Cold Temperature Effects on Geochemical Weathering

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and
Mehling Environmental Management
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  – Mehling Environmental Management – Peri Mehling, Shannon Shaw
  – Ulrike Kestler – Library services.
Outline

• Project Background
• Availability of Data
• Discussion of Low Temperature Effects.
• Technology Gaps.
• Conclusions and a Request........
Project Background

• “Update on Cold Temperature Effects on Geochemical Weathering”
  – Previous studies
  • MEND Project 6.1, Geocon 1993. Disposal of tailings in permafrost
  • MEND Project 1.61.2. Dawson and Morin 1996. Thorough review of the state of knowledge of ARD in low temperature environments.
  • MEND Project 1.61.1. CANMET 1996.
Project Background

• “Update on Cold Temperature Effects on Geochemical Weathering”
  – Broaden investigation to geochemical effects at low temperatures.
Project Background

- Geo(chemical) Effects
  - Oxidation rates of iron sulphide minerals.
  - Oxidation of other sulphide minerals.
  - Activity of different types of bacteria.
  - Solubility and reactivity of acid buffering minerals including carbonates and silicates.
Project Background

• Geo(chemical) Effects
  – Formation and solubility of secondary minerals (weathering products).
  – Freeze concentration.
  – Physical exposure of minerals due to freeze-thaw processes.
  – Solubility of oxygen in waters used to flood reactive wastes
Methods

• Literature search and review.
• SRK and MEM files.
• Contact with other practitioners.
• Compilation of case studies.
• Evaluation of mechanisms.
Literature Search

• Primary and spinoff papers - 44

• Criteria
  – Sites providing direct comparative information on the effect of temperatures (8 found).
  – Other sites showing geochemical processes operating at low temperature conditions (numerous).
Sites

• Canada
  – Cullaton Lake (NT), Ekati Diamond Mine (NT), Diavik Diamond Mine (NT), Keno Hill (YT), Rankin Inlet Mine (NU), Ulu Project (NU), Windy Craggy (BC).

• US
  – Pogo Mine (AK), Red Dog Mine (AK), Urad Mine (CO).

• Others
  – Citronen Fjord (Norway), Black Angel (Greenland), N Kolyma Lowland (Russia), Stekenjokk (Norway).
Results – Oxidation of Iron Sulphides

• Effect of temperature described by Arrhenius Equation

\[ k = Ae^{-\frac{E_a}{RT}} \]

\[ \ln\left(\frac{k_1}{k_2}\right) = \frac{E_a(T_1 - T_2)}{RT_1T_2} \]

– \( k_1 \) and \( k_2 \) reaction rates at temperatures \( T_1 \) and \( T_2 \) (in Kelvin)
– \( E_a \) - activation energy
– \( R \) - gas constant.
Results – Oxidation of Iron Sulphides

![Graph showing the reaction rate relative to 20°C as a function of temperature. The graph includes data points at 50°C and 60°C.](image-url)
## Results – Oxidation of Sulphides

<table>
<thead>
<tr>
<th>Site</th>
<th>Tests</th>
<th>Mineral</th>
<th>( \frac{k_4}{k_{20}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated</td>
<td></td>
<td>po, py</td>
<td>0.24 to 0.31</td>
</tr>
<tr>
<td>Diavik</td>
<td>4</td>
<td>po</td>
<td>0.3 to 0.4</td>
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<tr>
<td>Ekati</td>
<td>2</td>
<td>py</td>
<td>0.26</td>
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<td>Pogo</td>
<td>4</td>
<td>aspy, py</td>
<td>0.29 to 0.8</td>
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<tr>
<td>Red Dog Mine</td>
<td>4</td>
<td>py, py</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td>0.37, 0.40</td>
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<td>0.11</td>
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<tr>
<td></td>
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<tr>
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<tr>
<td>Windy Craggy</td>
<td>11</td>
<td>po, py</td>
<td>0.34 to 0.67</td>
</tr>
</tbody>
</table>
Oxidation of Other Sulphides

• Variable $E_a$’s indicate range of temperature effects
  – eg weak effect of $T$ on arsenopyrite
• Laboratory data confusing due to compounding $T$ effects and secondary mineral formation.
• Possible accelerated leaching of zinc under low temperatures.
Results - Bacterial Activity

• Demonstrated activity of bacteria at sub-zero conditions.
  – Present at very low temperatures (-30°C) but activity very low.
• Bacteria adapt to conditions.
Results – Acid Buffering Minerals

• Solubility of CO2 in water increases as temperature decreases
  – Lowers pH and increases solubility of carbonate minerals.
  – May also affect weathering of silicate minerals.
Results – Acid Buffering Minerals

![Graph showing the relationship between temperature and calcium concentration (Ca) and pH of carbonic acid for Calcite and Dolomite.](image-url)

- **Calcite**:
  - Calcium concentration decreases with increasing temperature.
  - pH of carbonic acid increases with increasing temperature.

- **Dolomite**:
  - Calcium concentration decreases with increasing temperature.
  - pH of carbonic acid increases with increasing temperature.

- **Carbonic Acid**:
  - Calcium concentration decreases with increasing temperature.
  - pH of carbonic acid increases with increasing temperature.
Results – Acid Buffering Minerals

• Implications
  – Increased delivery of dissolved alkalinity at low temperatures in rock mixtures.
  – Accelerated flushing of NP in small experiments.
  – Higher solubility of heavy metal carbonates (eg Zn).
Results – Freeze Concentration

• Increase in concentration
  – Solubility limits operate to limit freeze concentration effects (eg gypsum).
  – High solubility of MgSO4 results in high TDS.

• Freezing Point Depression
  – Build up of solutes particularly in the absence of solubility control allows water to remain liquid.
Results – Solubility of Oxygen in Water Increases

• Limited evaluation

• DO increases by a factor of 1.4 as T decreases from 15°C to 0°C.

• Elberling (2001) notes that oxygen diffusivity decreases by greater factor.
  – Therefore, water covers potentially **more effective** at low temperatures.
Technology Gaps

• Characterization methods
  – Possible need for specific leach and kinetic (lab and field) tests to address low temperatures.
Technology Gaps

• Predictions
  – Growing and consistent database of kinetic test data for T effects…..
  – …..but limited rigorous data on effects for different sulfide minerals
  – Little specific information on weathering of buffering minerals in short (non-geological) time frame.
  – Solubility of weathering products at low T.
Technology Gaps

• Geochemical design criteria for wastes at low temperatures.
  – Defining “low reactivity” at low temperatures.
  – Effectiveness of covers (parallel MEND project).
  – Effectiveness of water covers.
  – Behaviour of waste rock mixtures.
  – Low T behaviour.
Conclusions

• Compilation of information continues.

• Anyone willing to contribute low T case study data is invited to contact SRK or MEM:
  – Stephen Day – sday@srk.com
  – Peri Mehling – pemehling@mehlingenvironmental.com