Geochemical study of sulfidic mine tailings stored under a shallow water cover

Bernard Vigneault, Peter G.C. Campbell, et André Tessier
Acid Mine Drainage

**Pyrite Oxidation:**

\[
\text{FeS}_2 + \frac{7}{2} \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + 2 \text{SO}_4^{2-} + 2 \text{H}^+ \quad (1)
\]

\[
\text{Fe}^{2+} + \frac{1}{4} \text{O}_2 + \text{H}^+ \rightarrow \text{Fe}^{3+} + \frac{1}{2} \text{H}_2\text{O} \quad (2)
\]

\[
\text{Fe}^{3+} + 3 \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3(s) + 3\text{H}^+ \quad (3)
\]

\[
\text{FeS}_2 + 7 \text{Fe}_2(\text{SO}_4)_3 + 8 \text{H}_2\text{O} \rightarrow 15 \text{FeSO}_4 + 8 \text{H}_2\text{SO}_4 \quad (4)
\]

- Major pyrite oxidants: \( \text{O}_2 \) et \( \text{Fe}^{3+} \)

- \( \text{Fe(II)} \rightarrow \text{Fe(III)} \) (2), limiting step, catalysed by micro-organisms such as *Thiobacillus ferrooxidans*
Acid mine drainage prevention:

Physical barrier such as a water cover

Underwater disposal
- reduced costs
- limited post-closure intervention required

Efficiency of an engineered shallow water cover?

- Erosion (resuspension, ice...)
- Periphyton
Sampling Site

- Located 20 km East of Val-D’Or (Québec)
- Base metals (Zn/Cu)
- Reactive mine tailings (humidity cell tests)
Sampling site

Experimental cells (1996):
- 21 m x 21 m
- 3 m of mine tailings
- 0.3 m water cover
Sampling site

Presented results
Electrochemical micro-profiles
- pH et O$_2$
- Micromanipulator

1 mm vertical resolution
Micro-profiles, O₂
Micro-profiles, pH

![Graphs showing micro-profiles for pH levels over different depths and dates: June 1997, Aug. 1998, June 1999, and June 1999 at night.](image-url)
Periphyton, oxic layer and anoxic layer
In situ dialysis
In situ dialysis

- Peepers

1 cm vertical resolution

Interstitial water analysis:

- pH
- $[\text{Cl}^-]$ et $[\text{SO}_4^{2-}]$
- $[\Sigma H_2S]$
- $[\text{Cu}], [\text{Cd}]$ et $[\text{Zn}]$
In situ dialysis, pH
In situ dialysis, pH

FeS₂ + 7 Fe₂(SO₄)₃ + 8 H₂O → 15 FeSO₄ + 8 H₂SO₄ (4)
In situ dialysis, chloride
In situ dialysis, sulfate
*In situ* dialysis, sulfide
In situ dialysis, iron and manganese

Oct. 1996  
Depth (cm)
Concentration (µM)
0.00 5.00 10.00
0.00 5.00 10.00
0.00 5.00 10.00
0.00 5.00 10.00

June 1997

Aug. 1998

Fe

Mn
In situ dialysis, copper
In situ dialysis, cadmium and zinc
Cadmium and zinc fluxes

Diffusion from the tailings to the overlying water

Highest observed flux (nmol · cm⁻² · s⁻¹)

<table>
<thead>
<tr>
<th>Element</th>
<th>Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>1 x 10⁻⁹</td>
</tr>
<tr>
<td>Zn</td>
<td>1.5 x 10⁻⁷</td>
</tr>
</tbody>
</table>

What will be the impact on overlying water quality?
Cadmium and zinc fluxes

For a hypothetical impoundment of 1.5 km², with a depth of 1 m and residence time of 1 year, Cd and Zn fluxes will have minor impacts on the overlying water quality:

<table>
<thead>
<tr>
<th></th>
<th>WQG†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nM (ppb)</td>
</tr>
<tr>
<td>Cd</td>
<td>0.3 (0.04)</td>
</tr>
<tr>
<td>Zn</td>
<td>47 (3)</td>
</tr>
</tbody>
</table>

† Canadian water quality guidelines for the protection of aquatic life (CCME, 1999)
Solid phase analysis

**Sequential extractions**

- Core, surface layer extruded (0.5 cm)
Solid phase analysis

**Sequential extractions**

Consecutive metal extractions using:

1. **MgCl₂**
2. **CH₃COOH (pH 5)**
3a. **NH₂OH·HCl**
3b. **NH₂OH·HCl à 96°C**
4. **H₂O₂**
5. **HF, HNO₃ et HClO₄**
Sequential extractions, distribution

- MgCl₂
- CH₃COOH (pH 5)
- NH₂OH·HCl
- NH₂OH·HCl à 96°C
- H₂O₂
- HF, HNO₃ et HClO₄

1996

- Cd
- Cu
- Zn

1998
Conclusion

A shallow water cover effectively reduces tailings oxidation:

• Oxic layer < 10 mm and influenced by periphyton

• Oxygen consumption reduced 2000 times compared to humidity cell tests

• No evidence of Cu mobilisation
Conclusion

A limited oxidation of the tailings is observed at the mm scale beneath the tailings-overlying water interface:

- peaks of \([\text{H}^+]\) and \([\text{SO}_4^{2-}]\)
- Weak diffusion of Cd and Zn to the overlying water having minor impacts on the water cover quality
- Displacement of Cd and Zn from refractory to more labile solid-phase fractions
Acknowledgments

- Michèle Bordeleau (INRS-Eau)
- Pauline Fournier (INRS-Eau)
- Tom Pedersen (University of British Columbia)
- Stéphane Prémont (INRS-Eau)
- Lise Rancourt (INRS-Eau)
- René Rodrigue (INRS-Eau)
- Sylvie St-Pierre (INRS-Eau)
- Bernard Veilleux (INRS-Eau)

Canmet, Golder, Aur Ressources and FCAR
Sequential extractions, total concentrations

- Cd
- Cu
- Zn

October 1996
August 1998