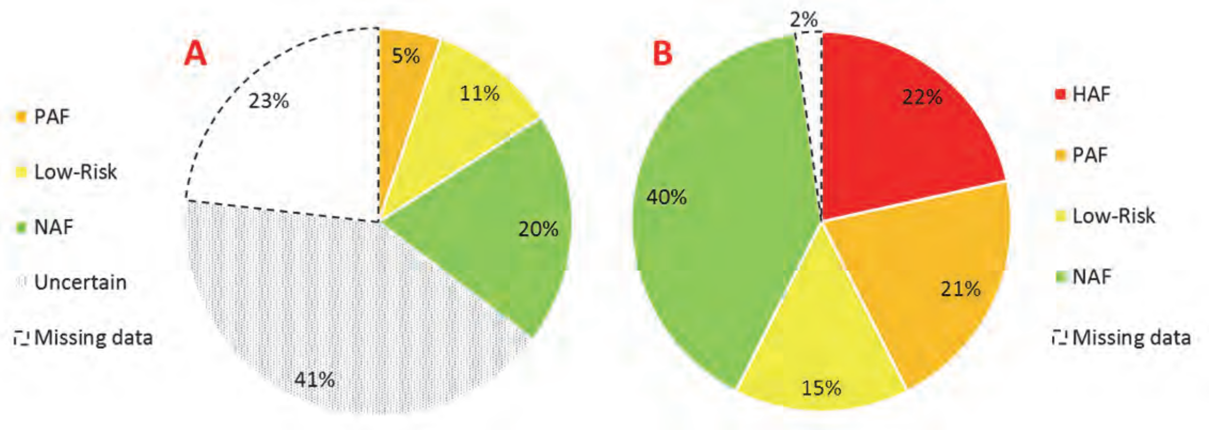

Figure 4. Sample classification by the (A) matrix-style and (B) process flow methodologies.

Using the current Resource Consent matrix-style AMD classification process results in 41% of samples being unclassified (Fig. 4A). A further 23% had insufficient data for classification under the matrix-style system. This lack of a definitive classification is likely to require further test work to confirm geochemical classification possibly delaying operational activities until confirming data are available.

Using the process flow methodology eliminates the uncertain category as the end point of each branch of the flow chart is a classification. Thus, 98% of materials (Fig. 4B) were classified using the process flow methodology. There were insufficient data for classification of the remaining 2% of samples, which is far superior to the matrix-style approach.

At the time of writing this paper the ABA database included 726 samples. Using the matrix-style method a total of 256 samples were successfully classified (as PAF, Low-Risk, or NAF) using ~1800 individual ABA analyses (total S, NAG pH, paste pH, ANC, sulfide S). Using the process flow methodology a total of 708 samples were successfully classified (HAF, PAF, Low-Risk, or NAF) utilising 1130 individual ABA analyses. On average, successful classification of a sample using the matrix-style and process flow methodologies took a total of 7 and 1.6 tests respectively, indicating the process flow methodology is more efficient to classify samples robustly.

Twenty field columns have been setup to test the reliability of the process flow methodology. The field columns consist of individual 20 L buckets filled with approximately 20 kg of crushed drill core (14 columns) and blast hole cuttings (6 columns) that has been classified for geochemistry based on the process flow methodology. Leachate volumes and chemistry (including pH and acidity) are monitored on a weekly to monthly basis. The leachate pH of the HAF and PAF lysimeters dropped rapidly to less than pH 3. The leachate pH from the low risk material varies, but is typically in the pH 3 to 4 range. The NAF leachate (and rainwater control) remained circum-neutral at around pH 5.

There is a limited acidity dataset from the field columns available at the time of writing this paper. The three available data points show a clear stepwise increase in leachate acidity from NAF rock to Low Risk to PAF to HAF. NAF leachate acidity was negligible at less than 20 mg $CaCO_3$/L for the most acidic column. The Low Risk rock leachate acidity varied between 30 and 100 mg $CaCO_3$/L. The PAF and HAF columns may have had a short time lag to acidity onset, with relatively low leachate acidity in the first sample collected. However, the PAF acidity increased to 300 to 500 mg $CaCO_3$/L and the HAF acidity increased to 800 to 1800 mg $CaCO_3$/L. In terms of acidity, the process flow classification method accurately identifies material likely to generate acidity with generated acidity increasing by a factor of five at each classification step.

This work confirms this site specific process flow methodology 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.

Martabe, Indonesia

Site description

The Martabe gold and silver mine, located in the Province of North Sumatra, is approximately 3 kilometres north of the township of Batangtoru and approximately 40 km south of the port of Sibolga (BDA, 2009). The mining operations active waste rock dump (WRD) is a valley-fill type WRD located south of the existing tailings storage facility.

The deposit is a high sulfidation epithermal deposit with fairly complex local geology that contains a package of altered volcanics. Generally mineralised quartz veins (that contain high grade sulfide 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 acid-base accounting interpretations were gypsum, calcite and ankerite.

Geochemical classification program

G Resources have expended a significant effort on 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 was available to develop the risk-based waste rock classification process flow methodology for operational use in characterising blocks of waste rock:

- Resource assay database – more than 10,000 data points for total sulfur, sulfide sulfur, and calcium content;
- Phase 1 geochemical testing programme – 225 samples analysed for acid base accounting (ABA): ANC, NAG, and paste pH;
- Phase 2 detailed testing – second phase of detailed testing including a range of laboratory analyses performed on ~50 samples, including total elemental analysis, (stored) acidic salt analysis, mineralogical analysis, static leach testing, kinetic NAG testing (KNAG), and acid buffering characteristic curves; and,
- Large scale leach columns –which have been operating at site for more than 10 years.

Data collected from the geochemical testing program generally shows samples contain a reasonable 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. The low paste pH values suggest significant water soluble acid salts such as melanterite and adsorbed/readily available H^+ acid. The higher paste pH values greater than pH 7 for PAF waste rock suggests there are some samples that have good initial ANC, greater than the initial acid generating reactions in the sample.

NAG pH, NAG acidity, and NAPP confirm that a significant proportion of the waste rock is PAF, although there are a number of NAF samples as indicated by negative NAPP values. ANC data indicated that some samples have a good 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.

Field testing process flow methodology

The waste classification process flow methodology utilises simple tests that can be collected rapidly to reduce operational delays. Although the process flow methodology only requires basic parameters for the classification process it utilises the knowledge gained from the previous detailed geochemical data sources. The use of such data allowed the consideration of kinetic factors for a risk-based waste rock classification process that differentiates between the various PAF materials.

The parameters required to implement the process flow methodology are paste pH, NAG pH, and NAPP, which require laboratory analysis and up to 7 days for results to be available. To reduce turn-around time 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. The typical methods to determine total sulfur (LECO) and ANC for NAPP calculations were substituted for sulfur and calcium assay results routinely determined on site as part of grade control activities. A process flow methodology was created to explain this approach and the subsequent geochemical classification (Fig. 5).

The results from earlier geochemical testing showed that sulfur and calcium data collected either with a field portable XRF or through routine assay analyses for grade control provided good proxies for maximum potential acidity (MPA) and ANC. MPA is calculated from Total S and ANC is calculated by multiplying calcium (wt%) by 0.04. NAPP was calculated from these parameters.

Field pH and field NAG pH results can be applied directly to the waste classification system without any data manipulation. 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). 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 Fig. 5 depending on the magnitude of NAG pH and NAPP.

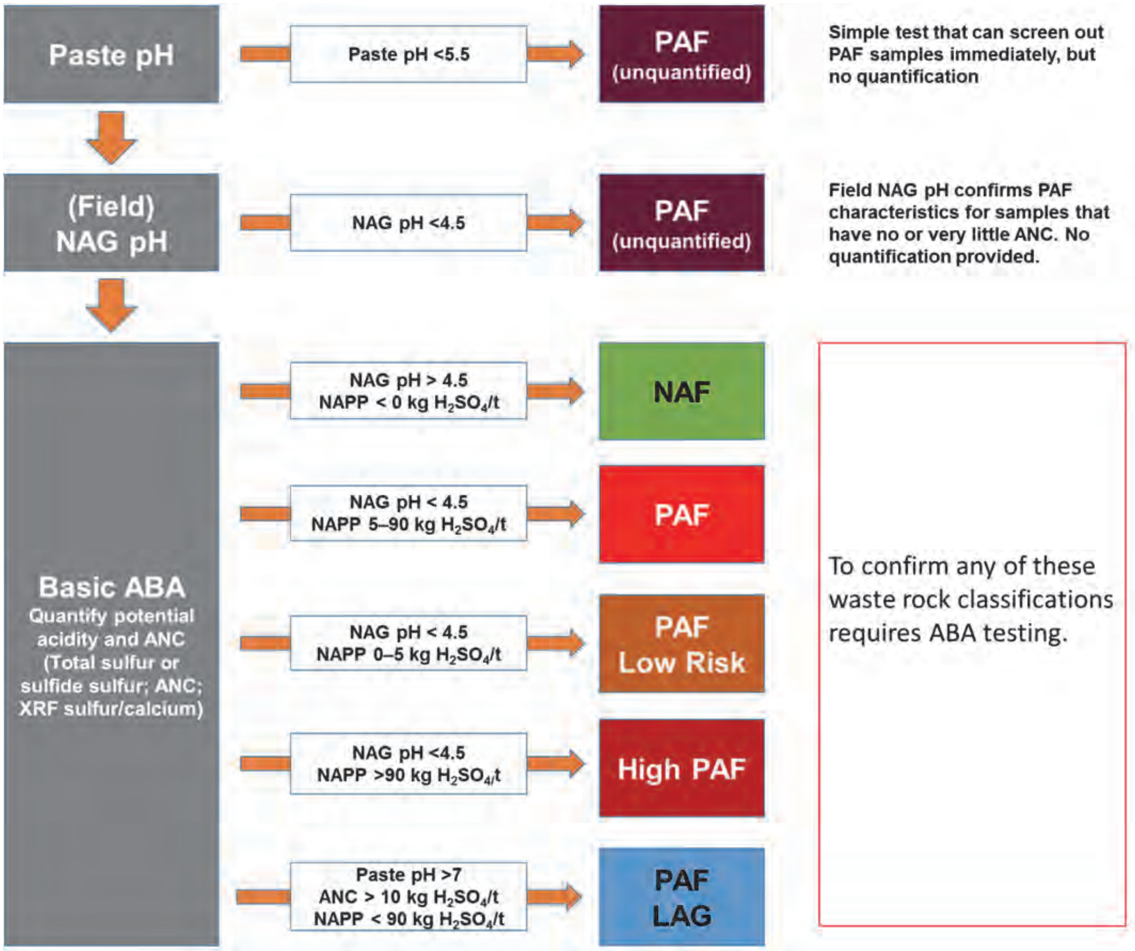

Figure 5. Process flow methodology for onsite waste classification at Martabe Gold Mine.

PAF – Low Risk materials are those with acidic field oxidation pH results (< 4.5) and a slightly positive NAPP (0 – 5 kg H_2SO_4/tonne). These materials require less strict handling and management requirements compared to the materials classified as PAF and High PAF. 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. Waste material containing stored acidity can be identified through field pH testing (pH less than 5.5). Acidic material can be treated or managed as per the PAF waste class.

PAF – LAG 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. PAF – LAG rocks are identified by a combination of NAPP, paste pH and ANC (calcium assay data) for samples that have already oxidised. Preliminary test work indicates that a paste pH of greater than 7 and ANC greater than 10 kg H_2SO_4/t may indicate a time lag to acid onset for materials with a NAPP less than 90 kg H_2SO_4/t.

This field-based process flow methodology was developed for the rapid assessment of waste rock to enable rapid waste rock classification for AMD management. It is performing well, although further refinements may be needed and the methodology should be considered organic in nature.

Conclusions

Process flow methodologies for waste rock classification applied to the existing ABA data for the Escarpment Mine has been 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 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 methodology there was a 38% reduction in testing from the previous matrix classification method, reducing the cost of geochemical analyses. Further savings could be realised by stopping sulfide sulfur analysis and reducing ANC testing.

At Martabe, the field based process flow methodology has been developed as a screening tool for the classification of waste rock. This process can be applied to validate the waste rock block model as part of operational activities. The testing process has been designed to provide an initial rapid screening tool to separate out potentially acid forming (PAF) waste rock, streamlining waste rock management procedures.

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

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