

# Appendix G

## Geochemical and ARD Assessment of Tailings

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**Geochemical and ARD Assessment of Tailings**

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## 1.0 Introduction

Environmental Geochemistry International Pty Ltd (EGi) was commissioned by Australian Tailings Consultants Pty Ltd to investigate the geochemistry and acid forming characteristics of tailings which will be produced at the Cloncurry Copper Project located in NW Queensland. The project is being developed by Exco Resources Limited and will involve open pit mining of copper-gold ore deposits in the Monakoff and Mt Margaret areas. Ore will be processed using conventional flotation technology in a new facility at the Mt Margaret site, with the tailings stored in a dedicated storage facility located adjacent to the plant site.

The copper-gold mineralisation system at Mt Margaret is hosted within metasediment or massive magnetite ironstones whilst the Monakoff deposit consists of a sulphide copper-gold mineralisation system, predominantly within a magnetite-pyrrhotite-chalcopyrite-pyrite mineral assemblage. The presence of pyrrhotite and pyrite are a potential concern since they are prone to oxidation processes if exposed to atmospheric conditions and could possibly result in tailings acidification in the longer term.

A sample of tailings slurry was prepared by AMMTEC Limited and despatched to EGi's laboratory in Sydney for geochemical characterisation. The main objectives of the laboratory testing program carried out by EGi were as follows:

- to quantify the acid forming characteristics of the tailings and the total capacity for acid generation using static testing procedures;
- to assess the reactivity of any carbonate mineralisation within the tailings and the extent to which such mineralogy might prevent or delay the onset of tailings acidification;
- to identify any environmentally significant metals that could mobilise from the tailings in the event that sulphide oxidation and acidification occur.

This report presents the results of the geochemical characterisation of the tailings and the findings with respect to acid forming potential and metals enrichments.

## 2.0 Testing Program

### 2.1 Sample Preparation

Approximately 12 kg of tailings slurry was provided within a sealed 20 litre plastic bucket. A 1 litre sub-sample of the tailings liquor was initially taken for elemental analysis and measurement of pH, alkalinity and electrical conductivity. Most of the remaining excess liquor was then decanted into a separate container and the wet tailings solids were thoroughly mixed. A sub-sample of the solids of approximately 1 kg was taken for geochemical analysis. The sub-sample was oven-dried at a low temperature (50 °C) prior to analysis. The excess tailings liquor and excess tailings solids were subsequently re-combined and sealed within a plastic container for possible future use.

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## 2.2 Testing Program

The tailings samples were assayed for the following parameters:

### *Tailings Liquors*

- pH, alkalinity and electrical conductivity (EC)
- Multi-element analysis

### *Tailings Solids*

- Multi-element composition
- Total sulphur content
- Sulphur and carbon forms
- Maximum potential acidity (MPA)
- Acid neutralising capacity (ANC)
- Carbonate neutralising value (CNV)
- Net acid producing potential (NAPP)
- Net acid generation (NAG) capacity
- Acid buffer characteristic curve

## 2.3 Analytical Procedures

The analytical methods used are summarised below.

### *Analysis of Liquors*

The pH, alkalinity and electrical conductivity of the tailings liquor were initially measured. A 100 mL sub-sample of liquor was then filtered through a 0.45 µm membrane filter and the filtrate preserved with 1 mL of high purity nitric acid prior to despatch to Australian Laboratory Services (ALS) in Sydney for multi-element analysis. The tailings liquor was analysed for a suite of 30 elements using a combination of inductively coupled plasma mass spectrometry (ICPMS), inductively coupled plasma optical spectrometry (ICPAES), FIMS mercury analyser, chloride discrete analyser, and fluoride potentiometric titrator.

### *Multi-Element Analysis of Solids*

The multi-element analysis of solids was carried out by Australian Laboratory Services (ALS) in Brisbane using NATA registered procedures. The solids were digested by multi-acid addition (*i.e.* hydrofluoric, nitric, perchloric and hydrochloric acids) and the digest was analysed for a suite of 25 elements using ICPAES. Mercury was also determined using an aqua regia digestion to ensure minimal volatilisation followed by analysis using ICPMS.

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### *Total Sulphur Content*

The total sulphur content of the tailings solids was determined by the Leco furnace method. The sulphur assay was carried out by Sydney Environmental & Soil Laboratory Pty Ltd under a quality assurance system certified as complying with ISO 9002.

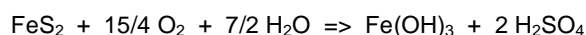
### *Sulphur and Carbon Forms*

Determination of sulphur and carbon forms within the tailings solids was carried out by Australian Laboratory Services (ALS) in Brisbane and included determination of the following:

- Total sulphur - Measured using a Leco sulphur analyser
- Sulphate-sulphur - The sample was leached with hot HCl to remove acid-soluble sulphates. The amount of sulphate within the leachate was then determined by ICPAES.
- Sulphide-sulphur - Calculated as the difference between Total-S and Sulphate-S values.
- Total carbon - Measured using a Leco carbon analyser
- Organic-carbon - The sample was digested with hot HCl to remove any carbonates, then rinsed with distilled/deionised water to remove any residual chloride. The residual carbon remaining in the residue (i.e. acid-insoluble carbon) was then measured by Leco.
- Inorganic-carbon - Calculated as the difference between Total-C and Organic-C values.

### *Maximum Potential Acidity*

The maximum potential acidity (MPA) is the amount of acid that theoretically could be generated by the sulphide mineralisation contained within a sample assuming that the sulphide occurs as reactive pyrite and that there is complete oxidation of the pyrite according to the reaction:



The MPA of the tailings was calculated from the sulphur content as follows:

$$\text{MPA (kg H}_2\text{SO}_4\text{/t)} = \% \text{ sulphide-S} \times 30.6.$$

### *Acid Neutralising Capacity (ANC)*

The acid produced by pyrite oxidation will to some extent react with other minerals contained within a sample. This inherent acid buffering is quantified in terms of the ANC which has the same units as MPA. The ANC of the tailings was determined using the Sobek Method. This involved reacting a sub-sample of

the tailings with a known amount of acid at around pH 1, then back-titrating to determine residual acid. The amount of acid consumed by the tailings was subsequently calculated by difference.

#### *Carbonate Neutralising Value*

The CNV is another measure of the inherent buffering capacity within a sample. The CNV was calculated from the carbonate-C content as follows:

$$\text{CNV (kg H}_2\text{SO}_4\text{/t)} = \text{Total \% Carbonate-C} \times 81.67$$

#### *Acid Buffer Characteristic Curve*

An acid buffer curve was produced by slow titration of the tailings solids with dilute HCl acid over a period of 24 hours. The curve provides a measure of the buffering provided by more soluble carbonates within a sample, with the readily available fraction typically defined as the amount of acid that was neutralised by a sample above pH 6.

#### *Net Acid Producing Potential*

The NAPP is the amount of acid that potentially can be produced by a sample after allowance for the ANC. It is calculated by subtracting the ANC value from the MPA value. If the NAPP is negative then it is likely that the material has sufficient inherent buffer capacity to prevent acid generation. Conversely, if the NAPP is positive then the material may be acid generating.

#### *Net Acid Generation (NAG)*

The NAG test is a rapid oxidation procedure for estimating the acid forming potential of a sample. Both acid generation and acid neutralisation reactions can occur simultaneously during a NAG test, hence the end result represents a direct measurement of the net amount of acid that a sample can generate. The test involves reaction of 2.5 g of sample with 250 mL of 15% hydrogen peroxide for 16 hours. Flasks are then gently heated for two hours to decompose any remaining peroxide, and after cooling the pH of the NAG liquor is recorded. If the sample after reaction has a pH of 4.5 or less (*i.e.* NAGpH $\leq$ 4.5) then it is considered to be acid forming. The actual amount of acidity generated by a sample (expressed as kg H<sub>2</sub>SO<sub>4</sub>/t) is subsequently determined by titration of the mixture with NaOH to an end-point of pH 7.

#### *Classification of ARD Potential*

The acid forming potential of a sample is commonly classified on the basis of the NAPP and NAG test results as either *Non-Acid Forming (NAF)* or *Potentially Acid Forming (PAF)*.

The criteria used to define PAF material are a positive NAPP and a positive NAG. By definition, PAF material has a significant sulphur content, the acid generating potential of which exceeds the inherent acid neutralising capacity of the material. This means there is a risk that such a material could oxidise and generate ARD if exposed to atmospheric conditions.

The criteria used to define NAF material are a negative NAPP and a NAG of zero. By definition, the ANC of a sample classified as NAF is more than adequate to neutralise any acid that theoretically could be produced by any sulphide minerals that may be present, and hence such material would be considered unlikely to produce ARD.

An *uncertain* classification may also be assigned when there is disparity between the NAPP and NAG test results: for example, when the NAPP is positive but the NAG is zero, or when the NAPP is negative but the NAG is positive. In such situations further testwork is required to confirm the acid potential but a tentative classification may be provided based on the results that are available.

### 3.0 Geochemical Characteristics of Tailings

#### 3.1 Composition of Tailings Liquor

The multi-element composition of the tailings liquor is given in Table 1. As is usually the case with flotation tailings, the liquor was moderately alkaline, with a pH of 8.1 and a titratable alkalinity of 33 mg CaCO<sub>3</sub>/L.

The soluble salt content was relatively high with an electrical conductivity of 3190 µS/cm. The major ion chemistry was dominated by sulphate (1550 mg/L), chloride (2170 mg/L), sodium (1270 mg/L) and calcium. There were also elevated concentrations of magnesium (181 mg/L) and potassium (28 mg/L).

The concentrations of environmentally important elements were generally low and in many cases at, or below the limits of analytical detection. They included aluminium (0.04 mg/L), antimony (0.01 mg/L), arsenic (0.004 mg/L), cadmium (<0.0001 mg/L), cobalt (0.001 mg/L), chromium (<0.001 mg/L), copper (0.004 mg/L), iron (<0.05 mg/L), lead (0.001 mg/L), manganese (0.2 mg/L), mercury (<0.0001 mg/L), nickel (<0.001 mg/L), selenium (<0.01 mg/L), tin (<0.001 mg/L) and zinc (0.01 mg/L). The low concentrations of dissolved metals are consistent with solubility constraints commonly observed under alkaline conditions.

#### 3.2 Composition of Tailings Solids

The multi-element results for the tailings solids are given in Table 2. Geochemical Abundance Indices (GAIs) were also calculated for each element and are included in Table 2. The GAI compares the actual concentration of an element in a sample with the median soil<sup>1</sup> abundance for that element. The main purpose of the GAI is to provide an indication of any elemental enrichments that may be of environmental importance. The GAI for an element is calculated as follows:

$$\text{GAI} = \log_2 [ C / (1.5 \cdot S) ]$$

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<sup>1</sup> References for median soil data were: (1) Bowen, H.J.M. (1997) Environmental Chemistry of the Elements. Academic Press, London. (2) Berkman, D.A. (1976) Field Geologists' Manual, The Australian Institute of Mining and Metallurgy, Parkville, Victoria, Australia

where C is the concentration of the element in the sample and S is the median soil abundance for that element. The GAI are truncated to integer increments (0 through to 6, respectively) which correspond to the following enrichment ranges:

- GAI=0 < 3 times median soil abundance
- GAI=1 3 to <6 times median soil abundance
- GAI=2 6 to <12 times median soil abundance
- GAI=3 12 to <24 times median soil abundance
- GAI=4 24 to <48 times median soil abundance
- GAI=5 48 to <96 times median soil abundance
- GAI=6 ≥ 96 times median soil abundance

As a general rule, a GAI of 3 or above is considered significant and may warrant further examination. Elements that were significantly enriched (GAI≥3) in the tailings solids relative to median soil concentrations were antimony (12 mg/kg), barium (6740 mg/kg), and molybdenum (51 mg/kg). There was also minor enrichment (GAI = 1 or 2) of the tailings solids with arsenic (33 mg/kg), bismuth (2 mg/kg), calcium (7.23 %), copper (296 mg/kg), iron (19.5 %), phosphorus (2970 mg/kg), and sulphur (0.34 %).

The enrichment with iron is consistent with the high magnetite content of the ore and is of no consequence environmentally. The significance of the sulphur and calcium enrichments is discussed in Section 3.3 in relation to the acid forming characteristics of the tailings. Amongst the other enrichments, the more environmentally important are likely to be copper, antimony and arsenic.

Copper is highly mobile under acidic conditions and elevated concentrations of this metal would be expected within tailings pore water if the tailings were to acidify below pH 6.5. The potential for mobilisation of semi-metals such as arsenic and antimony is difficult to predict, as the solubilities and geochemical behaviour of these elements in geological systems are usually controlled by adsorption or co-precipitation reactions involving other elements (e.g. iron at lower pHs and calcium at higher pHs).

### 3.3 Acid Forming Characteristics of Tailings Solids

The acid forming characteristics of the tailings solids are summarised in Table 3. Overall, the results confirmed the presence of some sulphide mineralisation within the tailings but there was also a high inherent neutralisation capacity associated with carbonates which far outweighed any acidity that might be generated by the tailings if sulphide oxidation were to occur. As such, the tailings were classified as non-acid forming.

More specific geochemical properties of the tailings are summarised below:

#### *Sulphur Speciation*

- The total sulphur content of the tailings was 0.37 %S, which is well above typical background soil contents but not particularly high for tailings from a flotation process.

- Approximately 0.07 %S was acid leachable. This fraction is generally considered to be sulphate-S and does not contribute to the acid forming potential.
- The sulphide-S content (calculated by difference) was 0.3 %S, which corresponds to a maximum potential acidity of 11 kg H<sub>2</sub>SO<sub>4</sub>/t.

#### Neutralisation Characteristics

- The inherent acid neutralising capacity of the tailings was 203 kg H<sub>2</sub>SO<sub>4</sub>/t, which is in the high range for process tailings and almost 20-times greater than the acid potential of the contained sulphides within the tailings.
- The carbonate-C content of the tailings was also high at approximately 2.3 %C. This corresponds to a carbonate neutralising value (CNV) of 185 kg H<sub>2</sub>SO<sub>4</sub>/t. The similarity between the CNV and ANC values suggests that carbonate mineralisation is responsible for most of the neutralisation capacity of the tailings.
- The acid buffer curve for the tailings is shown in Figure 1. There was a well defined plateau region consistent with strong circum-neutral buffering (*i.e.* between pH 6 to 8). The shape of the buffer curve corresponds with dolomitic mineralisation<sup>2</sup>, and overall the curve indicates that approximately 140 kg H<sub>2</sub>SO<sub>4</sub>/t was available for neutralisation above pH 6.

#### Net Acid Potential

- The NAPP of the tailings was strongly negative (-194 kg H<sub>2</sub>O<sub>4</sub>/t), consistent with the ANC being many times greater than the acid potential of the sulphides contained within the tailings.
- The acid-base balance is shown graphically in Figure 2. The tailings plot well above the NAPP=0 line, as well as above the ANC/MPA=3 line.
- There was very little response when the tailings were reacted with hydrogen peroxide in the NAG test, and no indication of acid generation (*i.e.* NAG=0 kg H<sub>2</sub>SO<sub>4</sub>/t). In fact, at the completion of the test the NAG liquor was alkaline with a pH of 9.3. Such a pH is relatively common for geological materials with high carbonate contents.
- On the basis of a strongly negative NAPP, and the absence of acidification in NAG test, the tailings are considered to be non-acid forming.

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<sup>2</sup> Calcite and limestone are usually readily available for neutralisation and can maintain a plateau at circum-neutral pH up until almost all of the ANC is consumed. Dolomite is also usually reactive, however the reactivity may decline when there is significant iron substitution, such as with ferroan dolomite. In contrast, magnesite and siderite are usually poorly reactive at circum-neutral pH, and significant dissolution of these carbonates often only occurs under laboratory conditions when the pH drops below about 4.

## **4.0 Summary**

This report presents the results of geochemical testing of a sample representing tailings that will be produced at the Cloncurry Copper project in NW Queensland. The results of static testing indicated that the sample of tailings contained some sulphide mineralisation, but the sulphur content was relatively low for a flotation tailings and the inherent neutralisation capacity of the tailings was approximately 20-times greater than the amount of acidity that could be generated by the sulphides within the tailings in the event that the tailings were exposed to atmospheric conditions and oxidation were to occur. Therefore, based on the NAPP and NAG test results, it is expected that Cloncurry tailings as represented by the sample tested will be non-acid forming (NAF), provided there is no preferential segregation of sulphide and carbonate mineralisation during discharge of the tailings into the storage facility.

# Tables and Figures

Table 1: Composition of Cloncurry tailings liquor

Parameter	Unit	Limit of Reporting	Result
pH		0.10	8.1
Alkalinity	mg/l	1	33
EC	µS/cm	0.001	3190
SO4	mg/l	1	1550
Cl	mg/l	1	2170
Ca	mg/l	1	342
K	mg/l	1	28
Mg	mg/l	1	181
Na	mg/l	1	1270
Ag	mg/l	0.001	<0.005
Al	mg/l	0.01	0.04
As	mg/l	0.001	0.004
B	mg/l	0.05	1.3
Ba	mg/l	0.001	0.029
Be	mg/l	0.001	<0.001
Cd	mg/l	0.0001	<0.0001
Co	mg/l	0.001	0.001
Cr	mg/l	0.001	<0.001
Cu	mg/l	0.001	0.004
F	mg/l	0.1	1.8
Fe	mg/l	0.05	<0.05
Hg	mg/l	0.0001	<0.0001
Mn	mg/l	0.001	0.2
Mo	mg/l	0.001	0.092
Ni	mg/l	0.001	<0.001
P	mg/l	1	<1
Pb	mg/l	0.001	<0.001
Sb	mg/l	0.001	0.01
Se	mg/l	0.01	<0.01
Si	mg/l	0.1	7.0
Sn	mg/l	0.001	<0.001
Sr	mg/l	0.001	2.3
Zn	mg/l	0.005	0.01

< element at or below limit of reporting.

Table 2: Composition of Cloncurry tailings solids

Element	Unit	Solids Composition	Median Soil Content	Geochemical Abundance Indices
Ag	ppm	0.6	0.1	2
Al	%	3.96	7.1	0
As	mg/kg	33	6	1
Ba	mg/kg	6740	500	3
Be	mg/kg	1.6	6	0
Bi	mg/kg	2	0.2	2
Ca	%	7.23	1.5	1
Cd	mg/kg	0.5	0.4	0
Co	mg/kg	21	8	0
Cr	mg/kg	193	70	0
Cu	mg/kg	296	30	2
Fe	%	19.5	4.0	1
Hg	mg/kg	0.057	0.06	0
K	%	1.90	1.4	0
Mg	%	1.11	0.5	0
Mn	mg/kg	2550	1000	0
Mo	mg/kg	51	2	4
Na	%	0.56	0.50	0
Ni	mg/kg	120	50	0
P	mg/kg	2970	800	1
Pb	mg/kg	22	35	0
S	%	0.37	0.07	1
Sb	mg/kg	12	1	3
Sr	mg/kg	159	250	0
Zn	mg/kg	19	90	0
<p># Median soil data from:</p> <p>Bowen, H.J.M. (1979) Environmental Chemistry of the Elements. Academic Press, London.</p> <p>Berkman, D.A. (1976) Field Geologists' Manual, The Australian Institute of Mining and Metallurgy, Parkville, Victoria, Australia.</p>				
<p>* Geochemical Abundance Indices (GAI)</p> <p>GAI=0 represents &lt;3 times median soil content</p> <p>GAI=1 represents 3 to 6 times median soil content</p> <p>GAI=2 represents 6 to 12 times median soil content</p> <p>GAI=3 represents 12 to 24 times median soil content</p> <p>GAI=4 represents 24 to 48 times median soil content</p> <p>GAI=5 represents 48 to 96 times median soil content</p> <p>GAI=6 represents more than 96 times median soil content</p>				

Table 3: Acid forming characteristics of Cloncurry tailings solids

Parameter	Unit	Dugald Tailings
Total Sulphur*	%S	0.37
- Acid Soluble Sulphur *	%S	0.07
- Acid Insoluble Sulphur *	%S	0.30
Total Carbon	%C	2.29
- Acid Insoluble Carbon	%C	0.02
- Carbonate Carbon	%C	2.3
Carbonate Neutralising Value	kg H <sub>2</sub> SO <sub>4</sub> /t	185
Acid Neutralising Capacity	kg H <sub>2</sub> SO <sub>4</sub> /t	203
Maximum Potential Acidity	kg H <sub>2</sub> SO <sub>4</sub> /t	9
Net Acid Producing Potential	kg H <sub>2</sub> SO <sub>4</sub> /t	-194
Net Acid Generation	kg H <sub>2</sub> SO <sub>4</sub> /t	0
NAGpH		9.3
ARD Classification	kg H <sub>2</sub> SO <sub>4</sub> /t	Non-Acid Forming

Footnotes:

\* Refer to Section 3.3 for discussion and clarification of sulphur forms

Methods:

Total Sulphur Content -- determined by Leco analyser  
 HCl Acid Soluble Sulphur - Sulphur leached with HCl acid  
 Acid Insoluble Sulphur - difference between Total-S and Acid Soluble-S  
 Total Carbon - determined by Leco analyser  
 Acid Insoluble Carbon - residual carbon after leaching with HCl acid  
 Carbonate Carbon - difference between Total Carbon and Acid Insoluble Carbon  
 Carbonate-C Neutralising Value (CNV) - calculated from the Carbonate-C value  
 Acid Neutralising Capacity (ANC) - determined using the Sobek method  
 Maximum Potential Acidity (MPA) - calculated from sulphide-S content  
 Net Acid Producing Potential (NAPP) - calculated from the sulphide-S and ANC values  
 Net Acid Generation (NAG) - measured using the hydrogen peroxide oxidation procedure

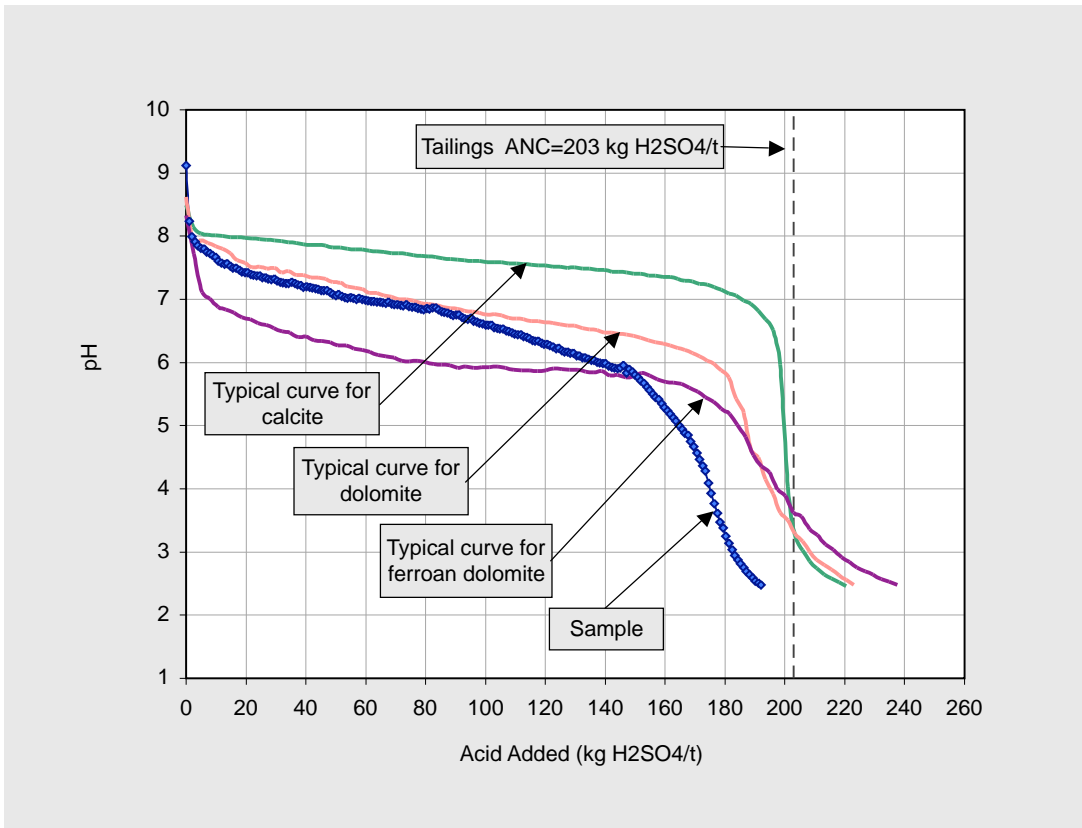


Figure 1. Acid buffer characteristic curve for Cloncurry tailings

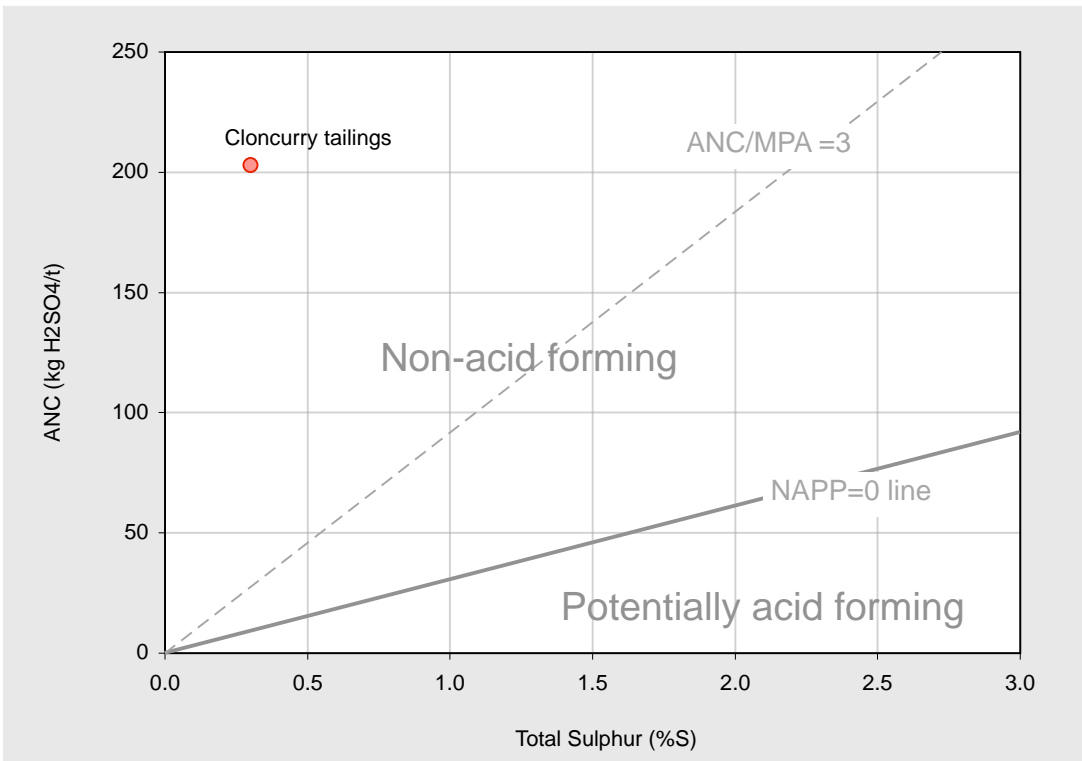


Figure 2. Acid-base account plot for Cloncurry tailings