Geochemical behavior of different waste rock configurations from the Lac Tio mine: comparison between column tests and experimental waste rock pile results

Bissé Poaty, B. Plante, B., Bussière & M. Benzaazoua
T. Pabst & V. Martin
M. Thériault
P. Nadeau

UQAT-RIME
Polytechnique Montréal-RIME
Lac Tio mine, Rio Tinto Fer et Titane
Rio Tinto Iron and Titanium

http://irme.ca/en/
Waste rocks and CND

Upon their exposure in piles, the sulfides within waste rocks oxidize, generating acid and metals. When in presence of sufficient buffering from gangue minerals...

- Contaminated Neutral Drainage (CND):
  - neutral pH
  - sulphates and metals over regulated limits
Waste rocks deposition method with capillary barrier effect

- Consists to use the **capillary barrier effects** to divert water to the sides and to avoid deep infiltration (Aubertin, 2013; Aubertin *et al.*, 2013)

- The approach has been tested in the **laboratory on a small scale** and using **numerical tools**; requires a **demonstration at the field scale**.

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Objectives

- The main objective is to validate this approach with a large physical model in the field.
  
  Construction of an experimental waste rock pile

- The specific objectives:
  - To evaluate the impact of the structure of this test pile on the quality of drainage water.
  - To study the hydrogeochemical behavior of waste rock in columns in the laboratory.
Site of the Lac Tio mine, located northeast of Havre-Saint-Pierre, Quebec (Canada)

Open pit mine, operated since 1950

The main phases:

- **hemo-ilmenite or HI** (associated to traces of sulphides, source of Ni in drainage waters)
- **anorthosite** (gangue; calcic plagioclase, does not generate contaminants, possesses a significant Ni sorption capacity) (e.g., Plante et al., 2011; Bussière et al., 2011)

Generation of sporadic **Ni-CND** above regulated limit (0.50 mg/L) in some waste rock piles (e.g. Bussière et al., 2011)
Materials and methods

- Construction of an experimental waste rock pile with a slope of 5% and a flow control layer (FCL) (Martin et al., 2017; Dimech et al., 2017; Dubuc et al., 2017).

- Monitoring of drainage water quality of the experimental pile.
Materials and methods

- **Column tests** were carried out in the laboratory to simulate the geochemical behavior of the waste rock used in the construction of the experimental pile.
Sampling of leachate (drainage water) on a monthly basis between April and November of each year.

Analysis of water samples for the following parameters: pH, conductivity and contaminants (metals and sulphates)
Column tests

- Two control columns:
  - Co-HI: hemo-ilmenite
  - Co-Anor: anorthosite

- Two mixed columns:
  - Co-Al: anorthosite layer over a HI layer
  - Co-Sandwich: HI layer between 2 anorthosite layers
    - 1 port in HI (P1), 1 port at the bottom (P2)

- Simulation of rainfalls:
  - 1.8L for 14cm columns (HI and Anor)
  - 8.4L for 30cm columns (AI and Sandwich)
  - Periods of higher (2x) and lower (½x) rainfalls
Waste rock characterization

<table>
<thead>
<tr>
<th></th>
<th>HI waste rock (test pile)</th>
<th>HI waste rock (columns)</th>
<th>Anorthosite (test pile and column)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe (%)</td>
<td>31.1</td>
<td>30.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Ti (%)</td>
<td>14.1</td>
<td>16.7</td>
<td>1.4</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.40</td>
<td>0.33</td>
<td>0.003</td>
</tr>
<tr>
<td>Ni (mg/kg)</td>
<td>633</td>
<td>560</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Si (%)</td>
<td>7.8</td>
<td>7.6</td>
<td>24.7</td>
</tr>
<tr>
<td>Ca (%)</td>
<td>2.0</td>
<td>1.6</td>
<td>5.7</td>
</tr>
<tr>
<td>Al (%)</td>
<td>5.1</td>
<td>7.6</td>
<td>13.2</td>
</tr>
</tbody>
</table>

- The composition of the HI (hemo-ilmenite) waste rocks from the experimental pile and those of the columns are nearly identical.
- Anorthositic waste rock sampled contains <0.1% sulfur and a low hemo-ilmenite content.
- The HI waste rock sampled contains over 40% hemo-ilmenite.
Test pile geochemistry results

Sulfates and Ni Concentrations:

- $[\text{SO}_4]$ and $[\text{Ni}]$ were **higher** in Lys 1 to 5 than in Lys 6.

- Water passing through the **anorthosite waste rock** is **less contaminated**.
Test pile geochemistry results

The cumulative nickel and sulfate loadings

- less Ni and SO$_4$ come out of lysimeter 6.

- Lower concentrations from the lysimeter 6 are not related to a dilution, but to its low sulfide contents.
Column test geochemistry results

Sulfates and Ni Concentrations:
- Co-Anor and port 2 (bottom) of Co-Sandwich ➔ the lowest Ni and SO$_4$ concentrations

- Anorthosite waste rocks are the less reactive materials ➔ < 0.1% sulfur content.

- The overlying hemo-ilmenite does generate Ni, intercepted by the lower anorthosite layer (by sorption phenomena).
Column test geochemistry results

Sulfates and Ni Concentrations:

- A higher volume of rinse water $\rightarrow [\text{SO}_4]$ and $[\text{Ni}]$ decreased by almost 50%.

- $\frac{1}{2}$ Volume of rinse water $\rightarrow [\text{SO}_4]$ and $[\text{Ni}]$ almost doubled.

- Relative liquid-solid ratio has a significant effect on the water quality.
Column test geochemistry results

Nickel and sulfate cumulative loadings:

- from **port 1 of Co-Sandwich** are the **highest of all the columns**.
- **Ni** cumulative loadings from **port 2** are the **lowest**.
- **Ni** generated by the **HI layer** was not influenced by the **upper anorthosite layer**.
Nickel and sulfate cumulative loadings:

- **Ni** generated by the hemo-ilmenite layer was removed $\leftrightarrow$ underlying anorthosite layer

- **Ni** cumulative loadings from **Co-HI** $\approx$ from **Co-AI**.
Conclusions

- **Use of anorthosite waste rock** in a flow control layer enable to control water infiltration.
  - Controlling the generation of CND from hemo-ilmenite waste rock by favoring water circulation within anorthosite waste rock that is non CND generating.
- This **new approach to the construction of waste rock piles** effectively enables to decrease the contamination of mine drainage.
- [Ni] and [SO₄] leached out of the columns are closely linked to changes in leaching volume.
- An upper anorthosite layer above HI does not affect nickel leaching.
- Ni generated from the HI is removed by an underlying anorthosite layer.
  - Using successive benches constructed as in the experimental pile described here would enable to intercept contaminated water and improve its quality.
Column tests

- Two control columns: 23.0 kg of anorthosite and 36.1 kg of hemo-ilmenite.

- Two mixed columns:
  - Co-Al: an anorthosite layer of 13.1 kg and a hemo-ilmenite layer of 132.9 kg
  - Co-Sandwich: 2 anorthosite layers of 51.5 kg each and a hemo-ilmenite layer of 71.8 kg

Simulation of rainfall conditions:

- Regular rinses:
  - 1.8 L and 8.4 L of rinse water

- Non-regular rinses:
  - 4 L and 0.9 L (for two control columns)
  - 12 L and 4.2 L (for two mixed columns)
Test pile geochemistry results

**pH values:**
- Between **6.5** and **7.5**
- Neutral pH

**Electrical conductivity:**
- Values of leachate from **Lys 6 << Lys 1 to Lys 5**
**Column test geochemistry results**

**pH values:**
- Between 6 and 8
- Neutral pH

**Electrical conductivity:**
Values of leachate from **Co-Anor << Co-HI and Co-Sandwich P1**
Comparison between laboratory and field scales

- The results of nickel and sulfate concentrations from the experimental pile and laboratory columns differ.

- $[\text{SO}_4]$ from the column tests (up to 1500 mg/L) < $[\text{SO}_4]$ from test pile (up to 3500 mg/L).

- $[\text{Ni}]$ from test pile (up to 8.8 mg/L) > $[\text{Ni}]$ from the column tests (<4.5 mg/L).

- Ni cumulative loadings in field (up to $3 \times 10^{-4}$ mg/kg) << those in columns (up to 8 mg/kg)

- $\text{SO}_4$ cumulative loadings in field (<25 mg/kg) << those in columns (up to 1100 mg/kg).

- ≠ in Ni and $\text{SO}_4$ release rates are also observed between the laboratory and field scales.

These differences ↔ factors: pH, liquid-solid ratio, precipitation of secondary minerals, temperature, grain size distributions, and surface phenomena.
Waste rocks

Mining operation