Geochemical Characterization

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Anchorage
Outline

• Geological context
• Overall program objectives and design
• Geochemical characterization of waste rock
GEOLOGICAL CONTEXT
Geology Map

Each dot is a drill hole
Geological Cross-Section

WEST STOCK MINERALIZING INTRUSION

VOLCANO-SEDIMENTARY ROCKS

EAST STOCK MINERALIZING INTRUSION

TERTIARY COVER ROCKS
Program Objectives

• To characterize weathering and leaching behavior of materials that will be produced during mining and processing

• Inform engineering design of waste and water management plans
Study Design Questions

- Potential for metal leaching (ML) and acid rock drainage (ARD) - Static Tests:
  - Waste rock types (Pre-Tertiary, Tertiary)
  - Tailings

- Waste management criteria - Static and Kinetic Tests:
  - Reaction rates

- Water quality predictions - Static and Kinetic Tests:
  - Water management
  - Impact assessments
# Tests Matrix

<table>
<thead>
<tr>
<th>Procedure</th>
<th>West Zone</th>
<th>East Zone</th>
<th>Tailings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-T</td>
<td>Tertiary</td>
<td>Pre-T</td>
</tr>
<tr>
<td>Acid-base accounting</td>
<td>485</td>
<td>145</td>
<td>200</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>17</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Extraction Tests</td>
<td>26</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>MWMP</td>
<td>0</td>
<td>27</td>
<td>0</td>
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<tr>
<td>Humidity Cells</td>
<td>21</td>
<td>15(^1) + 3(^2)</td>
<td>13</td>
</tr>
<tr>
<td>Bagged weathering tests</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Subaqueous Columns</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aerated Columns</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Field tests</td>
<td>4(^1)</td>
<td>2(^1) +3(^2)</td>
<td>0</td>
</tr>
</tbody>
</table>

1. Includes some replicate tests.
2. Three field tests contain mixed West and East Zone Tertiary rock.
## Chronology of Studies

<table>
<thead>
<tr>
<th></th>
<th>Number of kinetic tests running at end of each year (waste rock given as pre-Tertiary/Tertiary)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2005</td>
</tr>
<tr>
<td><strong>Humidity cell tests (waste rock)</strong></td>
<td></td>
</tr>
<tr>
<td>PEZ</td>
<td>0</td>
</tr>
<tr>
<td>PWZ</td>
<td>17/15</td>
</tr>
<tr>
<td>PEZ+PWZ</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subaqueous columns (waste rock)</strong></td>
<td></td>
</tr>
<tr>
<td>PEZ</td>
<td>0</td>
</tr>
<tr>
<td>PWZ</td>
<td>6/0</td>
</tr>
<tr>
<td><strong>Humidity cell tests (tailings)</strong></td>
<td></td>
</tr>
<tr>
<td>PEZ</td>
<td>0</td>
</tr>
<tr>
<td>PWZ</td>
<td>6</td>
</tr>
</tbody>
</table>
GEOCHEMICAL CHARACTERIZATION OF WASTE ROCK
Spatial Distribution Samples
ARD POTENTIAL OF ROCK
ARD Potential

- Cretaceous mineralized rock is mainly PAG.
- Tertiary rock is mainly non-PAG.

Charts show West Zone data
- East Zone shows similar results to West Zone
REACTION RATES FOR EXPOSED ROCK
Core Aging Effects

- Increase in sulfate sulfur relative to sulfur as the age of the core increased
- Coincident reduction in NP, development acidic paste pH
- Estimated timescale to acid onset, up to 40 years

Data shown for PWZ pre-T mineralised rock (stored at site)
Lab Kinetic Test Methods: Rock

Humidity Cell Tests

Bagged Weathering Tests

Subaqueous Columns
Humidity Cell Tests

To estimate reaction rates under aerobic conditions

Data relevant to:
- Waste rock dumps, pitwalls, stockpiles

Samples were selected to cover range of:
- Rock types
- S contents
- Sample ‘age’ (old core versus fresh core)
Humidity Cell Tests: Example Results

pH plotted as a function of time (days)

- Immediately acidic
- Initially pH-neutral, tending toward acidic pH with time
- pH-neutral for duration of tests
Humidity Cell Tests: Rocks

Site-Specific Criterion for PAG rock

Pebble site-specific NP/AP criteria: 1.6
Equivalent for pre-T and T rock
Humidity Cell Tests: Rocks
Release Rates Compared to Composition - Sulfate

Relationship independent of rock type, leachate pH

Only pre-T data shown
Humidity Cell Tests: Rocks
Timing of Onset to Acid Conditions

- HCT testing (laboratory conditions):

<table>
<thead>
<tr>
<th>NP/AP</th>
<th>Time to acid onset</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.1</td>
<td>&lt; 2 years</td>
</tr>
<tr>
<td>0.1 to 0.3</td>
<td>3 to 10 year</td>
</tr>
<tr>
<td>1.0</td>
<td>&gt; 20 years</td>
</tr>
</tbody>
</table>

- Consistent with core aging effects (site conditions)
Humidity Cell Tests: Rocks
Controls on Metal Release

Main control, leachate pH, higher release at acid pH

Potential for release linked to PAG materials

Oxyanions: (As, Mo, Se) - significant release at neutral pH
Field Weathering Tests
Field Weathering Tests

- To evaluate leaching behavior under field conditions
- Comparison with laboratory conditions
- Focus on Tertiary and West Zone Pre-Tertiary.
Field Weathering Tests: Example Results

Note that figure shows data collected over the period 2007 to 2011 (EBD document includes data available to end of 2009)

- ARLB001 (PWZ, mudstone, Y)
- ARLB002 (PWZ, mudstone, Y)
- ARLB003 (PWZ, intrusive, mixed G/D/N)
- ARLB006 (PWZ, intrusive, mixed G/D/N)
Field Weathering Tests: Summary of Data from 2007 to 2011

<table>
<thead>
<tr>
<th>Barrel #</th>
<th>Rock Type</th>
<th>Zone</th>
<th>pH</th>
<th>SO₄</th>
<th>As</th>
<th>Mo</th>
<th>Se</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>B03</td>
<td>G/D/N</td>
<td>West</td>
<td>7.67</td>
<td>1418</td>
<td>0.0009</td>
<td>0.03</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>B06</td>
<td>G/D/N</td>
<td>West</td>
<td>7.55</td>
<td>764</td>
<td>0.002</td>
<td>0.1</td>
<td>0.2</td>
<td>2.8</td>
</tr>
<tr>
<td>B01</td>
<td>Y</td>
<td>West</td>
<td>4.38</td>
<td>566</td>
<td>0.0004</td>
<td>0.0001</td>
<td>0.06</td>
<td>10.1</td>
</tr>
<tr>
<td>B02</td>
<td>Y</td>
<td>West</td>
<td>4.50</td>
<td>769</td>
<td>0.0005</td>
<td>0.00006</td>
<td>0.03</td>
<td>13.0</td>
</tr>
<tr>
<td>B10</td>
<td>TA+TB</td>
<td>East</td>
<td>7.85</td>
<td>33</td>
<td>0.001</td>
<td>0.05</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>B09</td>
<td>TD</td>
<td>East+West</td>
<td>7.85</td>
<td>12</td>
<td>0.001</td>
<td>0.05</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>B07</td>
<td>TC/TF</td>
<td>West</td>
<td>8.46</td>
<td>827</td>
<td>0.0006</td>
<td>0.02</td>
<td>0.01</td>
<td>0.002</td>
</tr>
<tr>
<td>B08</td>
<td>TC/TF</td>
<td>West</td>
<td>8.50</td>
<td>329</td>
<td>0.0005</td>
<td>0.1</td>
<td>0.03</td>
<td>0.001</td>
</tr>
<tr>
<td>B04</td>
<td>TW</td>
<td>East+West</td>
<td>8.48</td>
<td>315</td>
<td>0.004</td>
<td>0.2</td>
<td>0.1</td>
<td>0.004</td>
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<tr>
<td>B05</td>
<td>TY</td>
<td>East+West</td>
<td>7.87</td>
<td>661</td>
<td>0.007</td>
<td>0.1</td>
<td>0.1</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Average concentration, mg/L

Note that calculations are based on data to 2011 (EBD document based on data to 2009)

Highest Cu, coincident with acid pH
Field Tests: Observations

Two barrels have acidic leachate

- Barrels #1 and #2 – Pre-T sedimentary rock.
- Similar result in lab tests.

Broadly similar leachate chemistry for field and lab tests

- As, Mo, Se associated with leaching of Pre-Tertiary and Tertiary.
- Higher metals (e.g. Cu) associated with Pre-T materials.
REACTION RATES FOR SUBMERGED ROCK
Reactions Underwater: Study Design

Mine Feature

PAG waste rock

Rock exposed underground

Pit walls

Immediate storage underwater

Test Strategy

Subaqueous column using ‘fresh’ rock

Weathering and oxidation while rock exposed

Bagged weathering tests

Later submergence following flooding

Subaqueous column using ‘weathered’ rock
Shake flask extraction tests as a function of time:

- Some tests indicate production of acidic reaction products in the stored bags
- Coincident increase in soluble sulfate

Note that EBD document gives data to Week 4 (data available in 2009). Figures above show data for subsequent extraction tests in 2010 and 2011.
Underwater Reaction Rates Subaqueous Columns
To estimate reaction rates under saturated conditions

Samples selected to cover range of:

- Rock types
- Sulfur contents

![Bar chart showing number of tests for different materials (PEZ and PWZ) for subaqueous column tests. Total of 8 tests, 5 complete, 3 ongoing.]
Subaqueous Columns: Design Aspects

Bagged Weathering Test

- Stored in moist, aerobic conditions
- Aeration holes to ensure O\textsubscript{2} and H\textsubscript{2}O availability

Shake Flask Extraction Test

- To quantify readily soluble salts

Periodic removal of sub-samples

As accumulation of salts decreases

Subaqueous Columns
Subaqueous Columns: Outcomes Fresh PAG Rock Tests

- 2 samples acidic when submerged.
- Higher Cu leaching with acid leachate.
- 1 sample showed higher As leaching (first 2 years), pH neutral leachate.
- As leaching increasing with time, pH decreasing.
- Only PWZ tests shown.
GEOCHEMICAL CHARACTERIZATION OF BULK TAILINGS
ABA (Bulk Tailings)

Non-PAG tails low S tailings have been produced.
Kinetic Test Methods: Tailings

Humidity Cell Tests

Leach Columns

20 tests (9 complete, 11 ongoing)

Number of tests

Test Method

Humidity Cells

Columns

PEZ

PWZ
Humidity Cell Tests: Tailings

- Oxidation rates related to S content and particle size.
- To-date, no acidic leachates
Leach Columns: Outcomes

pH has remained near-neutral for duration of tests

Sulfate release towards low end of range shown by humidity cell tests

SO₄
mg/kg/week

S2-Scavenger Tails 3.57
S1-Scavenger Tails 2.94
Summary

• Waste rock
  • Large database of static test data have demonstrated distinctive characteristics of waste rock type.
  • Kinetic test data are suitable for input into waste rock management planning and water quality predictions.
  • Comparative data from field tests allow lab test data to be linked to field conditions.

• Tailings
  • Testing of simulated tailings indicates low ARD potential of bulk tailings.