Predicting Water Quality from the Reflooded Mine at the Crandon Project

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LOCATION
LOCATION

Regional Groundwater Flow

Soil Absorption System

TMA

Compliance Boundary

Mine
SOURCE TERM COMPONENTS

- Pyritic Paste Backfill
- Wall Rock in Access Workings
- Crown Pillar
- Combustion By-Products and Blasting Residues
APPROACH

- Best Engineering Judgment (BEJ)
- Upper Bound (UB)
  
  Waste characterization program and mine plan

- Sensitivity Analyses
PYRITIC PASTE BACKFILL – BLASTHOLE STOPES
PYRITIC PASTE BACKFILL – BLASTHOLE STOPES
PYRITIC PASTE BACKFILL – CUT AND FILL STOPES
PYRITIC PASTE BACKFILL COMPONENTS

- Oxidized Neutral Backfill
- Acidic Backfill
- Unoxidized Backfill
- Oxidized Neutral Backfill
ACIDIC BACKFILL

Estimate $O_2$ flux into backfilled stopes

Convert $O_2$ flux into volume of acidic tailings

Estimate water quality in acidic backfill
ACIDIC BACKFILL

BEJ Oxygen Transport

Assumption: Rate limiting step is diffusion into backfill

$O_2$ flux from results of column tests with pyritic paste backfill cubes
ACIDIC BACKFILL

UB Oxygen Transport

Assumption: Rate limiting step is diffusion through waste rock

Fick’s Law → \( O_2 \text{ Flux} = D \frac{dC}{dx} = D \frac{C_0}{L} \)
OXIDIZED NEUTRAL BACKFILL

Humidity cell test on (cemented) pyritic paste backfill
Remains neutral after 65 weeks

Rates of solute release from short term tests
BEJ $\rightarrow$ first five weeks
UB $\rightarrow$ all twenty weeks
UNOXIDIZED BACKFILL

Saturated column test on (cemented) pyritic paste backfill
Initial estimates of solute concentrations

Check equilibria with MINTEQA2
pH 11 and Eh –50 mV

Solubility controls on Ca, SO₄, Ni, Pb, Ba, Fe
AVERAGE SOLUTE CONCENTRATIONS IN BACKFILL

\[ C_{\text{overall}} = \frac{C_{\text{acidic}} \cdot V_{\text{acidic}} + C_{\text{ox-neut}} \cdot V_{\text{ox-neut}} + C_{\text{unox}} \cdot V_{\text{unox}}}{V_{\text{acidic}} + V_{\text{ox-neut}} + V_{\text{unox}}} \]
BEJ CONCENTRATIONS IN BACKFILL

<table>
<thead>
<tr>
<th></th>
<th>Volume</th>
<th>SO₄</th>
<th>As</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic</td>
<td>6.0x10²</td>
<td>164,000</td>
<td>650</td>
<td>59,800</td>
<td>9300</td>
</tr>
<tr>
<td>Oxid/Neutral</td>
<td>4.7x10⁵</td>
<td>2147</td>
<td>0.24</td>
<td>0.29</td>
<td>0.54</td>
</tr>
<tr>
<td>Unoxidized</td>
<td>2.1x10⁸</td>
<td>1250</td>
<td>0.0053</td>
<td>0.008</td>
<td>0.042</td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>1252</td>
<td>0.0076</td>
<td>0.18</td>
<td>0.070</td>
</tr>
</tbody>
</table>
### UB Concentrations in Backfill

<table>
<thead>
<tr>
<th>Volume</th>
<th>SO$_4$</th>
<th>As</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic</td>
<td>1.7x10$^5$</td>
<td>169,500</td>
<td>650</td>
<td>59,800</td>
</tr>
<tr>
<td>Oxid/Neutral</td>
<td>4.7x10$^5$</td>
<td>2659</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Unoxidized</td>
<td>2.1x10$^8$</td>
<td>1317</td>
<td>0.0053</td>
<td>0.037</td>
</tr>
<tr>
<td>Average</td>
<td>-</td>
<td>1451</td>
<td>0.52</td>
<td>47</td>
</tr>
</tbody>
</table>
SOURCE TERM COMPONENTS

- Pyritic Paste Backfill
- Wall Rock in Access Workings
- Crown Pillar
- Combustion By-Products and Blasting Residues
WALL ROCK

Hanging Wall Workings

- Master Composite Samples
- 1994-95 Waste rock column tests

- 2 shafts + vent raise
- Ramp, drifts, crosscuts
- Maintenance area
- Skunk Lake
- Rice Lake
- Upper Mole Lake
- Lower Mole Lake
WALL ROCK

Solute Release (mg)

= \Sigma \text{Specific release (mg ft}^{-2}\text{ yr}^{-1}) \times \text{Surface area (ft}^2\text{)} \times \text{Time (yr)}

- Waste rock column tests
- Mine plan
  - 30x
- 4 - 30 years

Skunk, Rice, Upper Mole, Lower Mole
Solute release divided by workings volume to give initial concentration.

Then checked solubility constraints with MINTEQA2

**Estimated Concentrations**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>$\text{SO}_4$</td>
<td>16 mg/L</td>
</tr>
<tr>
<td>As</td>
<td>0.023 mg/L</td>
</tr>
<tr>
<td>Fe</td>
<td>1.1 mg/L</td>
</tr>
<tr>
<td>Zn</td>
<td>0.049 mg/L</td>
</tr>
</tbody>
</table>
SOURCE TERM COMPONENTS

- Pyritic Paste Backfill
- Wall Rock in Access Workings
- Crown Pillar
- Combustion By-Products and Blasting Residues
CROWN PILLAR

10^{-7} \text{ mol O}_2/\text{m}^2/\text{s} \text{ from O}_2 \text{ diffusion}

10^{-9} \text{ mol O}_2/\text{m}^2/\text{s} \text{ from infiltrating water}

10^{-5} \text{ mol O}_2/\text{m}^2/\text{s} \text{ from ventilation air in stopes}
CROWN PILLAR

Solute Concentrations

Method same as wall rock, back of top stope only

Specific release rates calculated from humidity columns on high grade Zn ore

Estimated Concentrations

SO$_4$ 8.2 mg/L
As 0.00036 mg/L
Fe 0.024 mg/L
Zn 1.4 mg/L
SOURCE TERM COMPONENTS

- Pyritic Paste Backfill
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- Crown Pillar
- Combustion By-Products and Blasting Residues
COMBUSTION BY-PRODUCTS AND BLASTING RESIDUE

Natural Gas (heating) → Insignificant
Fuel Oil (equipment)

Blasting Residues → Mill Balance
## VOLUME WEIGHTED CONCENTRATIONS - BEJ

<table>
<thead>
<tr>
<th>Material</th>
<th>SO₄</th>
<th>As</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paste Backfill</td>
<td>1,252</td>
<td>0.0076</td>
<td>0.18</td>
<td>0.070</td>
</tr>
<tr>
<td>Wall Rock</td>
<td>16</td>
<td>0.023</td>
<td>1.1</td>
<td>0.049</td>
</tr>
<tr>
<td>Crown Pillar</td>
<td>8.2</td>
<td>0.00036</td>
<td>0.024</td>
<td>1.4</td>
</tr>
<tr>
<td>Average</td>
<td>1,145</td>
<td>0.0088</td>
<td>0.25</td>
<td>0.073</td>
</tr>
<tr>
<td>Material</td>
<td>SO$_4$</td>
<td>As</td>
<td>Fe</td>
<td>Zn</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Paste Backfill</td>
<td>1,451</td>
<td>0.52</td>
<td>47</td>
<td>7.3</td>
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<tr>
<td>Wall Rock</td>
<td>21</td>
<td>0.026</td>
<td>3.8</td>
<td>0.065</td>
</tr>
<tr>
<td>Crown Pillar</td>
<td>17</td>
<td>0.00048</td>
<td>0.30</td>
<td>5.2</td>
</tr>
<tr>
<td>Average</td>
<td>1,327</td>
<td>0.47</td>
<td>43</td>
<td>6.7</td>
</tr>
</tbody>
</table>
SENSITIVITY ANALYSES

- Number of stopes
- Surface area of exposed backfill (x-cut)
- Exposure time
- Pyritic paste backfill NP
- Wall rock surface area
- Early shutdown
- 100 runs of solute/groundwater model
SENSITIVITY ANALYSIS

- **BEJ Estimates**: insensitive
- **UB Estimates**: sensitive to acidic backfill volume
WHAT DOES IT MEAN?

- We have a problem...
  - Acidic backfill for metals
  - Rest of the backfill for sulphate
  - Wall rock a possible problem

- Solution?
  - Limit acidification of the backfill
SENSITIVITY ANALYSIS

- Oxygen barriers
  (90% - 99.99% effective)
- Direct removal of acidic backfill
- Cleaning wall rock surfaces
  (50% - 90% solute removal)

...can achieve significant reductions...
OTHER OPTIONS

Limiting $SO_4$ in unoxidized backfill:
use gypsum-free cement
wash the backfill
use Ba to precipitate $SO_4$

No proven methods
RFLOODED MINE MANAGEMENT PLAN

- Implementation of O$_2$ barriers
- Testing & removal of acidic backfill
- Wash mine workings
- Passive hydraulic control
- Monitoring
- Contingencies
  - High volume flushing
  - Hydraulic containment
REFLOODED MINE MANAGEMENT PLAN

- Continual evaluation of emerging technologies
- Existing plan is a work in progress