Metal Sulfide Mining

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Metal Sulfide Mining

- What is a Sulfide Mine?
- What is Acid Mine Drainage (AMD)
- What are the Risks of AMD?
- How “Sure” are Financial Sureties for Sulfide Mines?
- Example – NorthMet Project
Metal Sulfide Mining

**Metals Mined as Oxides**
- Iron (Hematite - Fe$_2$O$_3$, Magnetite Fe$_3$O$_4$), Magnesium, Titanium, Tin, Aluminum

**Base Metals Mined as Sulfides**
- Copper (Bornite - Cu$_5$FeS$_4$), Lead, Zinc, Molybdenum, Nickel

**Precious Metals Mined with Sulfides**
- Gold, Silver, Platinum
Typical Copper Sulfide Deposit

- 3% – 5% sulfide minerals
- 0.5% - 1.0% copper sulfides
- Iron Pyrite (FeS$_2$) – most common sulfide mineral

Nickel Sulfide Deposits

- Voisey’s Bay – ore 15% Ni sulfide, 10% Cu sulfide, 70% FeS
- NorthMet – ore 0.24% Ni sulfide, 0.70% Cu sulfide, 0.58% FeS
Acid Mine Drainage

\[
\text{AMD} = \frac{\text{Sulfide Minerals}}{\text{Metal Ion + Sulfur}} + \text{Oxygen} + \text{Water}
\]

Pyrite + Oxygen + Water = Sulfuric Acid + Ferric Hydroxide (orange)

\[
\text{FeS}_2 + \text{O}_2 + \text{H}_2\text{O} = \text{H}_2\text{SO}_4 + \text{Fe(OH)}_3
\]
# Acid Mine Drainage

## Metals of Concern

<table>
<thead>
<tr>
<th>Acid pH Metals</th>
<th>Neutral pH Metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>Cobalt</td>
</tr>
<tr>
<td>Lead</td>
<td>Uranium</td>
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<tr>
<td>Mercury</td>
<td>Zinc</td>
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<tr>
<td>Cadmium</td>
<td>Nickel</td>
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<tr>
<td>Aluminum</td>
<td>Molybdenum</td>
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<tr>
<td>Silver</td>
<td>Arsenic</td>
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<td></td>
<td>Selenium</td>
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<td></td>
<td>Antimony</td>
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<tr>
<td></td>
<td>Thallium</td>
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</tbody>
</table>
Mike Horse Mine, Montana
Dangers of Acid Mine Drainage

**People**
- Mercury (2 ppb)
- Lead (15 ppb)
- Arsenic (10 ppb)
- + more

**Aquatic Organisms**
(Fish / Insects / Plants)
- Cadmium (0.25 ppb)
- Mercury (0.77 ppb)
- Lead (2.5 ppb)
- Selenium (5 ppb)
- Copper (9 ppb)
- Nickel (52 ppb)
- Zinc (120 ppb)
- + more

1 part per billion ↔ 1 gallon of oil / 23.8 million barrels of oil (42 gallons/barrel)
Predicting Acid Mine Drainage

**Acid-Producing Minerals**
- Pyrite (FeS₂)
- Pyrrhotite (FeS)

**Acid-Neutralizing Minerals**
- Calcium & Magnesium Carbonates
  - Calcite – CaCO₃
  - Dolomite – CaMg(CO₃)₂

*Minor contributors*
- Plagioclase Feldspar
- Biotite
- Chlorite
- Amphibole
- Olivine
Prediction Complications

- Rate of Dissolution
  (carbonates dissolve >> sulfides oxidize)
- Physical Isolation
  (carbonates coated with iron hydroxide)
- Biologic Acceleration
  (Thiobacillus Ferroxidans)
- Metals Leaching (neutral and high pH)
  (arsenic, selenium, antimony, thallium)
Kuipers-Maest Study Results:

- 100 percent of mines predicted compliance with water quality standards before operations began.
- 76 percent of mines studied in detail exceeded water quality standards due to mining activity.
Kuipers-Maest Study Results:

- Mitigation measures predicted to prevent water quality exceedances failed at 64 percent of the mines studied in detail.

- 85% of the mines near surface water with elevated potential for acid drainage or contaminant leaching exceeded water quality standards.
Kuipers-Maest Study Results:

- 93% of the mines near groundwater with elevated potential for acid drainage or contaminant leaching exceeded water quality standards.

- Of the sites that did develop acid drainage, 89% predicted that they would not.
Financial Surety for Mine Closure

Major Issues with Financial Sureties

- Realistic Costs must be used to establish the amount of the surety
- The Surety must be in form that is redeemable and readily available
Alaska Surety Case Study

Alaska Large Mine Reclamation Bonding – 2005,
Center for Science in Public Participation, 2006

- Reclamation sureties were underestimated by 43% (average of $11 million)
- One Alaska mine bankruptcy (Illinois Creek, USMX/Dakota Mining) was underfunded
State and Federal Agencies should hire a professional consulting firm to calculate mine reclamation costs.

- Mines that require water treatment in perpetuity should not be permitted.
NorthMet Project

- Duluth Complex – “copper and nickel sulphides -- disseminated pyrrhotite and chalcopyrite in a coarse plagioclase gabbro”

- ore 0.24% Ni sulfide, 0.70% Cu sulfide, 0.58% FeS

- waste rock averages 0.08% S (sulfur), can have up to 6% S content
Waste Rock Seepage

Potential Issues:
- Seepage water quality
- Long term effectiveness of Cover & Liner
Tailings Seepage

Potential Issues:
- Seepage water quality
- Dam stability under seismic loading
Present discharge exceeds water quality standards for bicarbonates, hardness, conductivity, and iron. (RS55T, p. iv.) New floatation tailings are not projected to be “non reactive” but the contamination in the seepage from the new floatation tailings will likely be worse than that in the present discharges.
ISSUES

- Will there be AMD/Metals Leaching at NorthMet? Yes, there is some risk.
- How much risk are you willing to accept?
- Less Risk $\rightarrow$ Higher Mining Costs