Predicting ML/ARD from Low Acid Potential and Low Carbonate Neutralization Potential Rock

Baffinland Iron Mines, Mary River Project, Nunavut, Canada

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Acknowledgments

- Baffinland site support and geology staff.
- George H Wahl & Associates (modeling of waste types in pit).
- Knight Piésold (initial characterization work to 2009).
Outline

- Background
  - Site Location and setting.
  - Description of the ore.
- Waste rock geology and waste types.
- Summary of characterization work and results.
- Continuing and future work.
Site Location

Above the arctic circle at 71° N
Site Setting and Climate

- Very cold temperatures that average -30° Celsius in winter.
- 24-hour darkness from November to January.
- Summers with 24-hour daylight from May to August, but continued cool to cold condition.
- Average annual precipitation is 220 mm/year with ~75% falling between May and October.
- Continuous permafrost
  - Precipitation between October and May as snow.
  - Short melt and drainage period between June and September.
Mary River Project - Ore

- Estimated 365 Mt of high grade direct ship lump and fine iron ore.
- Algoma type iron formation consisting of hematite, magnetite and mixed hematite-magnetite-specular hematite.
- Deposit consists of a number of lensoidal bodies.
  - vary in their proportion of the main iron oxide minerals and impurity content of sulphur and silica (rarely Mn and P).
Summary of Sampling

- Estimated 566 Mt waste rock.
- Staged ML/ARD sampling.

<table>
<thead>
<tr>
<th>Program</th>
<th>Waste Rock Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006-2008</td>
<td>97</td>
</tr>
<tr>
<td>2010</td>
<td>180</td>
</tr>
<tr>
<td>2011</td>
<td>377</td>
</tr>
<tr>
<td>2012</td>
<td>230/489</td>
</tr>
</tbody>
</table>
Sampled Waste Rock Volume 2011

Plan View

Legend:
- High Grade Iron Formation
- Foot Wall Schist
- Foot Wall Waste (Undifferentiated)
- Hanging Wall Schist
- Hanging Wall Waste (Undifferentiated)
- Life of Mine Pit Boundary

North
**Sulphur Speciation**

**Total Sulphur vs. Sulphide Sulphur**

- Sulphide is predominant form of S
- 90\textsuperscript{th} percentile sulphide content (all samples) 0.6%
- Median sulphide content (all samples) 0.03%
- Sulphide sulphur of 0.01\% or less in almost 50\% of samples

\* Sulphide Sulphur = Total Sulphur – Sulphate Sulphur

Data to 2011
Modified Sobek NP vs. Carb NP

- Carbonate dominated
  - Particularly HW samples
- Probable Fe carbonates
  - Particularly MW samples, FWS and FW
- Non-carbonate dominated
  - Bulk of samples

Evaluation of NP

Data to 2011
Carbonate is a small portion of NP.

Data to 2011

Note: Based on 568 ABA samples. Excludes 45 ABA samples with Carbonate NP > modified Sobek NP.

Percentage Carbonate NP of Sobek NP

Data to 2011
Neutralization potential ratio (NPR) = NP/AP

PAG rock assumed for NPR < 2

Data to 2011
NPR vs. Sulphide S

Sulphide S > 0.2% is a strong indicator of NPR < 2

Data to 2011
Unsampled regions of pit

- Estimated 15% PAG rock overall.
Waste Rock Drilling 2012

2012 Boreholes
Modeled Waste Distribution in Pit 2013

Plan View

Cross section – north limb

Cross section – fold nose

500 m
Cross Section North Limb

Mary River Deposit # 1
2013 Waste Rock Model
(North Limb)
Cross Section – Fold Nose

Mary River Deposit #1
2013 Waste Rock Model
(Fold Nose)
<table>
<thead>
<tr>
<th>Waste Type</th>
<th>In-Pit Tonnage (Mt)</th>
<th>Waste (%)</th>
<th>Lithologies (in approximate order of abundance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanging wall (HW)</td>
<td>77.5</td>
<td>14</td>
<td>meta-volcanic (tuff); greywacke; amphibolite; chlorite, mica or amphibole schist; ultramafite; and gneiss</td>
</tr>
<tr>
<td>Hanging wall schist (HWS)</td>
<td>139.6</td>
<td>25</td>
<td>chlorite, mica, or amphibole schist; amphibolite; greywacke; and meta-volcanic (tuff); inter-bedded zones of banded iron formation</td>
</tr>
<tr>
<td>Internal waste (IW)</td>
<td>2.1</td>
<td>0.4</td>
<td>schist; amphibolite; and meta-volcanic (tuff)</td>
</tr>
<tr>
<td>Mineralized waste (MW)</td>
<td>9.7</td>
<td>1.7</td>
<td>high grade iron formation (elevated Mn, S or P); and banded iron formation</td>
</tr>
<tr>
<td>Footwall schist (FWS)</td>
<td>74.1</td>
<td>13</td>
<td>chlorite, mica, or amphibole schist; gneiss; greywacke; amphibolite; and meta-volcanic (tuff); inter-bedded zones of banded iron formation</td>
</tr>
<tr>
<td>Footwall (FW)</td>
<td>263.0</td>
<td>46</td>
<td>gneiss; metasediments (e.g., greywacke); chlorite, mica or amphibole schist; and amphibolites</td>
</tr>
<tr>
<td>Total</td>
<td>566</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

- Generally little primary or structural carbonate.
Proportions of Waste Types

Quantities - Mt
Inferred PAG Tonnage

<table>
<thead>
<tr>
<th>Waste Rock Domain</th>
<th>Tonnage (Mt)</th>
<th>No. Samples</th>
<th>Mean S %</th>
<th>Mean NPR**</th>
<th>% Samples NPR &lt;2</th>
<th>PAG tonnage (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW</td>
<td>77.5</td>
<td>61</td>
<td>0.10</td>
<td>17.7</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>HWS</td>
<td>139.6</td>
<td>260</td>
<td>0.68</td>
<td>1.6</td>
<td>27.7</td>
<td>38.6</td>
</tr>
<tr>
<td>IW</td>
<td>2.1</td>
<td>7</td>
<td>0.31</td>
<td>1.5</td>
<td>42.9</td>
<td>0.9</td>
</tr>
<tr>
<td>MW</td>
<td>9.7</td>
<td>21</td>
<td>1.06</td>
<td>1.3</td>
<td>38.1</td>
<td>3.7</td>
</tr>
<tr>
<td>FWS</td>
<td>74.1</td>
<td>161</td>
<td>0.30</td>
<td>2.4</td>
<td>15.5</td>
<td>11.5</td>
</tr>
<tr>
<td>FW</td>
<td>263.0</td>
<td>449</td>
<td>0.06</td>
<td>15.7</td>
<td>2.7</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>566</td>
<td>959</td>
<td>61.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Assumed NPR < 2 represents PAG rock, ** NPR = Modified Sobek NP/AP

- Estimated PAG tonnage for waste rock regions based on % PAG samples within each domain.
- Updated estimate is that PAG* rock represents 10.9% of the total waste rock (based on additional 2012 drilling).
Proportions of PAG and NPAG

- HWS and FWS contain largest quantities of PAG.
- FW is largest overall tonnage of material (almost 50% of rock) with low % PAG.
- MW is low tonnage with high % PAG.
Pyrite (FeS$_2$) is the most common sulfide mineral and typically occurs as disseminated anhedral to euhedral grains.

- Analysis of pyrite grains did not identify arsenic or mercury above detection limits.

Chalcopyrite (CuFeS$_2$) is the next most common sulfide.

NAG Leachate results are consistent with range of sulphides observed.
The sulfide assemblage pyrrhotite \((\text{Fe}_{1-x}\text{S})\), chalcopyrite, and pentlandite \((\text{Fe,Ni})_9\text{S}_8\) was identified in three of 20 samples.

- Analysis of pyrrhotite identified measurable levels of nickel.
- Pentlandite sometimes contained elevated cobalt.
- Sphalerite identified in 2 of 20 samples contained measurable amounts of cadmium.
- Marcasite \((\text{FeS}_2)\) identified in a single sample contained measurable amounts of nickel and copper.
● Ten standard humidity cells initiated in 2008 and operated for 53 weeks.
  ● Range of major lithology sub-types and NP/AP (7 samples with NPR < 2).
● Nine additional standard humidity cells and eight carbonate depleted humidity cells initiated in 2011.
  ● Standard cells selected to cover NPR range <1 to >2 (Carbonate NPR much less).
  ● Carbonate NP depleted cells prepared by Na acetate leach (pH 4.5) until >80% of inorganic carbon is removed.
  ● NP depleted cells selected to measure drainage from non-carbonate waste rock (non-carbonate NPR between 1 and just over 2).
  ● More than 80 and 64 weeks of data for standard and carbonate depleted cells respectively.
pH of Standard Cells

Most standard cells have very low carbonate content

Steady sulphate release rates between 2 and 12 mg/kg/wk
- except cell 5178 at ~ 20 mg/kg/wk
Maximum sulphide content of NP depleted cells 0.4%
Steady sulphate release rates in the range of 1 to 6 mg/kg/wk
Challenges

- Predicting long-term behaviour of sulphide-bearing rock when mechanisms of neutralization at low AP are not well understood.
  - For static tests Modified ABA and NAGpH are supportive of each other.
  - Get carefully selected and prepared humidity cells running early and keep running.
  - Build mineralogical understanding of samples and look for links to static and kinetic data for both AP and NP.
- Modeling water quality
  - Lack of acidic drainage from testing is a particular limitation.
  - What is representative acidic drainage for these low reactive materials and how is it best determined.
  - Utilize conservative assumptions in the absence of the defendable long-term rock behaviour while data is being gathered.
Continuing and Future Work

- Continuation of humidity cells.
- Planning for set up of field test pads.
- Additional detailed mineralogical assessment is being completed to better understand sources of NP and AP in relation to static and kinetic testing results.
  - 30 carefully selected samples from static data set by lithology, NPR, Carb NPR and NAGpH.
  - Mineral liberation analysis (MLA) being considered for selected humidity cell subsamples to relate quantitative mineralogy to available AP (occlusion) and possible non-carbonate NP sources based on mineral type and texture.