Predicting the Potential Geochemical Nature of Waste Rock

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Introduction

Key Mine domains that generate AMD are:

- Waste Rock Dumps (WRDs);
- Tailings Storage facilities (TSFs);
- Underground working;
- Low grade ore stockpiles and ROM pad;
- Heap leach pads; and
- Pit walls.

WRDs are generally accepted as the principal mine domain associated with contaminant generation. Typically > 60 – 80% of the site load.

WRDs therefore account for the majority of treatment costs and thus the costs and risks associated with treatment in perpetuity.

To understand the potential contaminant load from a WRD requires understanding the geochemical nature of the waste rock.
Geochemistry of Rocks

Geochemical Nature
- Refers to the rock geochemistry and whether they will generate acid drainage, metalliferous drainage, neutral mine drainage, or saline drainage.
- ABA data is the geochemical guide to what will happen.

Geochemical Signature
- Refers to the water quality expected from the rocks. For instance, what contaminants of concern are likely, what concentrations are possible, and how do they compare to closure water quality (concentration) guidelines.
- Project risks can generally be defined by the nature of the rocks.
- Understanding the geochemical signature helps refine these risks and helps determine management costs.
Geochemical Nature

- Geochemical nature is defined by acid base accounting and subsequent classification.

- ABA data is critical for the development of long term water quality models.
- Potential acidity (i.e., sulfides) and stored acidity (i.e., oxidation products) need quantification as part of the ABA process.
Potential Acidity

Potential acidity is generated by sulfide oxidation. Typically this is represented by pyrite oxidation:

$$\text{FeS}_2 + \frac{7}{2}\text{O}_2 + \text{H}_2\text{O} \Rightarrow \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+$$

Pyrite + oxygen + water \(\Rightarrow\) Fe + sulfate + acid

Fe\(^{2+}\) can create additional acidity by hydrolysis (Lewis Acidity)

$$\text{Fe}^{2+} + \frac{1}{4}\text{O}_2 + \text{H}^+ \Rightarrow \text{Fe}^{3+} + \frac{1}{2}\text{H}_2\text{O}$$

$$\text{Fe}^{3+} + 3\text{H}_2\text{O} \Rightarrow \text{Fe(OH)}_3(\text{s}) + 3\text{H}^+$$

The potential acidity is determined from the amount of S present.

Neutralisation of acidity can be achieved with limestone

$$\text{CaCO}_3 + 2\text{H}^+ \Rightarrow \text{Ca}^{2+} + \text{CO}_2 + \text{H}_2\text{O}$$

Limestone + acidity \(\Rightarrow\) dissolved calcium + CO\(_2\) + water

The potential acid neutralisation capacity (ANC) of a rock is determined by the above reaction.
Methods to determine Potential Acidity are well established and include:

**Acid Potential**
- Sulfur speciation
- Maximum potential acidity (MPA) (wt%S x 30.6)
- NAG testing (and variations) to determine acidity

**Neutralisation Potential**
- Acid Neutralisation Capacity (ANC)
- Acid Buffering Characteristic Curve (ABCC) test

Further details on these methods are available in the paper.
Stored Oxidation Products (Acidity)

- If there is incomplete oxidation of the ferrous ($\text{Fe}^{2+}$) iron to ferric ($\text{Fe}^{3+}$) iron then ferrous salts such as melanterite, $\text{FeSO}_4$ can form, which following any subsequent wetting can release the stored ferrous acidity.

$$\text{FeS}_2 + \frac{7}{2}\text{O}_2 + \text{H}_2\text{O} \Rightarrow \text{FeSO}_4 + \text{SO}_4^{2-} + 2\text{H}^+$$

$$\text{FeSO}_4 + \frac{1}{2}\text{O}_2 + \frac{5}{2}\text{H}_2\text{O} \Rightarrow \text{Fe(OH)}_3 + 2\text{H}^+ + \text{SO}_4^{2-} \quad \text{(Fast dissolution)}$$

- However, if oxidation to ferric ($\text{Fe}^{3+}$) iron is complete yet the hydrolysis is incomplete, jarosite type secondary minerals can form. The dissolution of jarosite releases the acidity

$$\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6 + 3\text{H}_2\text{O} \Rightarrow 3\text{Fe(OH)}_3 + 3\text{H}^+ + 2\text{SO}_4^{2-} + \text{K}^+ \quad \text{(Slow)}$$

- Quantification of stored acidity (metals) is required to develop long term water quality models.
- Melanterite forming on the collection vessel for lab-based PAF trials (Cypress)
- Proof – XRD being undertaken
ABA – Stored Acidity

ABA indicators of stored acidity include:

- Paste pH (and rinse pH) Represented by pH < 5.5
- Acid Neutralisation Capacity (ANC) Negative ANC values

Key static tests for the quantification of stored oxidation products

- **Soluble melanterite-type acidity / metals**
  - 1M KCl digestion including:
    - pH\textsubscript{KCl} - pH measurement after digestion
    - Titratable actual acidity (TAA) – back titration of the 1M KCl digestion liquor to quantify acidity load.
    - Solution can be analysed for sulfate and metals

- **Sparingly soluble jarosite-type acidity**
  - 4M HCl digestion
    - Measure solution for sulfate and metals
    - Jarosite type acidity determined by difference (4M HCl – 1M KCl)
ABA Indicators of Stored Acidity

- Average negative ANC being -6.7 kg/tonne acidity.
ABA Indicators of Stored Acidity

The scatter plot shows the relationship between NAG pH and ANC. The data points are distributed across the graph, with the red circle highlighting a particular area of interest. The x-axis represents ANC, ranging from -60 to 140, and the y-axis represents NAG pH, ranging from 0 to 12.
• Until now, the only rocks being mined at Cypress are acid forming.
• NAF and PAF-Lag rocks will be mined shortly.
Summary

- Potential acidity can lead to the ongoing generation of contaminants if oxygen is not limited.
  - It is often much higher than the stored acidity.
  - Management options require the control of oxygen flux.

- Stored acidity will be mobilised as a function of flow.
  - Management: Control water (run-on water and net percolation (NP) of rainfall).

Fanny Creek, Island Block Mine
Andrew Mackenzie (2010)
Case Study: Cypress Coal Mine

- 2 Mt of waste rock have been placed in the Cypress NELF over the last few years.
- ABA data informs us of the geochemical nature of the project - acid forming.
- The potential acidity is significant.
- Oxygen ingress needs to be managed.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Abbreviation</th>
<th>Criteria</th>
<th>Relevant Consent condition Criteria</th>
<th>No. of samples</th>
<th>Potential Acidity Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Acid Forming</td>
<td>NAF</td>
<td>NAPP &lt; 0</td>
<td>NAG Acidity = 0</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>Low Risk</td>
<td>LR</td>
<td>NAPP &gt; 0 and ≤ 20</td>
<td>NAG Acidity &lt; 20</td>
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<td>4.0</td>
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<td>Potentially Acid Forming</td>
<td>PAF</td>
<td>NAPP &gt; 20 and ≤ 50</td>
<td>NAG Acidity &gt; 20</td>
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<td>39.7</td>
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<td>High Acid Forming</td>
<td>HAF</td>
<td>NAPP &gt; 50</td>
<td>not applicable</td>
<td>11</td>
<td>54.7</td>
</tr>
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</table>
Case Study: Cypress Coal Mine

- Assessment of stored acidity indicates that within a few weeks of blasting significant oxidation products are present (~ 5 kg/tonne).
- Although data are limited (more work in progress) these numbers can be used to determine that ~ 10,0000 tonnes of stored acidity is present within the Cypress NELF.

### Table 3. Cypress ABA Data

<table>
<thead>
<tr>
<th>Sample</th>
<th>Paste pH</th>
<th>Total S</th>
<th>MPA</th>
<th>Water Soluble Titratable Acidity</th>
<th>1M KCl Leach Test</th>
<th>4M HCl Leach Test</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pH</td>
<td>kg H₂SO₄/t</td>
<td>pH</td>
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<td>2.66</td>
<td>81.4</td>
<td>2.94</td>
<td>4.66</td>
<td>3.58</td>
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<td>111.1</td>
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<td>0.48</td>
<td>3.49</td>
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<td>3.84</td>
<td>0.85</td>
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<td>25.7</td>
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<td>31.8</td>
<td>3.58</td>
<td>1.71</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Melanterite-type acidity > Jarosite-type acidity
Case Study: Cypress Coal Mine

- Previous work has shown that construction methods have reduced oxygen ingress into the core of the NELF and only the outer zone of each lift is oxidising. **This management option therefore addresses control of O2 flux**.

- Understanding the ABA data enables the development of a conceptual model for the NELF.

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**Zone 2**
- High Oxygen (20%)
- Stored acidity from oxidation prior to placement and ongoing oxidation of sulfides
- Stored acidity = variable (**Higher risk**)

**Zone 1**
- Low Oxygen (~1%)
- Stored acidity from oxidation prior to placement
- Stored acidity = ~5 kg H₂SO₄/t (**Lower risk**)

Running surfaces are well compacted and hence O2 depth is less.
The reason for limited oxygen ingress is due to:

- The use of 5 m lifts to minimise chimney zones (grainsize segregation)
- The textural properties of the Kaiata mudstone, where it weathers very quickly to smaller particles thereby preventing the advective ingress of oxygen
Case Study: Cypress Coal Mine

- ~5,000 tonnes of ANC (as CKD) was added to the running surfaces of the NELF.
- However, the current acid load from the NELF is ~350 tpa.
- Based on the stored oxidation products present (~10,000 t) poor water quality could last for many years.

- It is proposed that the NELF will be moved back into the Cypress Pit at the close of mining in 12 years.

- Placement back in the pit will also require the addition of alkalinity to neutralise any stored oxidation products generated during ex-pit storage.
- Neutralisation of the potential acidity is not required as the rock will be flooded (essentially a water cover).
Case Study: Cypress Coal Mine

- Understanding the potential acidity provides us a guide as to the geochemical nature and project risks.
- Understanding the stored oxidation products provides us tools to forecast poor water quality and quantify the amount of acid that can be mobilised by water flow.
- The current management plan for the NELF is to reduce oxidation around the edges of the NELF by recontouring and compaction.
During the approvals stage there often remains uncertainty, which needs to be resolved prior to mining commencing or adaptive management options determined.
O'Kane Consultants

Supporting:

- Rainbow of Hope for Children,
- Habitat for Humanity Initiative – El Salvador

Supporting:

- Mine Overlay Site Testing Facility – University of Saskatchewan (Canada)
- Centre for Minerals Environmental Research (New Zealand):