Identification and Management of Acid Generating Mine Wastes - Procedures and Practices in South-East Asia and the Pacific Regions

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ABSTRACT

Development of mineral resources in the Asian/Pacific region are a particular concern due to the generation of solid waste and disposal of this waste in a wet and humid environment. This paper addresses the major geochemical issues associated with mine waste disposal under these conditions with particular emphasis on acid mine drainage and acid generating waste materials. A strategy is presented for classifying the acid forming potential of mine waste based on the acid-base account and the net acid generation (NAG) confirmation test. The need for a correct and adequate sampling strategy is highlighted since sample selection is a crucial step in the identification of acid generating waste.

INTRODUCTION

One significant environmental concern associated with the development of mineral resources in the Asian/Pacific region is the generation and disposal of solid wastes in a wet humid environment. Disposal of mining wastes in high rainfall climates present particular problems with respect to contaminated leachate generation and the potential for chemical contamination of the immediate environment. Waste rock and mineral processing waste (tailings) are the two major solid wastes of concern. These waste materials generally require disposal on site and thus become majormanagement considerations. In the short term their disposal directly impacts on the overall water management scheme for the mine site and ultimately waste rock dumps and tailings impoundments require reclamation prior to decommissioning to minimise long term impact.

Legislation and regulations vary widely throughout the Asia-Pacific region. In Australia and New Zealand there is a general awareness of the potential problems associated with the presence of reactive sulfide in the mine waste and regulations require companies to provide details of the nature and occurrence of acid forming materials within the deposit and to provide a management plan for the disposal and reclamation of these materials.

Regulations covering the management of mine wastes within South East Asian countries are very limited. However, general pollution control and environment regulations do exist in many of these countries and apply to the mining industry. More importantly, many mining companies, particularly large companies, which are now developing mines in the region generally are aware of the need for sound environmental management.

The assessment and prediction of waste and mine rock characteristics is paramount to the development of an environmentally sound mining operation and waste disposal system. In practice, solid waste handling operations can be designed and managed to ensure that any toxic or potentially toxic material is disposed of in a controlled manner. Preventing acid drainage from underground mining operations in sulphide deposits is, however, a much more difficult task.

A number of factors determine the significance of waste management issues at a particular site. These include the nature of the deposit, the mineralogy of the ore, the processing operation as well as the physical environment. Therefore waste disposal and management must be considered on a site specific basis.

This paper addresses the major geochemical factors that must be considered during development of environmentally sound waste management operations for acid generating mine materials. The concepts and issues presented are applicable to various types of mining operations where sulfidic materials are commonly encountered, including gold, base metals and coal.

SAMPLE SELECTION

Sample selection is probably the most crucial aspect of an investigation aimed at determining the acid forming potential of mine waste. The spatial distribution of samples of mine rock within a deposit must be such that it provides sufficient intensity for detection of 'pockets' of particularly acid forming material requiring selective handling and management, yet at the same time must have sufficient breadth to ensure adequate overall coverage of the whole deposit and the various rock types therein.

It is essential that individual profile samples are selected and include both waste rock and resource. The number of samples selected for examination must be sufficient to be representative of the mineable reserves at the site. Samples should be selected from a number of drill holes and should represent intervals of drillcore no greater than 10 metres and preferably about 5 metres. Composite samples should be avoided since they tend to give biased results, generally underestimating the acid potential.

For the pre-mining characterisation of tailings and process residues, representative samples of all tailings types must be examined. It is advisable to prepare tailings samples specifically for the geochemical investigations. The tailings should be prepared according to the process design and delivered for geochemical testing as a slurry at the same solids density that will report to the disposal facility during operations.

ACID BASE ACCOUNT

There is no 'standard' approach for determining the acid forming potential of mine rock and tailings. However, the acid-base account is commonly used along with kinetic procedures such as column and batch leaching tests.

The approach we have adopted for mining operations in Australia and the Asia/Pacific region is generally two staged. The first stage is the basic characterisation and includes determination of:

- Paste pH and electrical conductivity;
- Total sulfur content; and
- Acid neutralising capacity (ANC).

This is usually followed by a more detailed stage 2 investigation including determination of the:

- Reactivity of sulfides and kinetics of acid formation by particular rock types identified in stage 1;
- Occurrence and environmental significance of toxic elements; and
- Leaching potential of toxic elements.

The initial stage 1 classification of waste rock types is based on the total sulfur content and ANC of the samples and is determined by plotting the sample results on an acid forming potential classification diagram as shown on Figure 1. The data points plotted on Figure 1 are from a proposed gold mining operation in South East Asia. Four geochemical rock types are identified on Figure 1. These are Acid Forming, Potentially Acid Forming, Non-Acid Forming and Barren.

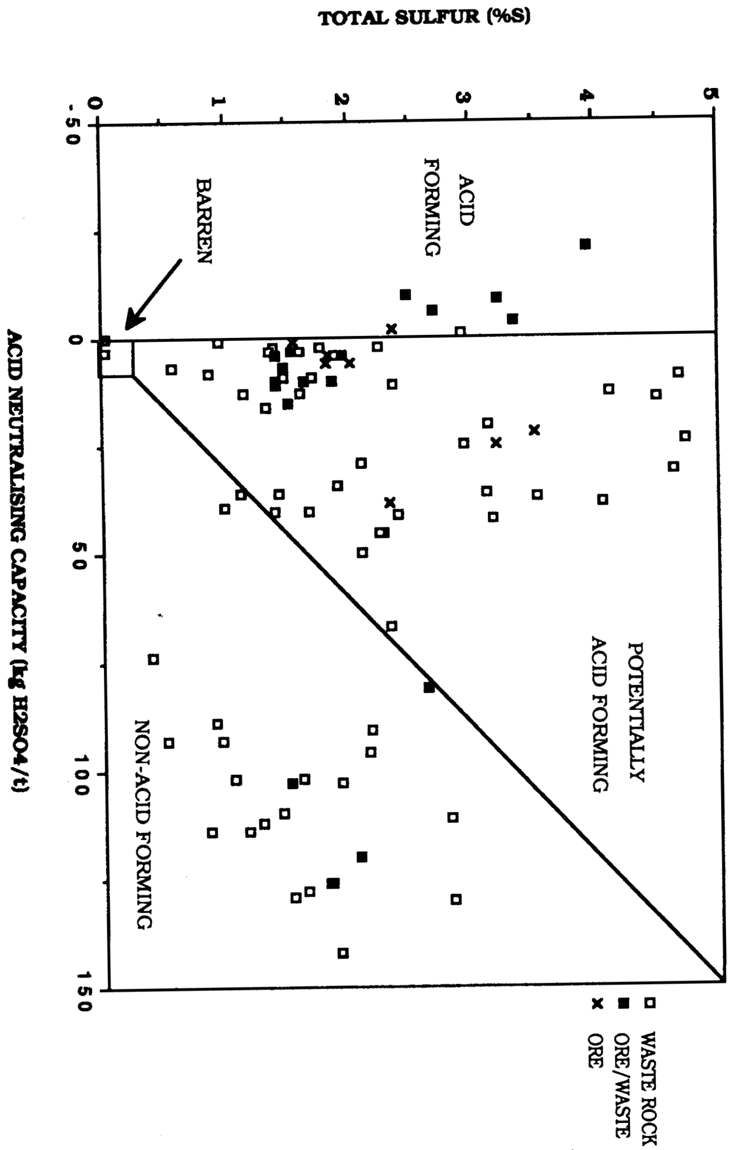

Figure 1: Acid Forming Potential of Drillcore Samples from a Proposed Gold Mine

The *Barren* category includes rock containing less than 0.2% Total S and an ANC less than the equivalent of 5 kg H_2SO_4/t. It is extremely unlikely that barren rock will be a source of acid drainage, but equally it will not provide any acid neutralisation capacity if blended with other acid and potentially acid forming rock within a dump.

The *Acid Forming* waste category includes sulfur bearing rock that is either devoid of ANC or which may already contain significant levels of free acid (*i.e.* negative ANC and paste pH less than 4).

The boundary between *Non-Acid Forming* and *Potentially Acid Forming* rock is initially based on the balanced acid-base account, *i.e.* where the ANC and the theoretical acid potential from oxidation of the sulfur (assuming all sulfur occurs as pyrite) are exactly balanced. At this boundary the material is said to have a zero net acid producing potential (NAPP), which has the units of kg H_2SO_4/t of solid waste. If the ANC of the rock exceeds the acid producing potential of the sample then the NAPP is negative and the sample is classified as non-acid forming. Conversely, if the acid producing potential exceeds the ANC then the NAPP is positive and the sample is classified as potentially acid forming. [Note: a positive NAPP value in this system is basically equivalent to a negative ('deficient') value in the Acid-Base Accounting system (*i.e.* t $CaCO_3$/1000 t of rock) which is conventionally used in the USA and Canada.]

NET ACID GENERATION

The net acid generation (NAG) procedure is used to confirm if acid generation is possible in the potentially acid forming material identified by the acid-base account and also to refine the boundary line between the non-acid forming and potentially acid forming rock types. The NAG procedure involves the addition of a hydrogen peroxide solution to the rock material and after reaction, the pH and acidity are determined on the suspension. Generally this results in the boundary line (shown on Figure 1) moving up *i.e.* increasing the non-acid forming zone, however we have had experience with materials where the line shifts down.

Figure 2 shows the relationship between corresponding NAPP (based on total sulfur and ANC) and NAG results for a series of rock samples from a proposed mine site in South East Asia. This type of direct correlation between NAPP and NAG is typical of mining wastes at most sites we have investigated. In this particular example, the NAG results were approximately two-thirds of the calculated NAPP results, irrespective of total sulfur content. This indicates that a constant fraction of the total sulfur in these samples

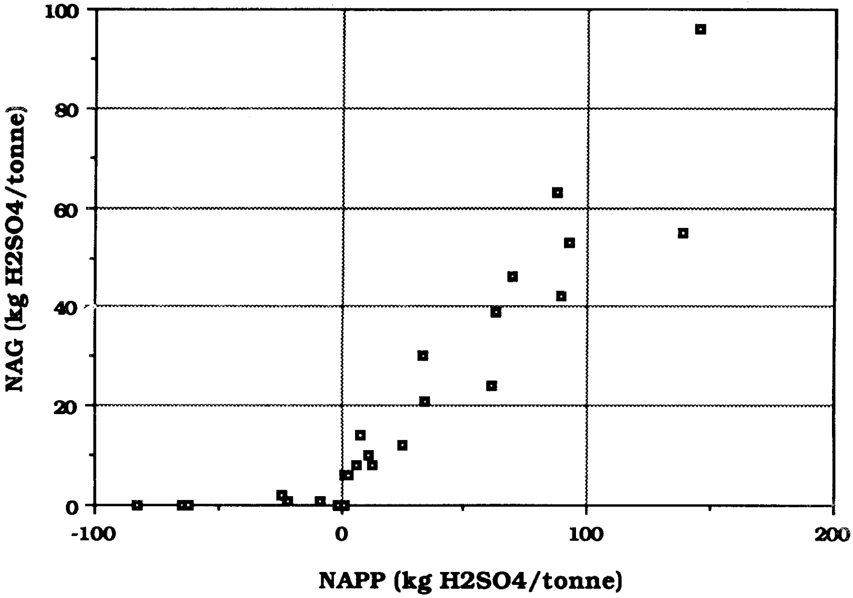

Figure 2. Relationship between NAG and NAPP for 25 Drillcore Samples

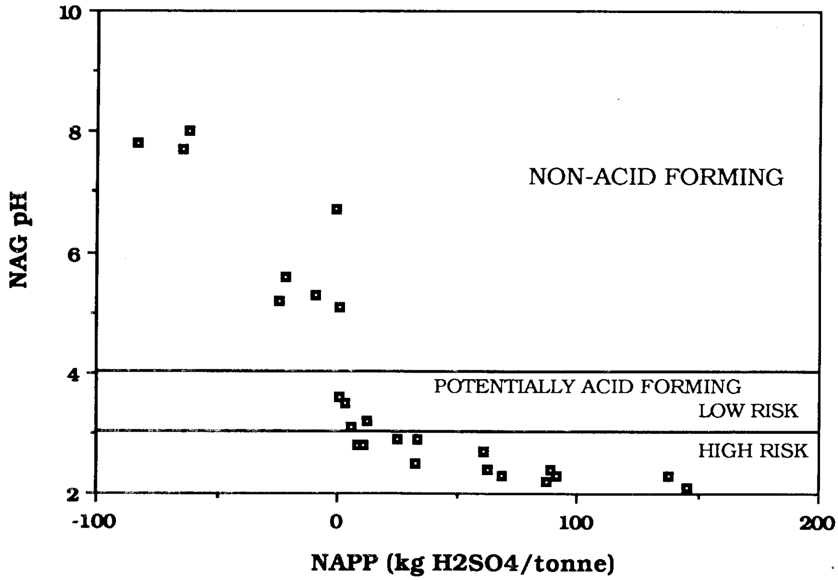

Figure 3. Relationship between NAG pH and NAPP for 25 Drillcore Samples

was either not 'available' to the oxidation process (*i.e.* unreactive) or was not present as pyrite.

The NAG testing procedure is providing to be ideal for in-pit identification of particular rock types. Development of the procedure is site specific and requires laboratory calibration to determine the most suitable sample preparation procedure, sample to solution ratio, hydrogen peroxide strength and reaction time. The NAG test provides a relatively quick assessment of the acid forming potential of mine rock, and has the advantage that it can be carried out routinely on-site using rudimentary laboratory facilities and equipment. The method therefore has wide appeal for use in remote areas of South East Asia where there is limited access to good assay laboratories.

The NAG test is well suited to in-pit monitoring since it requires only a few hours to complete and therefore can be used to test blast hole cuttings immediately prior to the mining of blocks of ore or waste. In most cases it appears that a simple pH determination after a reaction period of between 1 and 10 hours is adequate for sample identification. Figure 3 shows the typical relationship that exists between the final pH of the NAG solutions after reaction and the calculated NAPP. In this example, all potentially acid forming samples produced final NAG solution pH's less than 4, with pH decreasing to about pH 2 at very high NAPP values.

SULFIDE REACTIVITY

The exposure time required (or lag period) for a material to become acid is an important consideration for waste rock and tailings management. Generally the period of oxidised leaching required to generate acid conditions increases as the ANC increases. Also, the capacity for acid generation increases with increasing sulfur content. Using the results of laboratory based tests to predict the lag period in a particular field environment operation is difficult and requires careful assessment. Indications can be provided from column and batch tests, but these tests can take a considerable period of time to complete and the question of what particle size should be used for these tests is a common concern. The need for a rapid and reliable confirmation test for acid generation as well as a rapid test for assessing the lag period is a major area requiring further research and development. At the present time, we have been developing the NAG procedure for this function and are accumulating a data base for the field calibration of the test results.

Figures 4 and 5 demonstrate the variations which can occur in the kinetics of the NAG confirmation test, as exemplified by solution temperature and pH profiles. The NAG test on the acid forming rock sample (Figure 4) was virtually complete within 80 minutes whereas it took approximately 130 minutes for the test on the non-acid forming sample (Figure 5) to go to completion.

Since pyrite oxidation is an exothermic and acid-forming reaction, the rates of change of temperature and pH of the NAG solution provide a qualitative indication of the reactivity of the sulfides, and the final pH of the NAG solution indicates the overall extent of acid formation. With non-acid forming material the solution pH either does not change during the test or slowly increases (*e.g.* Figure 5). Acid forming and potentially acid forming materials (*e.g.* Figure 4) typically produce a steady decrease in the solution pH during the NAG test whilst the temperature of the solution rises, often to the point of boiling. The time to reach maximum temperature may be as short as five minutes for samples containing highly reactive sulfides and low ANC or as long as 500 minutes for samples dominated by slowly reactive sulfides and/or high ANC.

The reaction kinetics illustrated in Figures 4 and 5 exemplify the behaviour of acid forming and non-acid forming materials, respectively, and typify the range of reaction kinetics that can occur with the monitored NAG test procedure. At the present time, the data base is inadequate for NAG results to be confidently used for prediction of exposure (lag) times for materials to become acid, but as the results for column tests and field monitoring are accumulated, we are confident that this simple procedure will be a valuable tool for the classification of acid forming waste rock and tailings, particularly in remote areas where laboratory facilities may be limited.

DISPOSAL PRACTICE

The major disposal options for the management of acid forming and potentially acid forming waste rock include:

- isolation from leaching by cell or layer disposal;
- simple burial below non-acid forming materials;
- dilution mixing (i.e. co-disposal); and
- final surface sealing and covering.

The effectiveness of these procedures depends on the ability of the operator to adequately identify both acid forming and non-acid forming materials and the control of the waste disposal operation. In-pit monitoring using the NAG confirmation test will be a valuable tool in this respect.

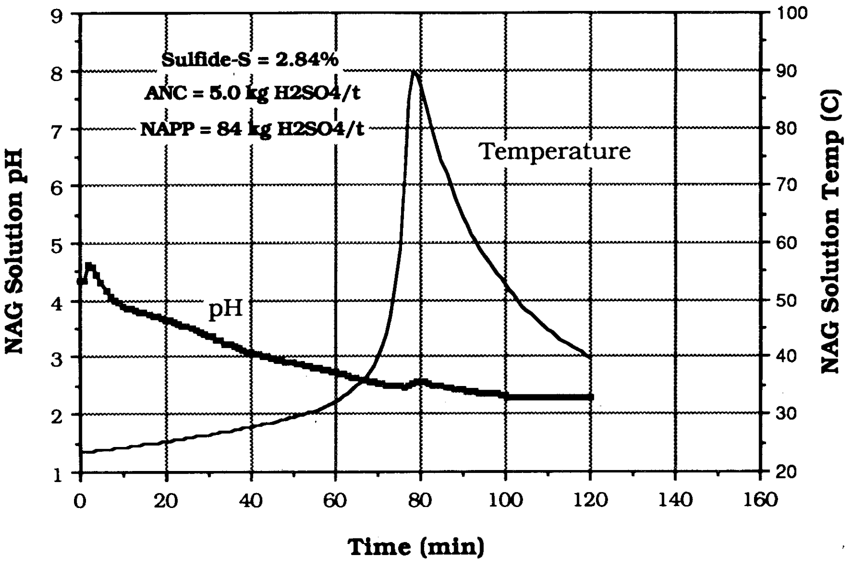

Figure 4. pH and Temperature profiles: Potentially Acid Forming Rock

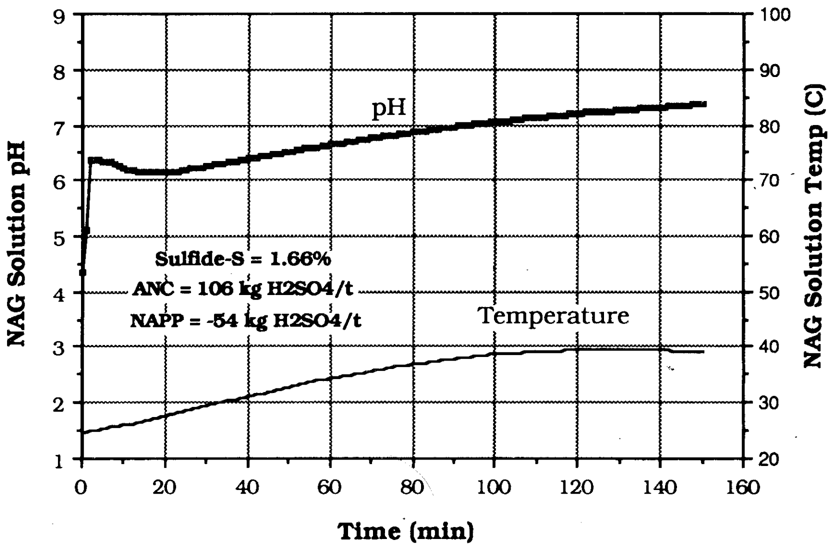

Figure 5. pH and Temperature Profiles: Non-Acid Forming Rock

For long term control of acid generation in tailings it is necessary to prevent free oxygen from entering the tailings mass. This can be achieved either by maintaining the tailings in a water saturated condition so that the availability of free oxygen for sulfide oxidation is limited, or by placing an oxygen consuming cover such as a compacted seal and active soil profile over the tailings.

In wet environments, the option of permanently flooding the tailings to create a lake/wetland environment may be a viable option and in some coastal regions, disposal of tailings and other mine wastes into the ocean may be feasible and can have many environmental benefits. The advantages of underwater disposal are particularly relevant to tailings because they generally consist of sand to clay sized particles and therefore have a high surface area exposed for leaching and oxidation.

Placement of mining and processing wastes permanently under water, either beneath the ocean or under large natural lakes and dams will prevent acid generation. This method of disposal for acid forming wastes (particularly tailings) is practised in South-East Asia and the Pacific and is receiving greater attention from the mining industry as well as governments within the region.

CONCLUSIONS

At many gold, base metal and coal mines, acid generation is the major potential mechanism for environmental contamination both in the short term (during operational life) and in the long term (following decommissioning). It is therefore essential that geochemical aspects associated with acid formation are critically assessed during the pre-mining development of a project so that findings can be considered and incorporated into strategies for design and management of waste disposal operations.

The potential for, and processes involved in, acid formation must be considered on a site specific basis as many environmental and mineralogical aspects influence the rate and nature of geochemical processes. In particular, the time required for a material to become acid is very site specific, and knowledge of this lag time is often critical for waste rock dumping operations where it may be necessary to cover or encapsulate particularly hazardous material.

A staged approach to the identification of acid generating mine wastes is recommended, beginning with an initial (stage 1) screening step in which the acid-base account is applied to a number of samples proportionate to the mineable reserves at the site. This should be followed by more detailed (stage 2) investigations of the kinetics of acid formation and the potential for elemental leaching from particular waste rock and tailings types identified as acid or potentially acid forming. Such geochemical information provides a basis for development of effective mining and waste management strategies. In addition, field monitoring techniques should be developed to assist in the rapid classification of mine waste for operational waste management.

A practical approach to assessing the geochemical characteristics of waste materials as well as communicating the engineering implications to the design and management personnel are essential for the development and operation of an environmentally sound waste disposal scheme.