Waste Characterization and Predicted Drainage Chemistry at the Antamina Mine after 10 Years of Operations

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Outline

1. Introduction to Antamina
   - Property
   - Geology and waste classification system
   - Current and New WQ regulations

2. Comparison between original EIA and present day
   - Project description
   - Predicted and current ML/ARD
   - Derivation of the waste classification system
   - Predicted vs. current drainage chemistry

3. Future estimates and management challenges
INTRODUCTION TO ANTAMINA
Timeline

1. Pre-mining baseline studies 1996 – 1997
2. EIA Approval 1998
3. EIA Addendums 1999
4. Peak Rock Program 2000
5. Full Production Capacity 2001
6. Waste Rock Classification System 2002
1. 5 general rock groups, 22 waste types
   - Intrusive
   - Skarns (brown garnet endoskarn, green garnet exoskarn)
   - Hornfels, Marble, Limestones
## Current Waste Classification System

<table>
<thead>
<tr>
<th>Class</th>
<th>Limit</th>
</tr>
</thead>
</table>
| **A** Reactive Material | Skarn/Intrusive Hornfels/Limestone/Marble  
>1500 ppm Zn, > 400 ppm As  
>3 % total sulphur; > 10% visual staining |
| **B** Potentially Reactive Material | Hornfels/Limestone/Marble  
700 - 1500 ppm Zn  
< 2-3 % total sulphur |
| **C** Non-Reactive Material | Hornfels/Limestone/Marble  
< 700 ppm Zn  
< 400 ppm As  
< 2-3% total sulphur  
Only Grey Hornfels and Grey and Black Marble are sent to Tailings Dam |

<10% FeOx  
(material routed to Tailings Dam)  
FeOx  
(no restriction, material to Tucush)
## Water Quality Limits

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effluent Limits</th>
<th>In-Stream Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>New (Oct 2012)</td>
</tr>
<tr>
<td>Sulphate</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Conductivity</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Calcium</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Arsenic Tot</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Copper Tot</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zinc Tot</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
EIA PROJECT DEFINITION

VS.

CURRENT CONDITIONS
### Comparison between then and now

#### Key Project Description Details

<table>
<thead>
<tr>
<th>1998 EIA</th>
<th>2011 VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Life of Mine:</strong> 2024</td>
<td><strong>Life of Mine:</strong> 2029</td>
</tr>
<tr>
<td><strong>1998 Life Of Mine Projections:</strong></td>
<td><strong>2011 Life of Mine Projections:</strong></td>
</tr>
<tr>
<td>• 500 Mt tailings</td>
<td>• 1.05 Bt tailings</td>
</tr>
<tr>
<td>• 1.36 Bt Waste Rock</td>
<td>• 2.2 Bt waste rock</td>
</tr>
<tr>
<td><strong>Mill throughput:</strong></td>
<td><strong>Mill throughput:</strong></td>
</tr>
<tr>
<td>70 ktpd</td>
<td>104 ktpd current average</td>
</tr>
<tr>
<td></td>
<td>130 ktpd in Jan 2012</td>
</tr>
<tr>
<td></td>
<td>145 ktpd in Jan 2013</td>
</tr>
<tr>
<td><strong>3 waste dump sites</strong></td>
<td><strong>2 waste dump sites</strong></td>
</tr>
<tr>
<td><strong>6 ore types</strong></td>
<td><strong>8 ore types</strong></td>
</tr>
<tr>
<td><strong>232 m high rockfill dam, 670 ha</strong></td>
<td><strong>285 m rockfill dam, 796 ha</strong></td>
</tr>
</tbody>
</table>
1998 EIA Waste Rock Geochemistry

Conclusions

1. Skarn-hosted mineralization like Antamina has a low potential to generate ARD or to become a source of widespread metal contamination, though it may be sulphide-rich

2. Non-PAG - Limestone, Marble and most green garnet skarn

3. Uncertain - Intrusives

4. PAG - Brown garnet skarn

5. Intrusive samples show Mo leaching under neutral conditions

6. Zn leached from all rock types

Waste Classification System Needed!!
WASTE ROCK CLASSIFICATION SYSTEM DEVELOPMENT
Derivation of Waste Classification System

Purpose was to develop a criterion for segregation of dam construction versus other waste material:

- Segregation of material suitable for Dam Construction was undertaken as part of the Peak Rock Program (2000)
  - Took loading rates from SFE tests and applied those to the mass of material placed in the dam then calculated the concentration in the dam seepage
  - Compared the resulting concentration to a site effluent discharge limit for zinc of 0.5 mg/L
Zinc Estimates in Dam Drainage
Derivation of lower limit 700 ppm
EIA Receiving Water Limit
= 0.13 mg/L

New ECA
= 2 mg/L

EIA Discharge Limit
= 0.5 mg/L

New LMP
= 1.5 mg/L

[Zn] Estimates in Dam Drainage
Discharge Limit 0.5 mg/L

[Zn] Estimates in Dam Drainage
diluted with Decant Volume
Zinc Estimates in Dam Drainage
Derivation of upper limit 1500 ppm
Refinements to the Classification System

1. Between 2000 and 2002 the classification system was refined
   • Sulphide content was established (> 3% for reactive material)
   • As solid phase content was defined based on the exposure of As minerals in the pit walls, an assessment of leaching chemistry and gut feel by geologists (400 ppm As cutoff)

2. Between 2004 and 2007
   • Intrusive Material regardless of sulphide was designated Reactive A material
   • Data collection has been underway to be able to refine or eliminate Class B, no conclusions
Re-Assessment of Dam Leaching

Similar exercise was undertaken to evaluate the leaching effects of using other types of Hornfels and Marbles as dam construction material.

- Results remain true that the Grey Hornfels and Grey and Black Marbles have the lowest effect on Ayash water quality.
- There was no effect on Zn concentrations by changing the material type sent to the dam.
- But there was a change in Ayash River SO4 concentration.
DRAINAGE CHEMISTRY PREDICTIONS VS. PRESENT DAY CONCENTRATIONS
# EIA Estimate of Operational TSF Pond

<table>
<thead>
<tr>
<th></th>
<th>1998 EIA TSF Pond Operational WQ</th>
<th>2011 TSF Pond Operational WQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>7 – 9</td>
<td>9 – 10</td>
</tr>
<tr>
<td><strong>SO4</strong></td>
<td>Not estimated</td>
<td>700 - 1500</td>
</tr>
<tr>
<td><strong>CN total</strong></td>
<td>0.01 – 0.03</td>
<td>0.04 – 1.5</td>
</tr>
<tr>
<td><strong>As</strong></td>
<td>0.002 – 0.004</td>
<td>0.001 – 0.009</td>
</tr>
<tr>
<td><strong>Cd</strong></td>
<td>&lt;0.0002</td>
<td>0.0002 – 0.0013</td>
</tr>
<tr>
<td><strong>Cu</strong></td>
<td>0.01 – 0.03</td>
<td>0.4 – 4.0</td>
</tr>
<tr>
<td><strong>Cr</strong></td>
<td>&lt;0.001</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td><strong>Fe</strong></td>
<td>&lt;0.1</td>
<td>0.001 – 0.12</td>
</tr>
<tr>
<td><strong>Mo</strong></td>
<td>Not estimated</td>
<td>0.4 – 0.6</td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>&lt;0.002 – 0.004</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Hg</strong></td>
<td>0.0002</td>
<td>&lt;0.0002</td>
</tr>
<tr>
<td><strong>Ni</strong></td>
<td>&lt;0.0005 – 0.001</td>
<td>0.001 – 0.02</td>
</tr>
<tr>
<td><strong>Zn</strong></td>
<td>0.05 – 0.10</td>
<td>0.001 – 0.05</td>
</tr>
</tbody>
</table>
## EIA Estimate of Year 10 Receiving WQ

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1998 EIA Estimated Concentrations (at 10 yrs of Operations) (mg/L)</th>
<th>2011 Concentrations (mg/L)</th>
<th>In-Stream Limit as of Feb 2016 (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Not shown</td>
<td>8.2 – 8.5</td>
<td>6 - 9</td>
</tr>
<tr>
<td>SO4</td>
<td>Not estimated</td>
<td>38 - 230</td>
<td>300</td>
</tr>
<tr>
<td>Copper</td>
<td>0.009</td>
<td>0.01 – 0.02</td>
<td>0.2</td>
</tr>
<tr>
<td>Lead</td>
<td>0.002</td>
<td>0.001 – 0.015</td>
<td>0.05</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.044</td>
<td>0.01 – 0.18</td>
<td>-</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.044</td>
<td>0.006 - 0.012</td>
<td>2</td>
</tr>
</tbody>
</table>
2006 Projected LOM WQ Tucush Dump

- **Zinc**
  - Zn (mg/L): 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7

- **Sulphate**
  - SO4 (mg/L): 0.00, 0.00, 0.00, 0.01, 0.01, 0.01, 0.01

- **Copper**
  - Cu (mg/L): 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2

- **Molybdenum**
  - Mo (mg/L): 0, 0.001, 0.001, 0.001, 0.001, 0.001, 0.001
2006 Projected LOM WQ East Dump

Zinc

Sulphate

Copper

Molybdenum
# Future Projections at In-Stream Compliance Point

<table>
<thead>
<tr>
<th></th>
<th>1998 EIA Estimated Conc. (at 10 yrs of Operations) (mg/L)</th>
<th>2011 Conc. (mg/L)</th>
<th>Projected In-Stream Conc. at the end of ops</th>
<th>In-Stream Limit as of Feb 2016 (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Not shown</td>
<td>8.2 – 8.5</td>
<td>8.4</td>
<td>6 – 9</td>
</tr>
<tr>
<td>SO4</td>
<td>Not estimated</td>
<td>38 - 230</td>
<td>550 – 600</td>
<td>300</td>
</tr>
<tr>
<td>Cu</td>
<td>0.009</td>
<td>0.01 – 0.02</td>
<td>0.039</td>
<td>0.2</td>
</tr>
<tr>
<td>Mo</td>
<td>0.044</td>
<td>0.01 – 0.18</td>
<td>0.07</td>
<td>-</td>
</tr>
<tr>
<td>Zn</td>
<td>0.044</td>
<td>0.006 - 0.012</td>
<td>0.036</td>
<td>2</td>
</tr>
</tbody>
</table>
Conclusions ML/ARD

1. Overall EIA conclusion was that the Antamina mine would not produce substantial ARD and become a source of widespread metals. So far, this is true.

2. Zn was thought to be the main element of concern in the EIA and the water quality modelling focused on Zn conc.

3. Waste rock classification system was derived based on Zn to segregate waste that could be used for dam construction from the remainder of waste based on a zinc criteria first.
   - The classification system is still used today and thought to be successful based on the relatively young age of the Antamina waste dumps and dam, zinc concentrations are low.
Conclusions Water Quality

1. EIA water quality modelling were low compared to present day, but not bad estimates

2. Water quality modelling of dump seepage undertaken in 2006 consistently underpredicted SO4 and overpredicted Cu and Zn, Mo was more difficult.

3. SO4 has been identified as the parameter of concern going forward. Antamina is currently evaluating treatment options to maintain compliance in Feb 2016 when the new limits are imposed that include SO4

4. Future modelling continues to assume Zn and Cu will be parameters of concern
GRACIAS.
SOMOS ANTAMINA
¡NOSOTROS CUMPLIMOS!

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