Evaluation of Mine Water Treatment by Monitored Natural Attenuation at the Troy Mine, NW Montana

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Why Care About Natural Attenuation of Metals

• It happens and it works!

• It can be an effective and economical part of a mine water management plan
What Is Natural Attenuation

• Reduction of metal concentrations in water by “natural” mechanisms:
  – Mineral precipitation
  – Adsorption

• In “natural” settings:
  – Soils and sediments
  – Groundwater
Troy Mine Natural Attenuation = Completion of Mineral Weathering Cycle

- Ore sulfide minerals (chalcolite, bornite, digenite) weather to release Cu ions to mine water (50 – 100 ppb)....

- Cu reacts with other ions in water to form more stable, low solubility copper minerals (carbonates, oxides, silicates) ...

- Which precipitate in sediments at the disposal site resulting in mine water/groundwater with low Cu concentration (5 ppb)
Monitored Natural Attenuation

It’s Science!  

not Magic!
Monitored Natural Attenuation

Science:

1. Need to understand attenuation mechanisms
2. Factors controlling mechanisms
3. Conditions that might reduce attenuation effectiveness
Monitored Natural Attenuation

It’s Management!

Not “Set it and forget it”
Monitored Natural Attenuation Management:
1. Monitoring
2. Maintenance
3. Mitigation

Not really “passive”
6,500 TPD; 0.75% Cu

Sediment-hosted stratiform Cu (chalcocite/digenite, bornite, native silver)
• Mine operated by Asarco from 1981 - 1993
• Troy Returned to production in late 2004
• 2009 production was 1.1M oz Ag and 8.6M lbs Cu
• 2010 production guidance: 1.1M oz Ag and 9.2M lb Cu
Interim Closure in 1993

Challenge:

• 1,000 gpm mine water w/ 50-100 ppb Cu

• Too much flow & too much Cu for discharge at mine site
Interim Closure in 1993

Interim plan:

• Allow partial mine flood

• Pump and pipe mine water to tailing impoundment for irrigation/dust control use

• Excess water allowed to pond on surface and infiltrate through decant pond
Revisions to Final Closure Plan
Began in 2000

• Observed copper goes in decant ponds but is not found in groundwater
• Looks like natural attenuation?
• Is it real?
• Need framework to prove it’s happening, understand why and how it’s happening, and plan to manage it.

1. Demonstration of active contaminant removal from ground water;

2. Determination of the mechanism(s) and rate of attenuation;

3. Determination of the long-term capacity for attenuation and stability of immobilized contaminants;

4. Design of performance monitoring program.
Step 1 - Evidence for Active Contaminant Removal:

1. Comparison of copper with conservative “tracer” elements (i.e., nitrate from blasting) demonstrates that mine water is traveling to wells but Cu is not

2. Analysis of pond sediments demonstrates enrichment in Cu – some sediments have 3x more Cu than ore!
Total Copper and Iron Content in Decant Pond Sediment

- Total Copper (mg/kg)
  - DP-1 Native Sand
  - DP-1 4” organic
  - DP-1 4”

- Total Iron (mg/kg)
  - Algae
  - Tailings

- Units: mg/kg
- Range: 0 to 25000

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Step 2 - Demonstration of Mechanisms of Removal:

Mineralogical and Geochemical Analyses:

• Optical Microscopic evaluation
• SEM and microprobe analysis
• Whole rock analysis
• Sequential extraction analysis
SEM images of copper carbonates and silicates

AKA the pretty blue and green stuff
SEM images of CuFe & CuMn silicates; CuFe oxides

AKA the brown stuff
Copper Sequential Extraction Fractions in Decant Pond Sediments

- Water Soluble
- Exchangeable Ions & Carbonate
- Manganese & Copper Oxides
- Organic Matter & Sulfides
- Amorphous Iron
- Silicates and Resistant Phases

Percent of Total Copper

DP-1 0-1”, DP-1 3 ¾”, DP-1 4”, DP-1 4” organic
## Summary of Attenuation Mechanisms

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonate Mineral Formation (malachite)</td>
<td>Sequential extraction</td>
</tr>
<tr>
<td></td>
<td>Visual identification</td>
</tr>
<tr>
<td></td>
<td>Electron microprobe analysis</td>
</tr>
<tr>
<td>Silicate Mineral Formation</td>
<td>Sequential extraction</td>
</tr>
<tr>
<td>(chrysocolla and CuMn silicate=Mn-rich hisingerite?)</td>
<td>Visual identification</td>
</tr>
<tr>
<td></td>
<td>Electron microprobe analysis</td>
</tr>
<tr>
<td>Oxide Mineral Formation and Co-precipitation with Iron oxides (tenorite, delafossite? copper ferrite?)</td>
<td>Sequential extraction</td>
</tr>
<tr>
<td></td>
<td>Visual identification</td>
</tr>
<tr>
<td></td>
<td>Electron microprobe analysis</td>
</tr>
<tr>
<td>Ion Exchange/Adsorption</td>
<td>Sequential extraction</td>
</tr>
<tr>
<td>Organic Matter (Adsorption)</td>
<td>Sequential extraction</td>
</tr>
<tr>
<td></td>
<td>Whole rock analyses</td>
</tr>
</tbody>
</table>
Step 3 - Long-term Capacity of Attenuation and Stability of Immobilized Contaminants

Copper Mineral Formation

• Are there limiting conditions?
• Are there limiting chemical reactants?
Mineral Formation Evaluated by Geochemical Equilibrium Modeling

1. Determine the geochemical conditions in water (redox, activities, saturation indices etc)

2. Identify the geochemical controls on copper mineral formation

3. Identify the potential geochemical changes that could impede or preclude copper mineral formation and identify potential mitigation methods.

4. Provide format for communication of conclusions
## Copper Phases Evaluated

<table>
<thead>
<tr>
<th></th>
<th>Field Evidence</th>
<th>Model Predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu carbonate</td>
<td>malachite</td>
<td>malachite</td>
</tr>
<tr>
<td>Cu oxide &amp; CuFe oxides</td>
<td>delafossite?</td>
<td>delafossite, tenorite, Cu ferrite</td>
</tr>
<tr>
<td>Cu silicate</td>
<td>chrysocolla?</td>
<td>dioptase</td>
</tr>
<tr>
<td>CuMn silicate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cu activity $= 10^{-6} = 0.08$ ppm

Cu-O system

Cu activity $= 10^{-7.5} = 0.006$ ppm
Cu activity $= 10^{-6} = 0.08$ ppm

Cu-Fe-O system

Cu activity $= 10^{-7.5} = 0.006$ ppm
Cu activity $= 10^{-6} = 0.08$ ppm

Cu-O-CO$_3$ system

Cu activity $= 10^{-7.5} = 0.006$ ppm
Cu activity $= 10^{-6} = 0.08$ ppm

Cu-SiO$_2$ system
(dioptase suppressed)

Cu activity $= 10^{-7.5} = 0.006$ ppm
## Summary of Mineral Formation

<table>
<thead>
<tr>
<th>Required Conditions</th>
<th>Limiting Factor?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral/alkaline pH;</td>
<td>No, mine water expected to be neutral in perpetuity</td>
</tr>
<tr>
<td>Oxidizing redox conditions</td>
<td>No, abundant oxygen</td>
</tr>
<tr>
<td>Moderate amounts of silica (8 – 12 ppm)</td>
<td>No, abundant silica in tails</td>
</tr>
<tr>
<td>Moderate amounts of Bicarbonate (100 ppm)</td>
<td>No, abundant atmospheric CO₂, carbonate in mine and tails</td>
</tr>
</tbody>
</table>
### Step 4 - Performance Monitoring and Maintenance Program

<table>
<thead>
<tr>
<th>Required Conditions</th>
<th>Maintenance</th>
<th>Contingency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral/alkaline pH;</td>
<td>Monitor</td>
<td>Alkaline addition</td>
</tr>
<tr>
<td>Oxidizing redox conditions</td>
<td>Monitor &amp; prevent over buildup of organic matter in pond</td>
<td>Aeration, dredge ponds</td>
</tr>
<tr>
<td>Moderate amounts of silica</td>
<td>Monitor</td>
<td>Increase contact with tailings</td>
</tr>
<tr>
<td>Moderate amounts of bicarbonate</td>
<td>Monitor</td>
<td>Alkaline addition</td>
</tr>
</tbody>
</table>
Step 5 - Regulatory Approval

Ongoing NEPA review and pending Agency approval …
Keys to Using Natural Attenuation for Treatment at Troy Mine

Good rock! So …

• Very good mine water quality initially – neutral pH, low metals
• Tailings do not negatively affect water quality
Keys to Using Natural Attenuation for Treatment at Troy Mine

Time …

1. For reactions to happen: in mine pool, in pipeline, running across tails, north cell pond, decant pond, percolation to groundwater

2. Interim closure: allowed full-scale proof and evaluation
Thermodynamics wins . . .

Chemical equilibrium may be achieved (or close enough) . . .

In the right conditions . . .

If you have enough time . . .
Questions?
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Percent of Total Copper

- Water Soluble
- Exchangeable Ions & Carbonate
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- Organic Matter & Sulfides
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- Silicates and Resistant Phases

Legend:
- DP-1 0-1"
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