Nano-scale mechanisms of metal(loid) rhizostabilization in desert mine tailings

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NIEHS Grant no. R01ES017079

Superfund Research Program

PATROL
DPS

Desert tailings parent mineralogy

Water, organic matter, roots, microorganisms

Biostabilized tailings

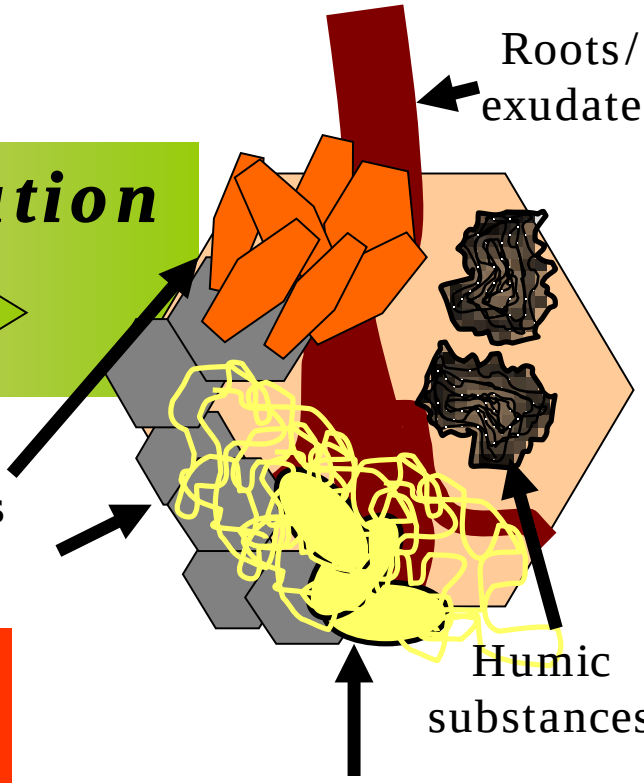
Low microbial counts

High microbial counts

Pb phases
Plumbojarosite
Anglesite
Galena
Zn phases
Goslarite
Zn-Fe sulfate
Sphalerite
As phases
Sorbed As(V)
Arsenopyrite

Also quartz, feldspar, Fe oxide, gypsum, clays

Phytostabilization



Neo-formed precipitates/plaques (FeOx, MnOx)

Form and fate of Pb, Zn, As, Cu

Project Goal and Specific Aims

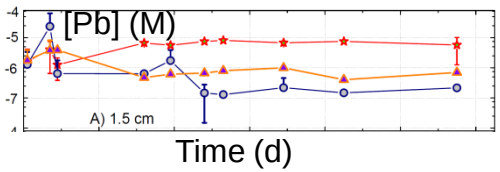
- **Overall goal:** Identify multi-scale process-links between biological structure and contaminant geochemistry during phytostabilization of mine tailings.
  - Evolution of tailings microbiology and geochemistry both in the rhizosphere and in the bulk tailings over the course of phytostabilization;
  - Time- and depth-resolved measurements of tailings pore waters (focusing on the mobility and bioavailability of metal contaminants);
  - Effects of particle-specific bioweathering processes on metal(loid) mobility and molecular environment;
  - Spatial correlations between biogenic (and geogenic) weathering products, roots and microbial cells;
  - Change in exposure and toxicity risks associated with tailings sites in arid environments.

Biogeochemical Analyses (Chorover group)

f (time, treatment)

Pore water samples

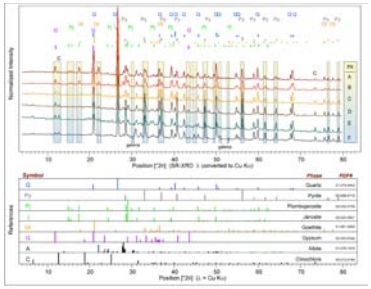
Aqueous geochemistry (ICPMS, IC, DOC, pH)



Aqueous speciation of metal(loid)s, geochemical modeling

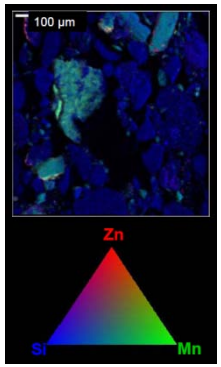
Tailings Samples

X-ray Diffraction (XRD)



Bioweathering & mineral transformation

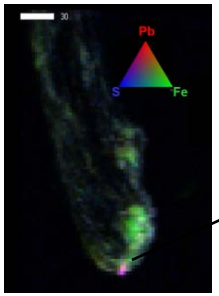
X-ray Fluorescence (XRF)

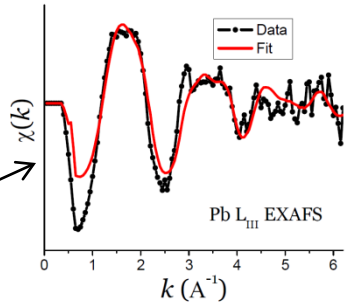


Contaminant distribution & element correlation

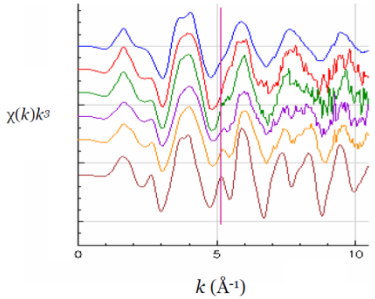
Root samples

Microbeam XAS and XRF





Bulk X-ray Absorption Spectroscopy (XANES, EXAFS)



Nano-scale contaminant bonding environment

Molecular Microbial Analyses (Maier group)

f (time, treatment)

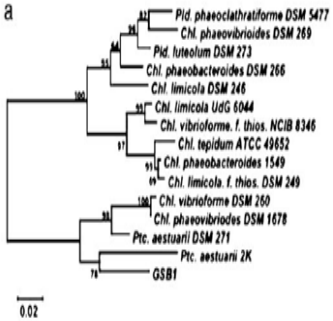
Tailings (Rhizosphere) Samples

Nucleic acids extraction

DNA

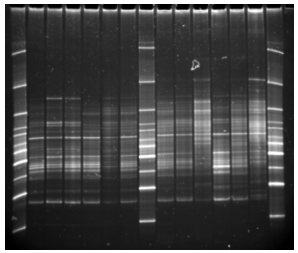
Ribosomal genes

Clone Libraries



Microbial community phylogenetic diversity

DNA fingerprint (DGGE)



Microbial community structure

Functional genes

Functional gene microarrays (Geochip)

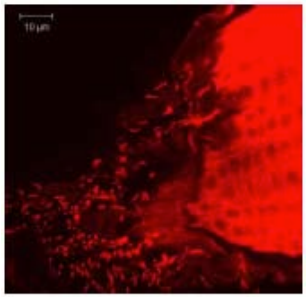
Microbial community metabolic potential

Root samples

RNA

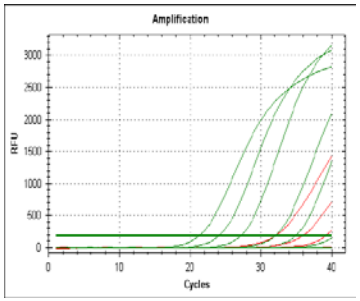
Cells fixation

Fluorescent In-situ Hybridization (FISH)



Visualization of cell-contaminant associations

RT-qPCR



Quantification of gene expression and abundance

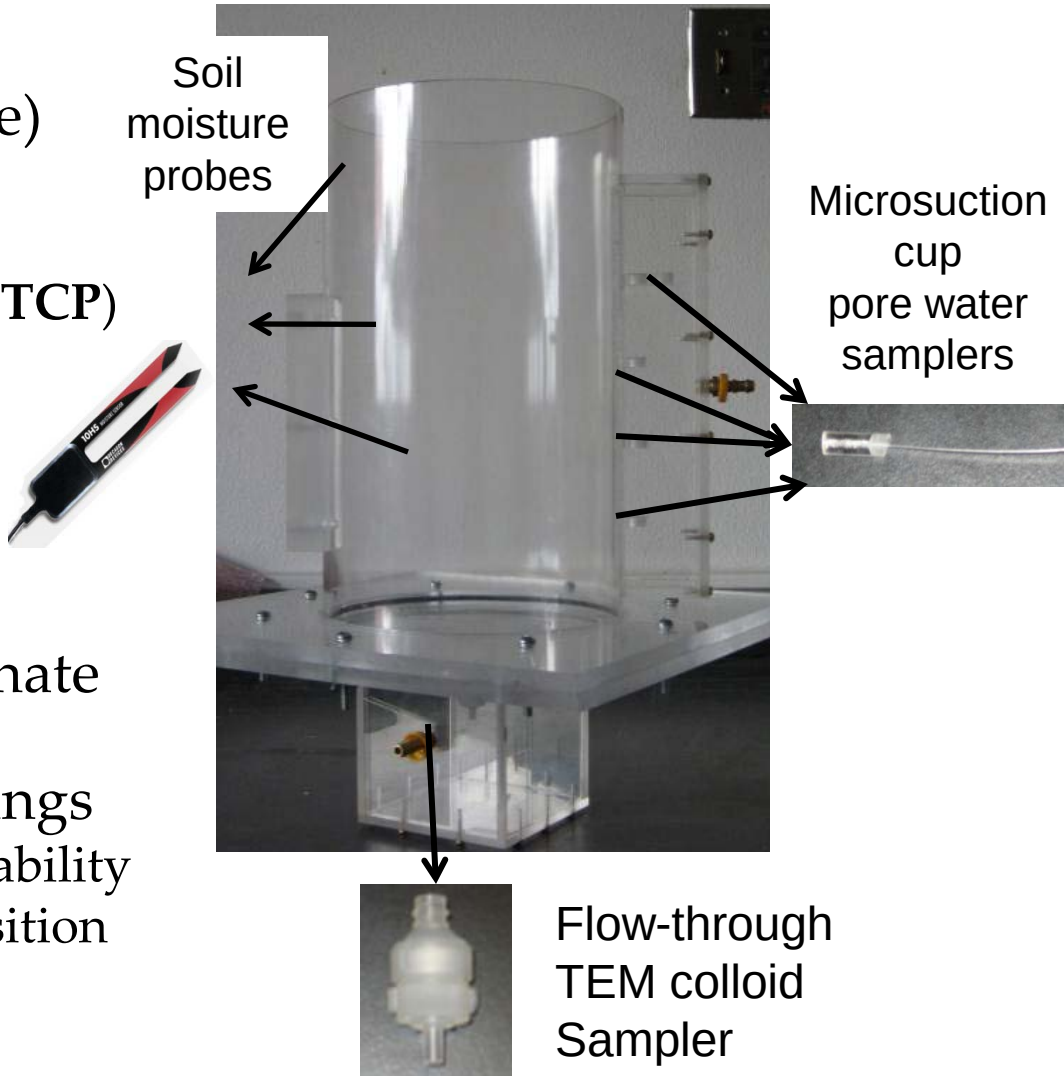
Site Characterization: Klondyke tailings contaminant speciation prior to phytostabilization (from XAS, XRD, Raman microspectroscopy)

- Pb
  - Plumbojarosite
    $PbFe_6(SO_4)_4(OH)_{12}$
  - Pb sulfate
    $PbSO_4$
  - Hydroxide-sorbed Pb
- Zn
  - Hemimorphite
    $Zn_4Si_2O_7(OH)_2 \cdot H_2O$
  - Zn talc
    $(Zn_{0.8}Mg_{0.2})_3Si_4O_{10}(OH)_2$
  - Zn sulfate
    $ZnSO_4$
  - Hydroxide-sorbed Zn

Hayes et al., in prep.

Klondyke tailings mesocosm experiments

- 115 day phytostabilization experiment
- Three treatments (in triplicate)
  - Tailings only (**TO**)
  - Tailings + Compost (**TC**)
  - Tailings + Compost + Plants (**TCP**)
- Columns
  - 19 cm diameter
  - 27 cm height
- Tracked dynamic changes in water content, pore water metal(loid) distribution, leachate composition
- Pre- and post analysis of tailings
  - metal speciation and bioavailability
  - microbial community composition



Conclusions

- Klondyke mesocosm studies indicate effects of organic matter additions and plant growth on Zn, Mn and Pb mobility.
- Organic matter additions affect microbial community composition.
- In amended tailings, weathering of primary silicate johannsenite ($CaMn^{(II)}Si_2O_6$) to form biogenic birnessite ($Mn^{(IV)}O_2$) results in Zn and Pb sorptive sequestration (root plaques and grain surfaces).
- Planted mesocosms showed reduced mobility and bioavailability of Zn and Mn than controls, but less pronounced for Pb and Cd.

Next up: Iron King NPL site mine tailings
Upscaling to larger instrumented mesocosms