Water Quality Predictions in 1992 – How do they Compare to Current On-site Conditions at the Closed Bell Mine Site in BC?

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Porphyry Copper Mine Background

• Porphyry Copper Deposit
  – Intrusive volcanogenic with hydrothermal alteration
  – Pyritic halo
• Staked first claims in 1962
• Mining started in 1970
• Milling started in 1972 with up to 15,500 tonnes per day
• Mine operated until March 1992
Porphyry Copper Mine
Background

Site History

• Operations
  – Open pit measures 2100 meters in diameter and is approximately 320 meters in depth
  – Total pit Volume of 61 Million cubic-metres
  – About 152 million tonnes (Mt) of material removed from pit (~ 79 Mt of ore , ~ 73 Mt of mine rock)
  – Tailings Management Area (TMA) just to the south of the pit (contains ~ 77 Mt of tailings)
Location
Mine Site
– Key Features
Porphyry Copper Mine Background

• Mine Closure
  – Earlier ARD work by regulator in 1980s focused on tailings
  – Systematic ML/ARD assessment in 1991-93 for closure
  – Key focus points included mine rock and tailings geochemistry, prediction of long term water quality, water management, pit filling and site reclamation
  – Mine closed in 1992
Exploration Sample Pulps
Porphyry Copper Mine

Background

• Current Conditions
  – ~ 30% of the site has been reclaimed (wildlife habitat)
  – ~ 62 Mt of potentially acid generating (PAG) rock and 77 Mt of tailings stored on site
  – Water management includes collection ponds and pump houses that collect and transfer water to the pit for storage with plans for treatment when discharge required
  – 3 permitted discharges of diverted clean water
Tailings
ML/ARD Assessment – 1991

- Rock types identified and inventories established
- Mineralogy and metal content analysis
- Acid base accounting (ABA) that included:
  - Sulphur species ($S_T, S^{2-}, SO_4$)
  - Sobek NP
  - Carbonate content
- Kinetic tests (Humidity cells)
- Interpretation of Heap Leach column test results
- Interpretation of on-site water quality
- Water quality modelling
Rock Types and Inventories

- 6 Major rock types
- 4 stockpiles
## Summary of ABA Results

<table>
<thead>
<tr>
<th>Data Set -Number of Samples</th>
<th>Year</th>
<th>NNP (t/1000t)</th>
<th>Paste pH</th>
<th>NP/AP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Mean</td>
<td>Max</td>
</tr>
<tr>
<td>38</td>
<td>99</td>
<td>-87</td>
<td>-32</td>
<td>+13</td>
</tr>
<tr>
<td>16</td>
<td>91</td>
<td>-86</td>
<td>-35</td>
<td>-5</td>
</tr>
<tr>
<td>5 (Tailings)</td>
<td>91</td>
<td>-120</td>
<td>-96</td>
<td>-14</td>
</tr>
<tr>
<td>10</td>
<td>91</td>
<td>-111</td>
<td>-43</td>
<td>-6</td>
</tr>
<tr>
<td>1 Composite</td>
<td>90</td>
<td>-28</td>
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<td></td>
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<tr>
<td>17</td>
<td>87</td>
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<td>-44</td>
<td>+18</td>
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<tr>
<td>7</td>
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<td>91</td>
<td>-86</td>
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<td>-5</td>
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<td>10</td>
<td>91</td>
<td>-111</td>
<td>-43</td>
<td>-6</td>
</tr>
</tbody>
</table>
Paste pH vs NP/AP Ratio (NPR)

Consistent with NNP

Morjwik, 1992

Potentially Acid Generating (PAG)

Non-PAG
Kinetic Test Program

- Heap leach test program established during operation to assess feasibility
- Three (3) additional humidity cells established specifically to assess:
  - Rates of acid generation, acid neutralization and metal leaching at neutral pH
  - Rates of acid generation and metal leaching at acidic pH values
Heap Leach Tests

- 4 – 4 inch diameter columns (25 kg)
- 12 – 24 inch diameter columns (2500 kg)
- 8 – 30 tonne cribs
Humidity Cell Tests

<table>
<thead>
<tr>
<th>Humidity Cell</th>
<th>Material</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A-Frame</td>
<td>Acidic</td>
</tr>
<tr>
<td>2</td>
<td>North Dump</td>
<td>Neutral</td>
</tr>
<tr>
<td>3</td>
<td>Dam #1</td>
<td>Neutral</td>
</tr>
<tr>
<td>TS-7, T1, T2,</td>
<td>Tailings</td>
<td>Neutral</td>
</tr>
<tr>
<td>OTB</td>
<td>Tailings</td>
<td>Acidic</td>
</tr>
</tbody>
</table>
Sulphide Depletion Rates

- Sulphide depletion rates derived from $\text{SO}_4^{2-}$ loading rates in Humidity Cells
NP Depletion Rates

- Theoretical NP depletion rate from $\text{SO}_4^{2-}$ production rate
- Estimated Carbonate NP depletion rate from Carbonate Molar Ratio $([\text{Ca}+\text{Mg}]/\text{SO}_4) \times$ Theoretical depletion rate

From MDAG, 1992
Sulphide and NP Depletion Times – Mine Rock

• Calculated times for onset of acid conditions ranged from 0 to 40 years

• Sulphide depletion times ranged from 10 to 125 years
Sulphide and NP Depletion Rates

Predicted “times” strongly depend on which model is selected.
Acid Generation Predictions

- Mine rock predicted to start generating acid between 2010 and 2030 – depending on available NP – assumed Linear model
- Water in tailings may become acidic in future but water moving down in tailings was expected to be neutral as a result of NP in tailings below the oxidation zone
- Water from tailings can be managed on site with storage in open pit
Empirical Drainage Chemistry Model  (MDAG.com Case Study #33, 2010)

![Graph showing empirical drainage chemistry model with pH and dissolved copper data.](image-url)
Site Water Quality

- Collection pond water sampled and analyzed regularly for;
  - pH, specific conductance, sulphate, hardness
  - Metals (copper, iron, zinc)
- Water quality prediction made in 1992 as part of closure plan
Collection Ponds
Collection Ponds
Water Quality

- Clean diversion water released to lake is permitted through strict monitoring protocols
- Any water exceeding limits remains on site
- Water quality in collection ponds reflects the release of oxidation products and ongoing neutralization of acid as predicted in Closure Plan
- Monitoring program is effective at identifying compliance with permits and managing discharges to lake
Chemistry in Collection Pond 3-1D

Changes in Sulphate Concentration Over Time at 3-1D

Changes in Hardness Over Time at 3-1D

Changes in Dissolved Zinc Concentration Over Time at 3-1D
If concentrations exceed Permit Limits then water is directed to the Tailings Pond (3-1D) or to the Open Pit (8D, 4-1)
Bell - Chemistry in Collection Pond 8 (always directed to Open Pit)

Changes in Field pH Over Time at CP-8

Changes in Hardness Over Time at CP-8

Changes in Sulphate Over Time at CP-8

Changes in Dissolved Zinc Over Time at CP-8
Bell - Chemistry in Collection Pond 8 (always directed to Open Pit)

Changes in Dissolved Copper Over Time at CP-8

All water directed to the Open Pit
Water Quality in Pit Water

Changes in pH Over Time in Pit

- pH Value vs Date Sampled

Changes in Sulphate Concentration Over Time in Pit

- Concentration (mg/L) vs Date Sampled

Changes in Dissolved Iron Concentration Over Time in Pit

- Concentration (mg/L) vs Date Sampled

Changes in Dissolved Copper Concentration Over Time in Pit

- Concentration (mg/L) vs Date Sampled

Changes in pH Over Time in Pit

- pH Value vs Date Sampled
Pit Water Profiles in October 2009
## Pit Water Quality with Depth

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Depth (m)</th>
<th>BMPW-0</th>
<th>BMPW-50</th>
<th>BMPW-100</th>
<th>BMPW-150</th>
<th>BMPW-200</th>
<th>BMPW-250</th>
<th>BMPW-300</th>
<th>BMPW-350</th>
<th>BMPW-400</th>
<th>BMPW-450</th>
<th>Average Values</th>
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<tbody>
<tr>
<td>pH</td>
<td>--</td>
<td>3.89</td>
<td>4.02</td>
<td>4.07</td>
<td>4.04</td>
<td>4.04</td>
<td>4.03</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>3.98</td>
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<tr>
<td>Hardness (as CaCO3)</td>
<td>mg/L</td>
<td>3010</td>
<td>2870</td>
<td>2840</td>
<td>2830</td>
<td>2770</td>
<td>2800</td>
<td>2770</td>
<td>2830</td>
<td>2780</td>
<td>2940</td>
<td>2844</td>
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<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>2940</td>
<td>2960</td>
<td>2960</td>
<td>2940</td>
<td>2970</td>
<td>2950</td>
<td>2960</td>
<td>2960</td>
<td>2970</td>
<td>2970</td>
<td>2930</td>
</tr>
<tr>
<td>Copper (dissolved)</td>
<td>mg/L</td>
<td>9.10</td>
<td>8.67</td>
<td>8.80</td>
<td>8.47</td>
<td>9.03</td>
<td>8.43</td>
<td>9.00</td>
<td>9.08</td>
<td>9.00</td>
<td>9.12</td>
<td>8.87</td>
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<tr>
<td>Iron (dissolved)</td>
<td>mg/L</td>
<td>0.41</td>
<td>0.70</td>
<td>0.69</td>
<td>0.68</td>
<td>0.69</td>
<td>0.70</td>
<td>0.68</td>
<td>0.71</td>
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<td>0.30</td>
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<td>Zinc (dissolved)</td>
<td>mg/L</td>
<td>1.32</td>
<td>1.26</td>
<td>1.29</td>
<td>1.23</td>
<td>1.30</td>
<td>1.22</td>
<td>1.32</td>
<td>1.32</td>
<td>1.27</td>
<td>1.32</td>
<td>1.29</td>
</tr>
</tbody>
</table>
Pit Water Predictions

**pH**

**Cu**

Dissolved Copper Concentration (mg/L)

Year


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# Water Quality Predictions

## Example – South Dump

<table>
<thead>
<tr>
<th>Location</th>
<th>*</th>
<th>pH</th>
<th>Copper Dissolved (mg/L)</th>
<th>Iron Dissolved (mg/L)</th>
<th>Zinc Dissolved (mg/L)</th>
<th>Sulphate (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Dump Plant Site (CP 2)</td>
<td>a</td>
<td>7.0</td>
<td>4.0</td>
<td>&lt;0.03</td>
<td>0.4</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>7.0</td>
<td>0.20</td>
<td>0.08</td>
<td>0.06</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>2.5</td>
<td>800</td>
<td>500</td>
<td>5.0</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>5.8</td>
<td>10.8</td>
<td>2.0</td>
<td>0.92</td>
<td>5230</td>
</tr>
</tbody>
</table>

- **a** = Measured in 1992
- **b** = Predicted for neutral pH conditions
- **c** = Predicted at full NP Depletion when pH becomes acidic
- **d** = Measured in 2008
Predictions in Tailings

• Tailings near surface will become acidic
• Acid front will advance 2 m in 11 years
• Sulphide depletion rate of 0.7 m/a

• Not net acidic seepage from tailings because shallow acidic pore water will be neutralized when moving through unoxidized tailings below the water table
Sulphide Depletion in Tailings 2009

Observed sulphide depletion much slower than predicted
Observed NP depletion much slower than predicted
Observed acid front advancing much slower than predicted
Water Quality in Tailings Pore Water 2009

Soluble Sulphate Concentrations in the Tailings with Depth (mg/kg)

Soluble Sulphate

Depth (cm)

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Water Quality in Tailings Pore Water 2009

Soluble Copper Concentrations in the Tailings with Depth (mg/kg)

Soluble Copper

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Tailings Water Quality

- Some shallow tailings porewater has is acidic with elevated acidity and metals
- Wetter areas of tailings remain neutral with low acidity and metals
- Porewater pH is partially to completely neutralized within 1 m from surface
- Oxidation and acidification progressing much slower than predicted
- Prediction of “no acidic tailings seepage” remains valid
Conclusions

• Extensive ABA and kinetic testing combined with available field data from 20 years of operation provided a basis for water quality predictions
• Static tests predicted acid generating conditions
• Kinetic data from several sources used to predict;
  – WHEN - acidic conditions will begin
  – WHEN – sulphide will be depleted
  – Water quality at neutral and acidic pH values
Conclusions

- Almost 20 years after predictions made;
  - Water quality associated with mine rock predictions remain valid and appear reasonable
  - Predictions for tailings were overly conservative for timing of acidification but remain valid for long-term seepage quality