The Effect of Tailings Characteristics on Cover System Success (or: What have we learned in 40 years?)

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Physical, Geochemical and Spatial Tailings Characteristics
Physical Characteristics

• Tailings are poorly graded
  – Mostly silt size
  – No soil structure
• Highly erosive (high intensity precipitation/wind)
• Impoundment construction results in additional sorting and layering
  – beach (sands)
  – slimes (silts)
  – mixed areas
• Moisture retention and permeability varies by material types
• Variable saturation and drainage
Tailings Segregation and Structure

- Beach (sand)
- Slimes (silt)
- Mixed Zone (sand & silt)
Geochemical Characteristics

- Can be moderately saline to hyper-saline
- Ore body mineralogy can result in:
  - High acid generation potential (and acidity) with high plant available metals (i.e. arsenic)
  - Moderate salts with no/ low plant-available metal content
- Typically low plant nutrient content
- Lack of organic matter and microbiota
To Cap or Not To Cap?
Reclamation Goals and Methods

Goals:
• Establish vegetation
• Minimize erosion and stabilize tailings
• Minimize deep percolation

Methods:
• Soil covers
• Direct revegetation w/ tailings amendments
Previously Reclaimed Tailings Surfaces (in AZ)

- ASARCO Mission Tailings No. 6 (1983: 12-inch cover)
- ASARCO Mission San Xavier Tailings 1,2, 3 (2011: 12 inch cover)
- Eagle Pitcher Mill site (1960s, 1989-92: 12-inch cover)
- Twin Buttes Tailing No. 2 (1986: 12-inch cover)
- Phelps Dodge Sierrita Esperanza Tailings (1986: 12-inch cover)
- San Manuel PS Tailings Impoundment 1/2 (1991-92: 6 to 8 inches cover)
- San Manuel Tailing Impoundments 1-6 (2008: 12-inch cover)
- San Manuel PS experimental biosolid plots (1998: no cover)
- McCabe Mine Tailings (1996: 24 inch cover)
- Phelps-Dodge Morenci Tailings 4W experimental test plots (1997: 12 to 24-inch of cover)
- Freeport McMoran Copper Queen CTSA Tailings (2012: 24 inch cover)

Circumneutral  
Potentially Acid Generating  
Acid
<table>
<thead>
<tr>
<th>Acid Generating Potential</th>
<th>Tailings Acidity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High AGP</strong></td>
<td><strong>High pH</strong></td>
</tr>
<tr>
<td>Moderate Risk</td>
<td>Potentially High Salinity/Phytotoxicity</td>
</tr>
<tr>
<td><strong>Moderate AGP</strong></td>
<td><strong>Circumneutral</strong></td>
</tr>
<tr>
<td>Moderate Risk</td>
<td>Potentially High Salinity/Phytotoxicity</td>
</tr>
<tr>
<td>Low AGP</td>
<td><strong>Low pH</strong></td>
</tr>
<tr>
<td>Low Risk/Benign</td>
<td>Moderate Salinity</td>
</tr>
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</table>
Vegetation on Reclaimed Tailings
ASARCO Mission Tailings
San Manuel
Circum-neutral
Mixed zone/ Slimes Tailings
Reclaimed in 1999

Vegetation in 2005
No cover. Biosolid/green waste amended
San Manuel
Circum-neutral Tailings,
Beach/Mixed
Reclaimed in 1999

Vegetation in 2005
30-cm cover, reseeding/mulching, hand planting
Morenci
Acid tailings, Side-slope
Reclaimed in 1998

Vegetation in 2007
30-cm cover, reseeded,
21 ton/acre biosolids,
30 cm Cover vs. 60 cm Cover

Different letters indicate significant differences.
Rooting Characteristics
Vegetation Considerations

• Rooting characteristics:
  – Actively root into circum-neutral tailings
  – Minor rooting into moderately acid tailings, primarily limited to cover and upper one foot of tailings
  – Form dense root mat above cover/acid tailings contact
  – Affected by tailings permeability

• Vegetative success generally greater in mixed zone than in beach areas and slime areas

• Vegetation characteristics varies with location (e.g. slimes vs. sands)
Vegetation Considerations (cont’d)

• Effect of cover depth
  – Nominal differences in vegetative covers > 30 cm thick
  – BUT native species perform better on thicker covers

• Effect of organic amendments:
  – Can successfully reclaim raw tailings with a biosolids/green waste (compost) mix
  – Results in significantly greater mean vegetation cover; however, less species diversity
  – In some cases, observed effects sustained for over 10 years

• Side slopes may require rock armoring; only seeded cover material may not adequately stabilize slopes
Low-pH and Saline Solution Migration into Monolayer Covers?
Trench Sample Design

Cross-Section View

Key

- Soil sampling locations at:
  - 2 inches below cover surface
  - 2, 4, 6, 8 inches above contact
  - 2 inches below contact

- Root density sampling frames (4 inches x 4 inches) at:
  - 0-4, 4-8, and 8-12 inches below cover surface and
  - 0-4 inches above contact
pH Profiles

Typically Phytoxic

- SW2 (1% pyrite tailing, 15% ANP Cover, 10 years)
- CTSA Demonstration (8% pyrite tailing, 14% ANP Cover, 7 years)
- CTSA South Slope (8% pyrite tailing, 5% ANP cover, 19 years)
- 4W - 60 cm (5% pyrite tailing, 3.5% ANP cover, 10 years)

Cover-Tailings Contact
EC Profiles

- SW2 (1% pyrite tailing, 15% ANP Cover, 10 years)
- CTSA Demonstration (8% pyrite tailing, 14% ANP Cover, 7 years)
- CTSA South Slope (8% pyrite tailing, 5% ANP cover, 19 years)
- 4W - 60 cm (5% pyrite tailing, 3.5% ANP cover, 10 years)
- Cover-Tailings Contact
Acid and Salinity Migration Considerations

- In a semi-arid environment salinity and acid migration observed in Southwest US environment to be limited to ≈ 15 cm above contact
- Phytotoxic levels of pH and salinity in cover material generally absent ≈ 5 cm above contact
- Increased migration above contact with decreased cover thickness (30 vs. 60 cm)
- Acidity and salinity migration may be limited due to:
  - Unsaturated hydraulic conductivities and upward flux rates greatly diminish with distance above the contact
  - High calcium carbonate contents in the cover material can neutralize low-pH solution
Infiltration/Net Percolation
Calculated 1D Net Percolation Flux

<table>
<thead>
<tr>
<th>Sensor Nest/Plot Location</th>
<th>Total Downward Flux (cm)</th>
<th>Annual Flux (cm/yr)</th>
<th>Annual Flux Rate (cm/s)</th>
<th>Estimated Flux as Percent of Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm cover, low vegetation</td>
<td>3.23</td>
<td>0.37</td>
<td>1.16E-08</td>
<td>1.29%</td>
</tr>
<tr>
<td></td>
<td>1.61</td>
<td>0.26</td>
<td>8.14E-09</td>
<td>1.04%</td>
</tr>
<tr>
<td>30 cm cover, high vegetation</td>
<td>0.84</td>
<td>0.12</td>
<td>3.80E-09</td>
<td>0.34%</td>
</tr>
<tr>
<td>60 cm cover, low vegetation</td>
<td>6.52</td>
<td>0.07</td>
<td>2.24E-09</td>
<td>0.30%</td>
</tr>
<tr>
<td>60 cm cover, high vegetation</td>
<td>4.20</td>
<td>0.55</td>
<td>1.74E-08</td>
<td>1.68%</td>
</tr>
<tr>
<td></td>
<td>7.37</td>
<td>0.55</td>
<td>1.76E-08</td>
<td>1.35%</td>
</tr>
<tr>
<td>Average 60 cm cover, high vegetation</td>
<td>3.84</td>
<td>0.48</td>
<td>1.53E-08</td>
<td>1.53%</td>
</tr>
<tr>
<td></td>
<td>3.10</td>
<td>0.29</td>
<td>9.13E-09</td>
<td>1.24%</td>
</tr>
<tr>
<td>Bare Tailings</td>
<td>0.17</td>
<td>0.02</td>
<td>6.56E-10</td>
<td>0.09%</td>
</tr>
<tr>
<td></td>
<td>0.28</td>
<td>0.03</td>
<td>1.11E-09</td>
<td>0.16%</td>
</tr>
</tbody>
</table>

**Shallower (30 cm) cover/ Lower permeability tailings**

**Deeper (60 cm) cover/ Higher permeability tailings**

**Low permeability bare tailings: > runoff, less infiltration**
Predicted Effect of Increasing Cover Thickness

Average Annual Net Percolation (mm/yr)

- Tailings Ksat = 3.2E-4 cm/s
- Tailings Ksat = 2.2E-5 cm/s
- Tailings Ksat = 2.2E-6 cm/s
- Tailings Ksat = 2.2E-7 cm/s

Tailing sideslope
Tailing beach
Tailing slimes

Cover Depth (cm)
Net Percolation Considerations

- Lower permeability tailings reduce net percolation
- Increasing cover thickness can have less influence on net percolation than tailings characteristics
- Shallow covers or direct reclaimed tailings can have less net percolation than deeper covers
- **Tailings are an integral part of store and release cover systems and their influence should be considered during cover design**
Conclusions

- Circumneutral tailings can be revegetated with organic amendments (if available); net percolation may actually decrease because of low permeability material at surface.
- Low permeability tailings serve to slow down infiltration and retain water in cover; can have greater effect on net percolation than cover depth.
- Revegetation seed mixes should consider differences between sand and slimes area; deeper covers are better for native seed mixes.
- Cover system modeling should acknowledge ET depth into tailings.
- Upward acidity and salinity migration into monolayer covers may be limited.
THANK YOU!

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More information at
http://www.gsanalysis.com/minepub.html