ASSESSMENT OF PASTE ROCK AS A COVER MATERIAL IN MINE RECLAMATION AT THE CANADIAN MALARTIC MINE

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What is a Paste Rock Mixture?

- What we call « paste rock » or « co-mixing » is in fact an homogeneous mixture of fine tailings and waste rock;
- Used in the past by coal mines and some oil sands operations;

Could this material successfully be used as a reclamation cover?
ABOUT THE CANADIAN MALARTIC MINE

• The Canadian Malartic Mine is one of Canada’s biggest open pit gold mine. Owned by a partnership – 50% Agnico Eagle Mines and 50% Yamana Gold.

• Commercial production started in 2011 and is presently at a rate of 55,000 tpd.

• Canadian Malartic mine is currently conducting an assessment of various reclamation scenarios for both potentially acid generating (PAG) waste rocks and PAG tailings.
THE CANADIAN MALARTIC MINE
Reclamation Domains (5)

TSF : 639 ha

A. Flat areas – Top of the tailings : 354 ha
B. Flat areas – berms : 234 ha
C. Inclined areas – Bench faces : 51 ha

WRF : 417 ha

D. Flat areas – Top of the pile : 253 ha
E. Inclined areas – Benches and terraces : 164 ha

Source : Golder, 2014

Source : WSP, 2016
RECLAMATION CHALLENGES

✓ Size
✓ Chemical (ARD) and geotechnical stability
✓ Cover material availability
✓ Constructability
✓ Progressive rehabilitation
✓ Community consultations
OutLine

➢ Reclamation options

• Laboratory characterization

• Reclamation cells for tailings and waste rock

• Summary and on-going work
RECLAMATION OPTIONS

1. Cover with capillary barrier effect (CCBE)
   I. Desulfurized or amended tailings + Waste rock
   II. Paste rock + waste rock

2. Bilayer cover
   I. Desulfurized or amended tailings + Waste rock
   II. Paste rock and waste rock

3. Monolayer – Paste Rock

4. Geosynthetic cover

5. Flow control layer
   (WRF only)
COMPARATIVE ANALYSIS OF POSSIBLE RECLAMATION SCENARIOS FOR CMM

– All closure methods → Go / No Go threshold criteria
– Analysis
  • Costs
  • Construction Feasability
  • Environmental Performance
  • Stakeholder consideration
RECLAMATION COSTS EVALUATION

1 – Materials, Area and Volumes

2 – Preparation costs

3 – Materials costs – Production and supply

4 – Construction costs
PASTE ROCK AS COVER MATERIALS

Hypothesis: paste rock mixture can be used as low permeability layer of a reclamation cover that can be used to reduce water infiltration and limit the diffusion of oxygen towards reactive materials.

- Well designed paste rock possesses both similar mechanical properties as the waste rock and the hydrogeological properties of the tailings (Wilson, 2008);
- Previous field work (Wilson, 2008) demonstrated that infiltration rates and drainage are reduced when the mixture is used to construct a cover system on mine tailings;
- It promotes the use of mining waste in mine site reclamation instead of impacting additional areas to get natural materials.
OUTLINE

• RECLAMATION OPTIONS

➢ LABORATORY CHARACTERIZATION

• FIELD TEST CELLS

• SUMMARY AND ON-GOING WORK
LABORATORY CHARACTERIZATION

Physical
- Grain size distribution
- Relative density ($D_r$)
- Proctor tests

Chemical
- ICP-AES
- Carbon and Sulphur analysis

Mineralogy
- X Ray Diffraction (XRD)

Hydrogeological
- Saturated hydraulic conductivity ($K_{sat}$)
- Water retention curve (WRC)
Several ratios tested (waste rock/ tailings): 2.4/1, 3/1, and 3.6/1

Several tailings solid % \((C_w)\) tested: \(C_w\) tailings = 68%, 70%, 75%, 78%
Laboratory Characterization

Properties of different paste rock mixture

Paste rock mixture preparation

- $C_w$ tailings = 68%
  - Pasterock mixture with ratio 2.4/1
  - Pasterock mixture with ratio 3/1
  - Pasterock mixture with ratio 3.6/1

- $C_w$ tailings = 70%
  - Pasterock mixture with ratio 2.4/1
  - Pasterock mixture with ratio 3/1
  - Pasterock mixture with ratio 3.6/1

- $C_w$ tailings = 75%
  - Pasterock mixture with ratio 2.4/1
  - Pasterock mixture with ratio 3/1
  - Pasterock mixture with ratio 3.6/1

- $C_w$ tailings = 78%
  - Pasterock mixture with ratio 2.4/1
  - Pasterock mixture with ratio 3/1
  - Pasterock mixture with ratio 3.6/1
HYDROGEOTECHNICAL CHARACTERIZATION

- Variable head permeability tests
- Compaction tests

Example of Proctor test results

\[ k_{\text{sat}} = \frac{L}{(t_2 - t_1)A} \alpha \ln \left( \frac{h_1}{h_2} \right) \]
LABORATORY CHARACTERIZATION

Appearance of the Paste rock

Ratio 3.6/1 (waste rock/tailings):
\[ C_w \text{ tailings} = 70\% \]

Ratio 2.4/1 (waste rock/tailings):
\[ C_w \text{ tailings} = 68\% \]

Ratio 3/1 (waste rock/tailings):
\[ C_w \text{ tailings} = 75\% \]

Column dismantling

Ratio 3.6/1 (waste rock/tailings):
\[ C_w \text{ tailings} = 70\% \]
## Laboratory Characterization

### Results

<table>
<thead>
<tr>
<th>Ratio (Waste rock/Tailings)</th>
<th>Tailings C&lt;sub&gt;W&lt;/sub&gt; (%)</th>
<th>k&lt;sub&gt;sat&lt;/sub&gt; (cm/s)</th>
<th>ρ&lt;sub&gt;dry&lt;/sub&gt; (Kg/m³)</th>
<th>w&lt;sub&gt;opt&lt;/sub&gt; (%)</th>
<th>n&lt;sub&gt;opt&lt;/sub&gt;</th>
<th>Slump (on 40cm)</th>
<th>Particles segregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4 / 1</td>
<td>68</td>
<td>3.4x10⁻⁵</td>
<td>2310</td>
<td>4.2</td>
<td>0.18</td>
<td>40 cm</td>
<td>High</td>
</tr>
<tr>
<td>2.4 / 1</td>
<td>75</td>
<td>1.4x10⁻⁵</td>
<td>2290</td>
<td>7.2</td>
<td>0.18</td>
<td>/</td>
<td>zero</td>
</tr>
<tr>
<td>2.4 / 1</td>
<td>78</td>
<td>5.8x10⁻⁶</td>
<td>2390</td>
<td>6.4</td>
<td>0.15</td>
<td>/</td>
<td>zero</td>
</tr>
<tr>
<td><strong>3 / 1</strong></td>
<td><strong>75</strong></td>
<td>1.0x10⁻⁵</td>
<td>2315</td>
<td><strong>7.4</strong></td>
<td><strong>0.17</strong></td>
<td><strong>/</strong></td>
<td>zero</td>
</tr>
<tr>
<td>3.6 / 1</td>
<td>70</td>
<td>1.9x10⁻⁵</td>
<td>2320</td>
<td>6.1</td>
<td>0.17</td>
<td>15 cm</td>
<td>zero</td>
</tr>
<tr>
<td>3.6 / 1</td>
<td>75</td>
<td>9.3x10⁻⁶</td>
<td>2320</td>
<td>5.6</td>
<td>0.17</td>
<td>/</td>
<td>zero</td>
</tr>
</tbody>
</table>

**Best hydrogeological properties**

Ratio 3/1 with tailings C<sub>W</sub> of 75% is the paste rock ratio used for the construction of the reclamation cells.
OUTLINE

- Reclamation options
- Laboratory characterization

-field test cells

-summary and on-going work
# Field Test Cells

**Objective:** To assess *in situ* the efficiency of the paste rock as cover material in regards to ARD control (as both water and oxygen barrier)

## Cells configuration (see Slide 22)

<table>
<thead>
<tr>
<th>Cell Configuration</th>
<th>Materials Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolayer cover of paste rock cell on tailings (CR-4)</td>
<td>171</td>
</tr>
<tr>
<td>2 m of non-amended paste rock</td>
<td></td>
</tr>
<tr>
<td>1 m of CM tailings</td>
<td>7</td>
</tr>
<tr>
<td>Monolayer cover of paste rock cell on waste rock on horizontal surfaces (CS-4)</td>
<td>285</td>
</tr>
<tr>
<td>2 m of non-amended paste rock</td>
<td></td>
</tr>
<tr>
<td>4 barrels filled with 1 m of each lithology 0-38mm</td>
<td></td>
</tr>
<tr>
<td>Monolayer paste rock cell on waste rock on slope (CP-1)</td>
<td>498</td>
</tr>
<tr>
<td>2 m of non-amended paste rock</td>
<td></td>
</tr>
</tbody>
</table>
FIELD TEST CELLS

Paste rock preparation

A. Belt sieving the rough mix and spilling at a height of 2 m

B. Paste rock at the belt sieve output

C. Forming of a ball to test the paste rock cohesion

D. Carrying the paste rock to the storage area

E. Final paste rock
FIELD TEST CELLS

Cells configuration: Monolayer cover of paste rock on tailings
**Field test cells**

**Cells configuration:** Monolayer cover of *paste rock* on waste rock on horizontal surfaces

- **Drain dia:** 2"
- **Slope:** 1%
- **Length:** 13 m

Burrowed barrels filled (0.5 m³) with each lithology and the Mix

2 m paste rock

285 m³
**FIELD TEST CELLS**

**Cells configuration:** Monolayer *paste rock* on sloping waste rock

![Diagram of field test cells with measurement stations and waste rock in-place.](image-url)
FIELD TEST CELLS

Cells instrumentation

- 5TM for tailings
- GS-3 for waste rock

VWC probes

- Matric suction probes
- Water level probes

VWC data logger

Probe support

VWC GS3 Probes

VWC 5TM Probes

Watermark matric suction probes
FIELD TEST CELLS

Hydrogeological behavior monitoring (example of results)
**FIELD TEST CELLS**

**Leachates water quality monitoring (examples of results)**

<table>
<thead>
<tr>
<th>Measured parameters</th>
<th>Control cell</th>
<th>Reclamation cell (example of Monolayer of 2m-paste rock™)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (−)</td>
<td>7–8</td>
<td>7–8</td>
</tr>
<tr>
<td>As (mg/L)</td>
<td>&lt; 0.06 (DLM)</td>
<td>&lt;DLM</td>
</tr>
<tr>
<td>Cu (mg/L)</td>
<td>&lt;0.003 (DLM)</td>
<td>&lt;DLM</td>
</tr>
<tr>
<td>Fe (mg/L)</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Ni (mg/L)</td>
<td>0.04-0.05</td>
<td>0.04-0.05</td>
</tr>
<tr>
<td>Pb (mg/L)</td>
<td>&lt;0.02 (DLM)</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Zn (mg/L)</td>
<td>0.006-0.05</td>
<td>0.006-0.05</td>
</tr>
<tr>
<td>SO₄</td>
<td>≈2500</td>
<td>≈1500</td>
</tr>
<tr>
<td>Period</td>
<td>May 25- November 07, 2017</td>
<td>May 25-November 07, 2017</td>
</tr>
<tr>
<td>Area (m²)</td>
<td>25</td>
<td>179</td>
</tr>
<tr>
<td>Precipitations (m)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Precipitations (m³)</td>
<td>12</td>
<td>89</td>
</tr>
<tr>
<td>Discharged water (m³)</td>
<td>1.5</td>
<td>5</td>
</tr>
<tr>
<td>Infiltration(%)</td>
<td><strong>13</strong></td>
<td><strong>6</strong></td>
</tr>
</tbody>
</table>
WASTE ROCK SIZE VS CONSTRUCTABILITY

Objective: To evaluate the influence of waste rock particle size on the performance of paste rock as cover materials

- Three field pads (CPR-1, CPR-2 and CPR-3) made with paste rock were constructed over a horizontal portion (1D) of the waste rock disposal area.

- Three different paste rock recipes were preliminary prepared using different waste rock particle size.

<table>
<thead>
<tr>
<th>Cell</th>
<th>Thickness</th>
<th>Dimensions</th>
<th>Slope</th>
<th>Ratio Waste rock/ tailings</th>
<th>Waste rock Grain size</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPR-1</td>
<td>1 m</td>
<td>5x5 m</td>
<td>1H:1V</td>
<td>3/1</td>
<td>0-50 mm</td>
<td>17 m³</td>
</tr>
<tr>
<td>CPR-2</td>
<td>1 m</td>
<td>10x10 m</td>
<td>1H:1V</td>
<td>1.3/1</td>
<td>0-100 mm</td>
<td>82 m³</td>
</tr>
<tr>
<td>CPR-3</td>
<td>1 m</td>
<td>10x10 m</td>
<td>1H:1V</td>
<td>1.3/1</td>
<td>50-100 mm</td>
<td>82 m³</td>
</tr>
</tbody>
</table>
WASTE ROCK SIZE VS CONSTRUCTABILITY

Paste rock pad construction

Monolayer of 1m paste rock (ratio 3/1 - Cw 75%); using waste rock of 0-50mm

Monolayer of 1m paste rock (ratio 1.3/1 - Cw 75%); using waste rock of 0-100mm

Monolayer of 1m paste rock (ratio 1.3/1 - Cw 75%); using waste rock of 50-100mm
**Waste Rock Size vs Constructability**

**Result:** In-situ density and unit weight Results and in-situ porosity estimations

<table>
<thead>
<tr>
<th>Cell</th>
<th>Layer</th>
<th>Dry density (Kg/m³)</th>
<th>Water content (%)</th>
<th>Porosity (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPR-1</td>
<td>0-0.25m</td>
<td>2162</td>
<td>7</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>0.25-0.50m</td>
<td>2174</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>0.50-0.75m</td>
<td>2196</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>0.75-1m</td>
<td>2106</td>
<td>7</td>
<td>0.23</td>
</tr>
<tr>
<td>CPR-2</td>
<td>0-0.25m</td>
<td>2025</td>
<td>11.0</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>0.25-0.50m</td>
<td>1938</td>
<td>11.0</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>0.50-0.75m</td>
<td>1689</td>
<td>9.0</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>0.75-1m</td>
<td>1682</td>
<td>10.0</td>
<td>0.39</td>
</tr>
<tr>
<td>CPR-3</td>
<td>0-0.25m</td>
<td>1951</td>
<td>10.5</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>0.25-0.50m</td>
<td>2050</td>
<td>14.0</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>0.50-0.75m</td>
<td>2080</td>
<td>12.0</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>0.75-1m</td>
<td>1985</td>
<td>12.0</td>
<td>0.28</td>
</tr>
</tbody>
</table>

- In-situ porosity > in pads CPR-2 et CPR-3 than that in pad CPR-1:
  - more tailings in the paste rock (ratio 1.33/1) than in pad 1 (3/1) to get a better mixture.
  - the porosity in pads 2 and 3 is controlled by the tailings porosity.
OUTLINE

- Reclamation options
- Laboratory characterization
- Field test cells

➤ Summary and on-going work
SUMMARY

• The option of using paste rock as cover material at the Canadian Malartic Mine is investigated through laboratory and field work.

• Preliminary results are encouraging (low $k_{\text{sat}}$, good water retention properties, in situ preparation feasible) but the ratio (waste rock/tailings) used is a critical parameter (both technically and economically).

• The work is performed in close collaboration between the mine, consulting firms and RIME (two master students are working on paste rock as cover material).
ON-GOING WORK

- Other hydrogeological characterization tests are in progress (permeability test after various freeze/thaw cycles, water retention curves).
- Geomechanical characterization is also planned using shear box tests.
- Columns tests are underway to evaluate the geochemical behavior of paste rock and amended paste rock (to mitigate potential ML/ARD)
- Large scale field test (1-2 ha) to be built summer 2018 at the mine site will be part of the program.
A UNIQUE PARTNERSHIP FOR PRACTICAL AND SUSTAINABLE SOLUTIONS

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MINE RAGLAN UNE COMPAGNIE GLENCORE

Rio Tinto