FACT SHEET 4 - HOW TO PREDICT AMD

AMD MANAGEMENT TRAINING SERIES

Prediction of the potential for AMD, the type (being acidic, metalliferous, or saline drainage), severity, time to onset, and subsequent longevity are determined by a process of materials characterisation.

Each project will have different AMD characterisation requirements to understand potential effects and risks for the project, which is specific to the deposit type, alteration styles, material quantities, weathering effects, physical setting, and regulatory setting.

Materials should be characterised so that material-specific AMD risks are understood, and hence also, the potential geochemical risks for mine domains containing these materials. Furthermore:

1. Understanding the potential AMD characteristics for various materials and subsequent mine domains enables a risk assessment based on scientific and engineering data to determine management options.
2. An **AMD risk assessment** is a fundamental step in AMD prediction and will be revisited many times over the project life.
3. The AMD risk assessment process determines the AMD management requirements for the project (e.g., prevention, minimisation, control and treat).
4. Hence, prediction drives AMD management options.

Prediction has several components, potentially requiring more detail as the mine matures through exploration, mine development, mine operation, and mine closure. The components of prediction can be simplified as follows:

1. Geoenvironmental Models
2. Material Characterisation
3. Material Geochemical Signature
4. Water Quality Predictions
5. AMD Risk Assessment

GEOENVIRONMENTAL MODELS (ANALOGUE MODELS)

Geoenvironmental models provide fundamental information on the type of deposit and the likely environmental risks associated with geochemistry (e.g., Plumlee, 1999). It has been suggested that deposit type can contribute to 30% of the maximum potential AMD risks for a site (Richards et al, 2006), which means that important information can be gained from understanding the deposit type.

Further information can be gained from analogue models, which include:

- Local mine operations that disturb similar geological materials;
- Other mine domains (e.g., waste rock dumps, pit voids); and
- Knowledge and data about specific problematic lithological materials.

Such analogue models can be used to provide evidence of similar geochemical effects and risks. Often such information is obtained from desktop investigations and provide initial guidance on the potential AMD risks for a project.

Visual Clues

- Are there any visual indicators of AMD generation such as iron oxide crusts on exposed rocks or iron oxide precipitates in nearby streams?

Analogue Models

- Are there any other mines in the area, which have targeted the same lithologies, minerals, ore type? Do these mines have issues with AMD?
- Globally, are these types of mines known to have AMD issues?

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MATERIAL GEOCHEMICAL CHARACTERISATION

Material geochemical characterisation, or source hazard characterisation, is a fundamental step in the assessment of any project in regards to the potential risks for AMD. Materials should be characterised so that AMD risks are understood, and hence also, the potential geochemical risks for mine domains containing these materials.

Characterisation involves assessment of:

- **Geochemical Nature** (Acid Base Accounting), for instance, potentially acid forming (PAF); or non-acid forming (NAF).
- **Geochemical Signature** of water quality (potential effects), for instance acidic, metalliferous, or saline drainage.

Material Sampling Program

Several guidance documents are available to assist the development of a project specific sampling and analysis program (AMIRA, 2002; Price, 2009; INAP, 2010; DTIR, 2016), which all give consideration to the following:

- Project phase;
- Quantity of material to be disturbed through mining;
- Existing datasets;
- Variability of critical parameters (geology / alteration / mineralogy / degree of weathering); and
- Social value and regulatory requirements.

Where prior information is not available, a common guide to an initial sampling frequency is provided in the below table (variations presented in both Price, 2009, and DTIR, 2016).

Tonnage of Unit (metric)	Minimum Number of Samples
<10,000	3
<100,000	8
<1,000,000	26
<10,000,000	80
>10,000,000	Few hundred

Testing (chemical and physical) involves the use of geoenvironmental models, laboratory tests, field tests, and other observations. Further information on acid base accounting (ABA) to understand the geochemical nature of materials as well as test methodologies to understand the potential geochemical signature are provided in Fact Sheet 11 (Laboratory Test Methods).

*Although this fact sheet is focused on AMD characterisation, there are other environmental geochemical effects that might be identified during investigations including risks associated industrial diseases (asbestosis, silicious), carcinogenic compounds (e.g., As), radioactivity, spontaneous combustion, and greenhouse gas emissions, which all have potential receptors (environment, community, closure).

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Geochemical Nature (Acid Base Accounting)

Acid base accounting (ABA) uses laboratory data to determine if the material is NAF or PAF, which is based on the difference or ratio between acid forming and acid neutralising minerals in the rock. Classification is typically based on either (or both) the AMIRA (2002) or Price (2009) classification schemes until site-specific classification systems are developed. Examples are available in the GARD Guide (INAP, 2010) and the Leading Practice Sustainable Development Program for the Mining Industry - Preventing Acid and Metalliferous Drainage (DTIR, 2016).

The acid generating potential of a rock is determined by measuring the sulfur (or sulfide) content and calculating the maximum potential acidity (MPA) that would be generated, assuming all the sulfur (or sulfide) is present as pyrite and completely oxidises.

The acid neutralisation capacity (ANC) is determined by laboratory testing (acid digestion), which is designed to assess neutralising minerals in the material. ANC can also be calculated from carbonate content where data are available and there is confidence in the approach.

$$\text{MPA} = \text{S (wt\%)} \times 30.63 \qquad \text{Units: kg } H_2SO_4/t$$

MPA and ANC data are fundamental data for ABA for determining the net acid producing potential (NAPP) where NAPP positive data suggests the sample is PAF and NAPP negative data suggests the sample is NAF.

$$\text{NAPP} = \text{MPA} - \text{ANC} \qquad \text{Units: kg } H_2SO_4/t$$

The net acid generating capacity (NAG) of a sample can also be determined to provide quantification of the overall acid generating capacity (kg H_2SO_4/t) of a sample where acidity generated reacts with any neutralising minerals to provide an overall final NAG pH.

ABA data can also provide guidance on the potential for neutral metalliferous drainage (NMD), for instance:

- Where elevated sulfide sulfur is present, yet the sample is NAPP negative due to abundant ANC; and
- Where NAG testing provides circum-neutral pH yet significant sulfide oxidation has occurred and metals of potential concern remain in solution.

Additional assessment is often required to understand and quantify the potential for NMD including kinetic testing and other wet laboratory techniques to understand the geochemical signature of the materials.

Further information on test methods is provided in Fact Sheet 11.

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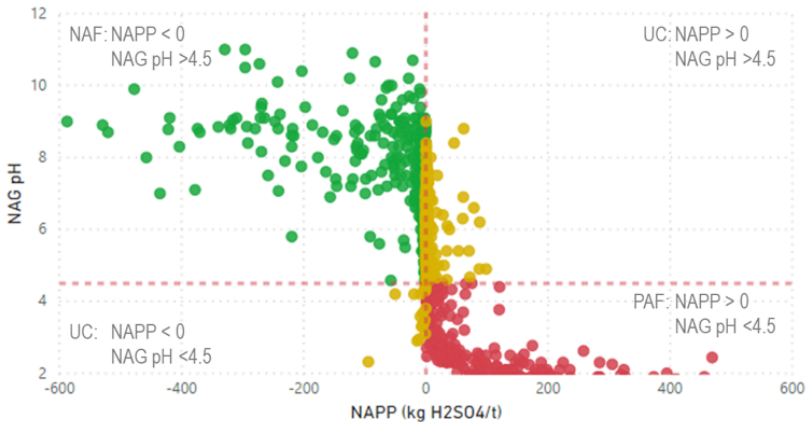
AMIRA Classification System

The AMIRA Classification system uses NAPP and NAG pH to classify samples as PAF, NAF or Uncertain (UC). Where NAPP is positive and NAG pH is less than 4.5, samples are classified as PAF. Where NAPP is negative and NAG pH is greater than 4.5, samples are classified as NAF. Samples with conflicting NAPP and NAG pH are classified as UC.

Note that although a sample may be classified as NAF it does not infer low geochemical risk.

High sulfide and high carbonate samples may present NMD or Saline Drainage (SD) risks requiring management.



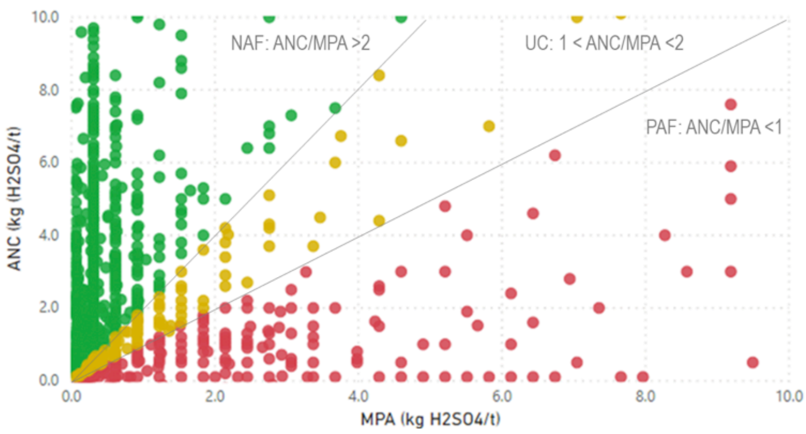
Areas within a plot of NAPP and NAG pH which are classified as NAF, PAF, and UC.

Price Classification System

The Price Classification system uses the ratio between ANC and MPA to classify samples as PAF, NAF or UC. Furthermore, the Net Potential Ratio (NPR) = ANC/MPA. Where ANC/MPA is less than 1, samples are classified as PAF.

Where ANC/MPA is greater than 2, sufficient neutralising capacity is inferred to account for acid production and the samples are classified as NAF. Where ANC/MPA is between 1 and 2, samples are classified as UC.

Areas within a plot of MPA and ANC which are classified as NAF, PAF and UC.



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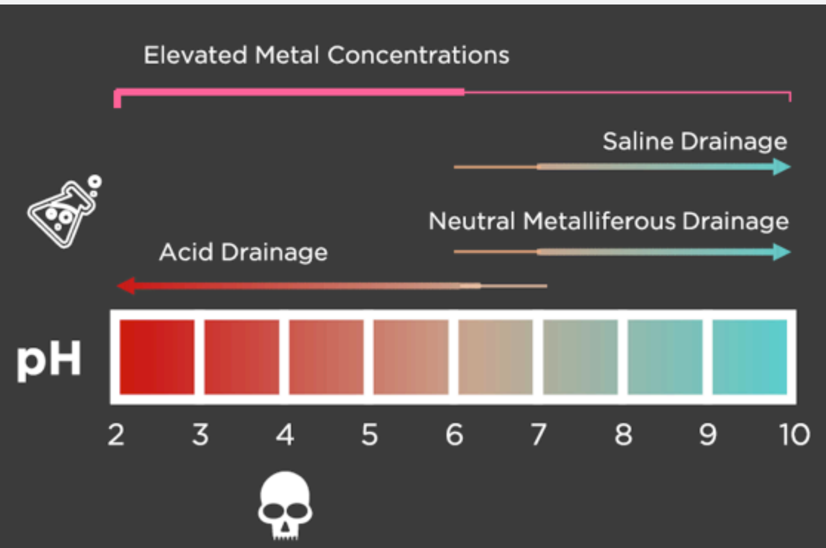
Geochemical Signature

The geochemical signature of a material can be inferred from ABA characterisation and the geochemical nature of a sample. However, further information is required to validate these assumptions, which can include data from Geoenvironmental models, field data and additional laboratory tests such as kinetic testing.

Kinetic testing generally involves oxidising a material sample in the presence of water to understand trends in water quality and quantify oxidation rates, neutralisation rates and contaminant loads with respect to time. Such data is used to determine the potential for acid rock drainage, neutral metalliferous drainage, or saline drainage, which provides an indication of the potential geochemical signature of water quality and initial data for risk assessments.

Further information on test methods is provided in Fact Sheet 11.



Characterisation data, coupled with material schedules, and mine plans can be used to predict water quality from mine domains.

This is an essential step in prediction and such data should be used for risk assessments and can include:

- Numerical modelling;
- Geochemical modelling; and
- Groundwater and surface water modelling.

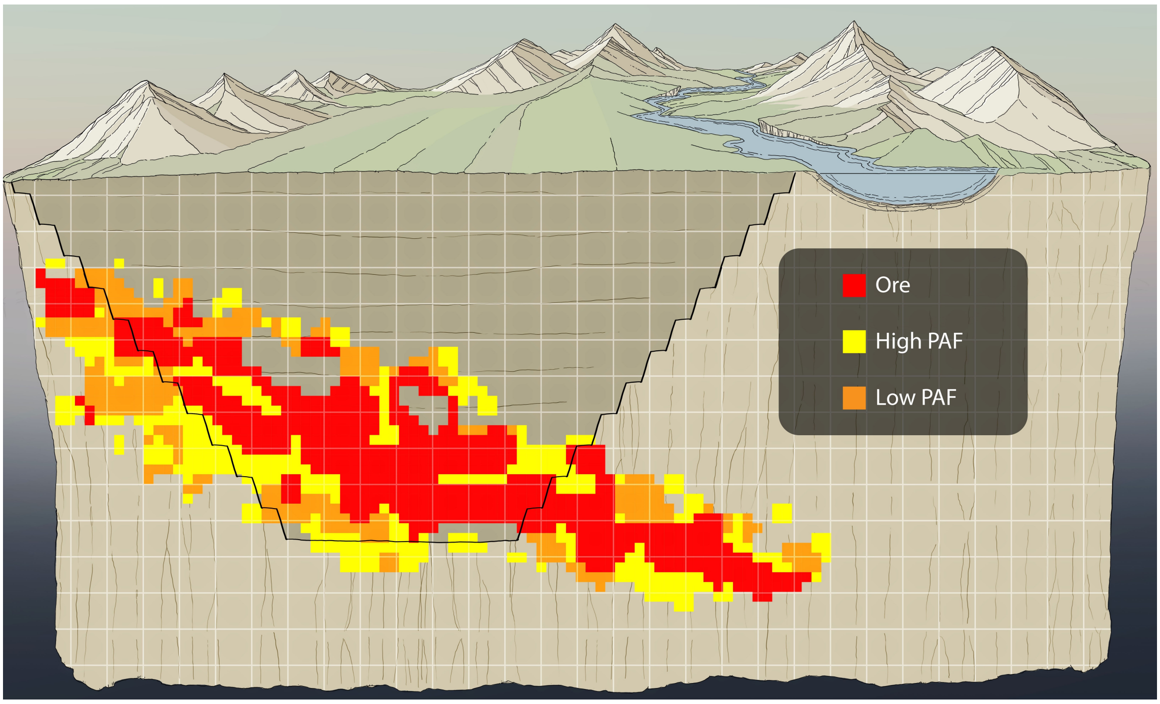
MATERIAL SCHEDULES

The data obtained from materials characterisation processes enables a classification system to be developed. Classification systems are often site-specific and can be used to develop a waste rock block model.

A block model is an essential step in AMD management as it is used to develop a materials schedule for the different material types over the project life cycle. This helps to quantify the potential risk from materials.

For instance, block modelling could indicate:

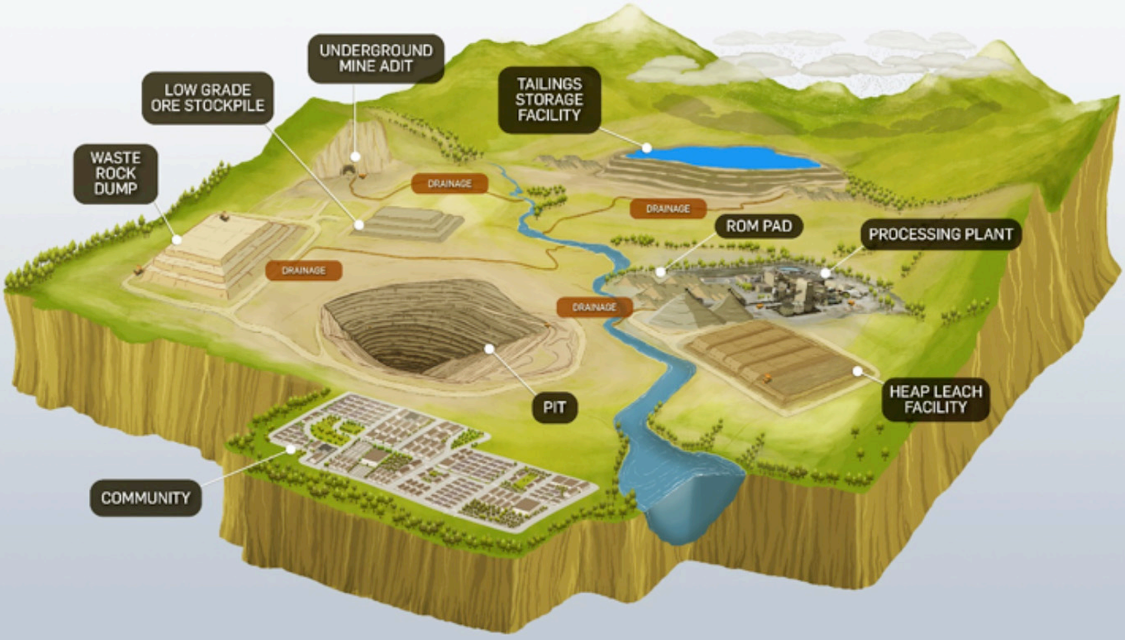
- That the risk for AMD is low as PAF materials represent a very small fraction of the materials schedule.
- Shortfalls in NAF materials later in the mine life, which could indicate stockpiling may be required.
- Identify higher risk materials that may require more intensive management options.



AMD RISK ASSESSMENT

The data obtained from the geochemical characterisation of materials can be used to support AMD risk assessments, which will become increasing more detailed, coincidental with project development study phases. These risk assessments should be coupled with conceptual site models and an understanding of source-pathway-receptor analysis for informed risk-based decision making processes.

Geochemical characterisation investigations assess source materials to understand potential hazards. To understand possible effects on receptors requires an understanding of pathways, which can include for instance surface water, groundwater, and emissions to air.



NOMENCLATURE

This Fact Sheet, when describing key mine drainage terms, uses South Pacific nomenclature. The following North American synonyms have been summarised from Price (2009):

South Pacific Conventions		North American Conventions	
Potentially Acid Forming	PAF	Potentially Acid Generating	PAG
Non-Acid Forming	NAF	Non-Potentially Acid Generating	Non-PAG
Acid Neutralising Capacity	ANC (kg H_2SO_4/t)	Neutralisation Potential	NP (kg $CaCO_3$/t)
Maximum Potential Acidity	MPA (kg H_2SO_4/t)	Acid Potential[1]	AP (kg $CaCO_3$/t)
Net Acid Production Potential	NAPP (kg H_2SO_4/t)	Net Neutralisation Potential[2]	NNP (kg $CaCO_3$/t)
ANC to MPA Ratio	ANC/MPA	Net Potential Ratio	NPR

[1]AP = 31.25 × %S (kg $CaCO_3$/t)

[2]NNP = NP – AP (different to NAPP which subtracts the acid neutralising capacity from the maximum potential acidity)

Conversion Factors: ANC = 0.98 × NP; MPA = 0.98 × AP

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