Phytostabilization of Mine Tailings in Arid and Semi-Arid Environments

Regional Science Council Seminar Series

Mining Issues in Region 9 - Status, Cleanup, and Research

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The Earth's Open Wounds
Abandoned and Orphaned Mines

Why are abandoned mining sites a problem?
Abandoned Mine Lands in the U.S.

(Ferderer 1996)
What problems are associated with mine tailings in semiarid and arid environments?

- wind erosion
- water erosion
Routes of exposure

- inhalation
- ingestion
The wind is blowing the tailings over the neighborhood

Courtesy Blenda Machado
Children playing in a stream with elevated levels of arsenic in Cerrito Blanco

Courtesy Blenda Machado
Site owned by Phelps-Dodge near Green Valley, AZ
Comprised of 1800 acres of tailings
What are common characteristics of semiarid and arid mine tailings?

- High metals
- Low pH/high pH
- No organic matter
- No soil structure
- Severely impacted microbial communities
- Barren of vegetation

Can these sites be revegetated?
A sensible strategy for remediation/treatment

Phytoextraction

vs.

Phytostabilization
Considerations for phytostabilization

• Plant criteria
  Native plants (grasses, shrubs, trees)
  Drought tolerant
  Metal tolerant
  Salt tolerant

• Amendments required for revegetation
  Inorganic
    - NPK fertilizers: increase nutrient content
    - Lime: increases pH of acidic mine tailings
  Organic (biosolids/compost)
    - Increases pH of acidic mine tailings
    - Improves physical structure
    - Slow-release nutrient source
    - Complexation of heavy metals
Considerations for phytostabilization (cont.)

• **Metal accumulation into plants**
  Elevated shoot accumulation is undesirable
  - Foraging animals (domestic animal toxicity limits)
  - Plant turnover

• **Long-term fate of metals in tailings**
  Does speciation of tailings metals in the rhizosphere change in the short- or long-term?

  What impact might this have on metal mobility and bioavailability?

**Case studies**
Case Study 1: Acidic Pb-Zn Mine Tailings
The Klondyke Site

- Aravaipa Creek, Graham County, AZ
- Pb and Zn ore processing operation from 1948 to 1958

- pH ranges from 2 to 6
- Metal concentrations:
  - Lead ($\rightarrow$ 20,000 mg/kg)
  - Arsenic ($\rightarrow$ 10 mg/kg)
  - Cadmium ($\rightarrow$ 100 mg/kg)
  - Copper ($\rightarrow$ 6,000 mg/kg)
  - Zinc ($\rightarrow$ 20,000 mg/kg)
- Heterotrophic counts < 100 CFU/g
- Autotrophic counts $10^4$ to $10^5$ CFU/g
Klondyke Plant Screening Study

- Buchloe dactyloides (buffalograss)
- Prosopis velutina (velvet mesquite)
- Atriplex lentiformis (quailbush)
- Atriplex canescens (fourwing)
- Sporobolus cryptandrus
- Sporobolus wrightii (big)
- Sporobolus airoides (alkali)
- Distichlas stricta (inland)
Results

• Treatments
  5, 10, 15, 20, 25, 50, 75% compost
Total biomass of *A. lentiformis*

**Total biomass (g plant⁻¹)**

- **pH 3**
  - K475
  - K485
  - K495
  - K490
  - K4100

- **pH 6**
  - K675
  - K685
  - K695
  - K690
  - K6100

**Treatment**

- K4-95
- K4-90
- K4-85
- CC

Mendez et al., 2007. *J. Env. Qual.*
Results

• Treatments
  5, 10, 15, 20, 25, 50, 75% compost

• Compost addition
  increased pH
  increased nutrients
  increased heterotrophic counts

• No accumulation of Pb, Cu, Cd, and As in shoot material

• Microbial community analysis indicates level of disturbance
**Clone libraries**

- **Firmicutes**
  - K4 (8)
  - H:A = 1.7
  - 0% oblig het
  - ~10 CFU/g H
  - ~10^5 CFU/g A

- **Actinobacteria**
  - Off-site control (42)
  - H:A = 9.5
  - 88% oblig het
  - ~10^6 CFU/g H
  - BDL - A

- **β-Proteobacteria**
  - Planctomycetes
  - H:A = 3.0
  - 25% oblig het

- **γ-Proteobacteria**
  - Verrucomicrobia
  - K6 (24)
  - ~200 CFU/g H
  - ~10^5 CFU/g A
  - H:A = 3.0
  - 25% oblig het

- **δ-Proteobacteria**
  - Acidobacteria
  - H:A = 3.0
  - 25% oblig het

- **ε-Proteobacteria**
  - α-Proteobacteria
  - Bacteroidetes
  - Gemmatimonadetes

**H:A**

- Off-site control: H:A = 9.5, 88% oblig het
- K4: H:A = 1.7, 0% oblig het
- K6: H:A = 3.0, 25% oblig het
Question

If iron and sulfur-oxidizers are responsible for creating an acid environment in tailings and AMD, and preventing normal soil formation processes, can we use heterotrophs to help restore normal soil formation functions and establish a vegetative cap?

Mesquite

Buffalo grass

A. lentiformis
Plant Growth-Promoting Bacteria (PGPB)

- Enhance phytostabilization using PGPB
- Mutualistic relationships between plant and bacteria
- Provide plant with:
  - Nutrients: nitrogen, phosphate, iron
  - Growth factors: IAA, ACC-deaminase (Glick, 1998; Patten and Glick, 2002)
- Demonstrated effectiveness
  - Majority agricultural (Bashan et al., 1998; 2006; Cakmakc et al., 2005; Canbolat et al., 2005; Cattelan et al., 1999; Chung et al., 2005; Gray and Smith, 2005; Vessy, 2003)
  - Desertified sites (Barriuso et al., 2005; Carrillo et al., 2002; Garcia et al., 1999; Requena et al., 1996; 1997)
  - Very few studies in metal contaminated soils (Burd et al., 1999; Dell 'Amico et al., 2005)
  - No studies using PGPB in mine tailings
A. *Lentiformis* Growth in Klondyke Tailings

0% Compost

- Avg. survival: 4.8 ± 1.5 per treatment
- 4 isolates with < 3 surviving plants
- 7 of 20 treatments had larger avg. root biomass

<table>
<thead>
<tr>
<th>Inoculated Isolate</th>
<th>Average Dry Plant Biomass (g)</th>
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<tbody>
<tr>
<td>B. viel K4-10B</td>
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<tr>
<td>K6-11B</td>
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<td>MTR-45B</td>
<td>B</td>
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<td>MTR-71</td>
<td>A</td>
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SP -1: *Microbacterium sp.*
K6-11B: *Methyllobacterium sp.*
MTR-71: *Erythromonas sp.*
A. *Lentiformis* Growth in Klondyke Tailings
10% Compost (w/w)

- 19 of 20 treatments w/ larger avg. biomass
- Avg. survival: 7.9 ± 1.6 treatment⁻¹

**Inoculated Isolate**

- B. viet-K6-11B
- K4-10C
- K6-19
- MTR-1
- MTR-11: Gordonia sp.
- MTR-18: *Microbacterium* sp.
- MTR-21A: *Clavibacter* sp.
- MTR-21B: *Streptomyces* sp.
- MTR-32: *Gordonia* sp.
- MTR-35B
- MTR-3A
- MTR-45B
- MTR-61
- MTR-70
- Pa 902/2
- Sp-1
- Sterile Control
- Non-Sterile Control

• +200% • +250%
**Buchlue dactyloides** Total Biomass
Klondyke T1 Tailings 0% Compost
Long-Term Study

![Bar chart showing average dry plant biomass for different inoculated isolates and sterile control.](chart.png)
Case Study 2: Neutral Au/Ag Mine Tailings
The Boston Mill Site

- Mined for gold and silver from 1879 to 1887
- Metal levels similar to Klondyke
- Heterotrophic counts ~ $10^5$ CFU/g
- Plants beginning to encroach at the site
- Field trial using *Atriplex* transplants tested whether compost was required.
Results

- 80% of transplants survived
- Biomass increased significantly
- No difference between compost/no compost treatments
- Bacterial community monitored to indicate plant and soil health
Effect of plants on heterotrophic counts

With plants

No plants
Multidimensional scaling analysis of DGGE data

Largest changes between 0 and 3 and 3 and 5 months

Are there microbial isolates that can enhance plant establishment?

Rosario et al., J. Env. Qual., in press
Future Work

- Further investigation of isolates
  - other isolates
  - mycorrhizae (Azcon and Barea, 1997; Requena et al., 1996; Shetty et al., 1994)

- Different native plants

- Inoculation methods
  Surface coating vs. alginate encapsulation (Gonzalez and Bashan, 2000)

- Isolate tracking, community structure

- Field studies Klondyke, Nacoza, Phelps-Dodge
UA Superfund Basic Research Program and Research Translation:

- Community meetings to educate the public about mine tailings and exposure routes
- Field trials to test phytostabilization strategies
  - Boston Mill
  - Klondyke
  - Phelps-Dodge
- US-Mexico Binational Center partnership with Mexican Universities to:
  - test phytostabilization - Nacozar site
  - hold community meetings - Nacozar site
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