A Review of Performance of the Whistle Mine Backfilled Pit Cover System – Four Years after Construction

By: B. Ayres, P.Eng. – O’Kane Consultants
L. Lanteigne, P.Eng. – Vale Inco
M. O’Kane, P.Eng. – O’Kane Consultants

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Presentation Outline

- Background
- Cover System Design Approach
- Cover and Landform Design Modelling

- Sustainability of the Cover and Final Landform
- Construction of the Pit Cover
- Performance of the Pit Cover
- Concluding Remarks
• Site ~ 60 km NW of Sudbury
• Canadian Shield – numerous bedrock outcrops and lakes
• Open pit mining (nickel) between 1988-91 & 1994-98
• 6.4 Mt of waste rock on surface – 80% is mafic norite, avg. S of 3%
• Several acidic seeps developed
• Semi-humid climate – annual precip. of 900 mm (30% as snow) & potential evaporation of 520 mm
*Background (cont’)*

- Not feasible to reclaim WRDs in-place
- Based on available data, Inco decided to *relocate all waste rock to open pit* (with lime addition @ 2kg/tonne) & construct an *engineered cover system*

- Pit surface area ~ 10 ha

- **Objectives of the pit cover:**
  1. *Limit oxygen ingress!!*
  2. *Reduce meteoric water infiltration*
  3. *Growth medium for vegetation*
Cover System Design Approach

Cover System Field Trials

Geochemical Modelling

Selection of Barrier Layer Material

Soil-Atmosphere Cover Design Modelling

Erosion and Landform Evolution Modelling

Slope Stability Analysis

Consideration of Processes Potentially Impacting on Sustainable Performance

Cover Design Criteria!
## Preliminary Cover Design Modelling

<table>
<thead>
<tr>
<th>Barrier Layer Thickness</th>
<th>Growth Medium Layer Thickness</th>
<th>Simulation</th>
<th>Barrier Layer Deg of Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm</td>
<td>90 cm</td>
<td>Initial conditions</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 1</strong></td>
<td>78%</td>
</tr>
<tr>
<td>45 cm</td>
<td>90 cm</td>
<td>Initial conditions</td>
<td>92%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 1</strong></td>
<td>82%</td>
</tr>
<tr>
<td>60 cm</td>
<td>90 cm</td>
<td>Initial conditions</td>
<td>93%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 1</strong></td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 2</strong></td>
<td>78%</td>
</tr>
<tr>
<td>30 cm</td>
<td>120 cm</td>
<td>Initial conditions</td>
<td>93%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 1</strong></td>
<td>83%</td>
</tr>
<tr>
<td>45 cm</td>
<td>120 cm</td>
<td>Initial conditions</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 1</strong></td>
<td>94%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 2</strong></td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dry year – run 3</strong></td>
<td>86%</td>
</tr>
</tbody>
</table>
2-D Cover System Performance

<table>
<thead>
<tr>
<th>Lower Slope</th>
<th>Upper Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Net Percolation</td>
<td>Low Net Percolation</td>
</tr>
<tr>
<td>Higher Degree of Saturation</td>
<td>Decreased Degree of Saturation</td>
</tr>
<tr>
<td>Lower \textit{In Situ} Oxygen Conditions</td>
<td>Higher \textit{In Situ} Oxygen Conditions</td>
</tr>
</tbody>
</table>
Detailed Cover Design Modelling

Topography

Required Minimum $O_2$ Diff. Coeff. for Barrier Layer

Final Barrier Layer $O_2$ Diff. Coeff.

Initial Barrier Layer $O_2$ Diff. Coeff.

Distance (m)

North South

Oxygen diffusion coefficient ($m^2/s$)

$1 \times 10^{-14}$ $1 \times 10^{-12}$ $1 \times 10^{-10}$ $1 \times 10^{-8}$ $1 \times 10^{-6}$ $1 \times 10^{-4}$ $1 \times 10^{-2}$ $1 \times 10^0$ $1 \times 10^{-2}$ $1 \times 10^{-4}$ $1 \times 10^{-6}$ $1 \times 10^{-8}$ $1 \times 10^{-10}$ $1 \times 10^{-12}$ $1 \times 10^{-14}$

Elevation (m)

0 50 100 150 200 250 300 350 400

0 10 20 30 40

-10 -20 -30
Preferred Cover System Design

- Growth Medium / Protective Layer
  - Non-compacted sandy-gravel till
  - 120 cm minimum on slope, with 8 cm of topsoil admixed to the near surface material
  - 60 cm minimum in the ponds

- Barrier Layer
  - Compacted Copper Cliff clay
  - 45 cm minimum on slope
  - 60 cm minimum in the ponds

- Levelling Course
  - Non-compacted sandy-gravel till (~ 10 cm thick)

- Waste Rock
Original Landform Design – Input to the SIBERIA Model
Significant Gully / Rill Development and Interill Erosion

Original Landform Design – Output from the SIBERIA Model (after 100 yrs)
Sustainable Cover Performance

INITIAL PERFORMANCE

Physical Processes
- Erosion
- Slope Instability
- Wet/Dry Cycles
- Freeze/Thaw Cycles
- Consolidation/Settlement
- Extreme Climate Events
- Brush Fires
- Construction

Chemical Processes
- Osmotic Consolidation
- Dispersion/Erosion
- Dissolution/Precipitation
- Acidic Hydrolysis
- Mineralogical Consolidation
- Sorption
- Salinization
- Oxidation

Biological Processes
- Root Penetration
- Burrowing Animals
- Bioturbation
- Human Intervention
- Bacteriological Clogging
- Vegetation Establishment

LONG-TERM PERFORMANCE

(Adapted from INAP, 2003)
Design Elements Addressing Issue of Sustainable Performance

- Erosion control measures
- Revegetation plan
- Growth medium layer
  - Competent material
  - Thickness!
- Barrier layer
- Geotextile
- Performance monitoring system
Key Construction Activities

- Started May 2004
Key Construction Activities (cont’)

- Completed November 2005
Pit Cover – 2006
Cover Performance Monitoring

- **Primary in situ cover monitoring sites (x 2):**
  - Automated
  - Net percolation
  - Suction / water content
  - Temperature
  - $O_2 / CO_2$ (manual)

- **Secondary in situ cover monitoring sites (x 13)**
  - Portable soil w/c probe & $O_2 / CO_2$ gas analyzer
  - Groundwater monitoring wells
  - Surface runoff (automated weirs)
  - Meteorological monitoring
**Water Content Profiles**

Measured in 2008

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**Vol. Water Content \((\text{cm}^3/\text{cm}^3)\) at P-01**

June 1

June 15

July 1

July 15

Aug. 1

Aug. 15

Sept 1

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**Vol. Water Content \((\text{cm}^3/\text{cm}^3)\) at P-02**

June 1

June 15

July 1

July 15

Aug. 1

Aug. 15

Sept 1

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**Barrier Layer**
Degrees of Saturation for the Pit Cover Barrier Layer

- P-01 Top of Barrier (n = 36%)
- P-01 Middle of Barrier (n = 30%)
- P-02 Top of Barrier (n = 34%)
- P-02 Middle of Barrier (n = 36%)
## Pit Cover Water Balance

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value (mm)</td>
<td>Percentage of Total Precipitation</td>
</tr>
<tr>
<td>Precipitation</td>
<td>765</td>
<td>-</td>
</tr>
<tr>
<td>Runoff and interflow</td>
<td>475</td>
<td>62.1%</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>269</td>
<td>35.2%</td>
</tr>
<tr>
<td>Net percolation</td>
<td>21</td>
<td>2.7%</td>
</tr>
<tr>
<td>Change in storage</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Net percolation measured in 2008 was 11 mm or 1% of precipitation
Soil Temperature Contours - 2008

P-02 Temperature

Rock Armoring

Barrier Layer
Evolution of Pit Water Quality

Graph showing the evolution of pit water quality from 2002 to 2009. The graph displays the changes in pH and levels of Copper, Nickel, Zinc, and pH over the years. The data indicates fluctuations in these parameters, with peaks and troughs at different times.
Concluding Remarks

- Pit cover performing as expected …
  - Growth medium for a variety of local plant species
  - Minimal soil erosion ... stable landform
  - $H_2O$ and $O_2$ ingress substantially reduced since 2005

- Final landform analogous to a natural system ... will aid in the sustainability of the pit cover

- Quality of site runoff and pit overflow waters improving with time
Concluding Remarks

- Ultimately decommission collection ponds, batch treat pit overflow water
Concluding Remarks

- 2009 recipient of the Tom Peters Memorial Mine Reclamation Award (CLRA)