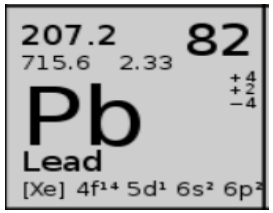


# Geochemical controls on **mobilization of metals from** tailings and implications for cover amendments

**Linda Figueroa[1], Sarah Doyle[2]**

1: Colorado School of Mines
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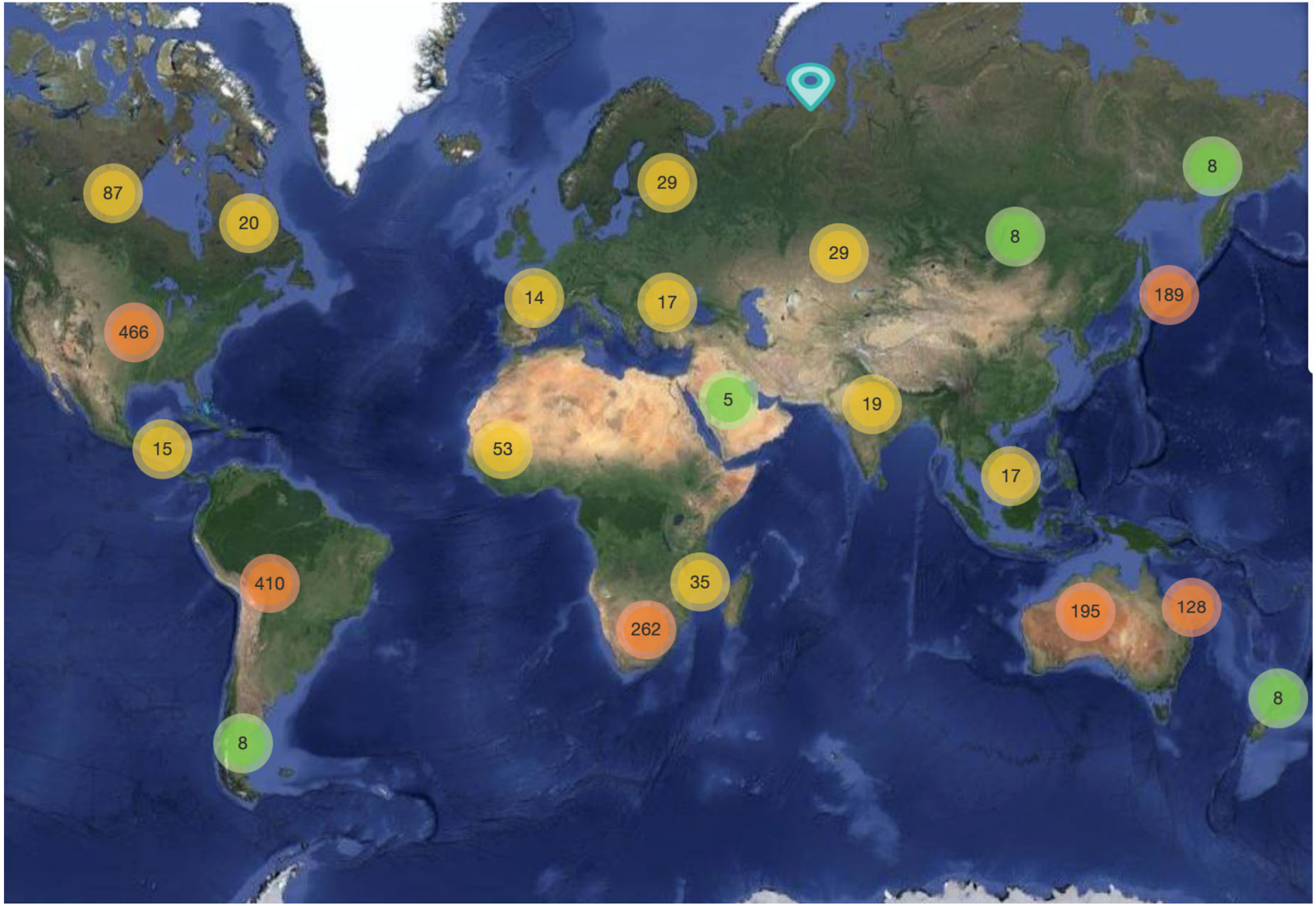
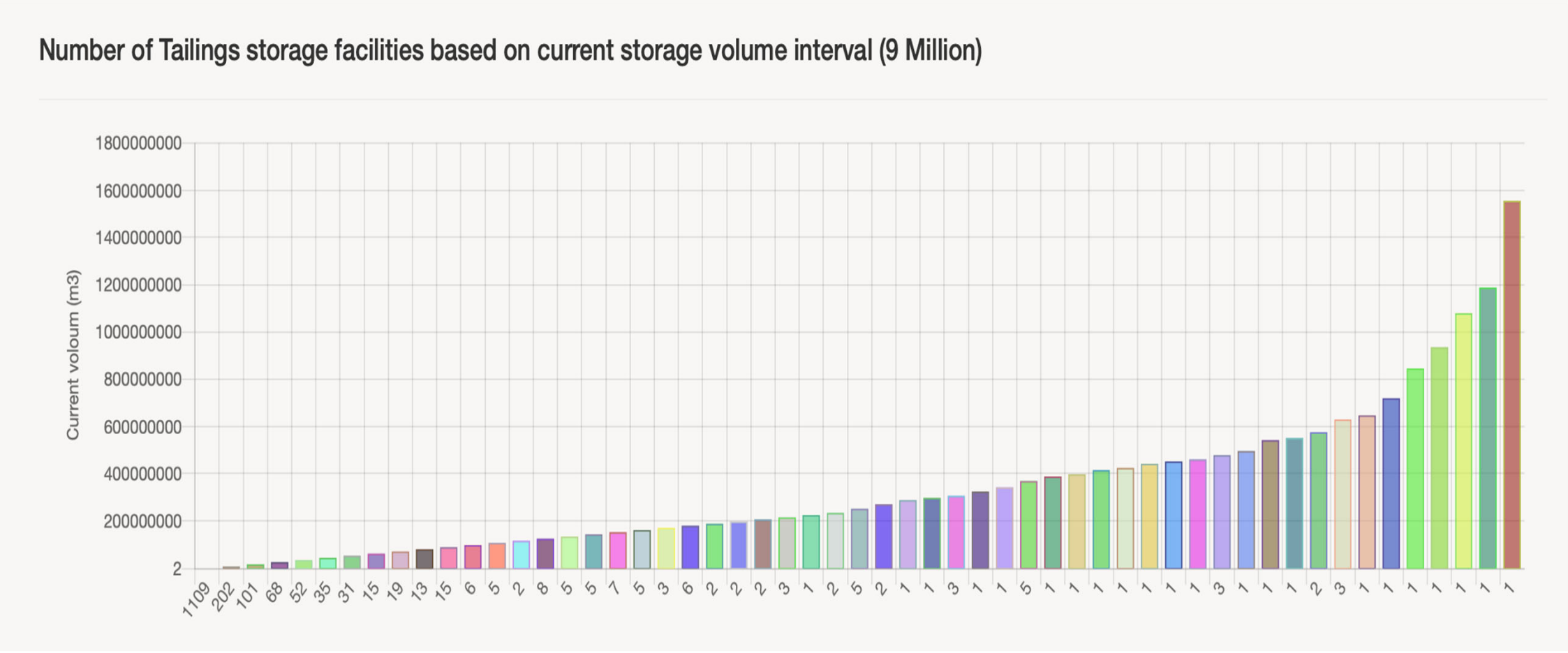
WVTF IMWA 2024

# World-wide tailings facilities location reported by Industry




https://tailing.grida.no/map/maps/

# World-wide tailings facilities volume reported by Industry




https://tailing.grida.no/map/overview/

# Motivation

## Potential Environmental impacts from Tailings, Waste Rock and Mine Drainage

- Fresh rock surfaces are exposed to atmospheric conditions
- Oxidation & mineral dissolution cause metals-laden drainage
- Drainage often requires treatment
- Dust produced from erosion mobilize by wind and human activities

Historic mine wastes near Leadville, Photo: Sarah Doyle

Tailings Facility, Questa, Photo: Sarah Doyle

# Metals Mobilization Reported from Typical Amendments

| Amendment | Metals Mobilized | | | | Reference |
|---|---|---|---|---|---|
| | Cu | Cd | Pb | Zn | |
| Sewage sludge | ✓ | | | | Andrés and Francisco 2008 |
| Sewage sludge | | | | ✓ | Andrés and Francisco 2008 |
| Sewage sludge | | ✓ | ✓ | | Harwood et al. 1986 |
| Leaf cover | | | ✓ | | Harwood et al. 1986 |
| Composted yard waste | | ✓ | ✓ | ✓ | Schwab et al. 2006 |
| Composted cattle manure | | ✓ | ✓ | ✓ | Schwab et al. 2006 |
| Aged cattle manure | | ✓ | ✓ | ✓ | Schwab et al. 2006 |

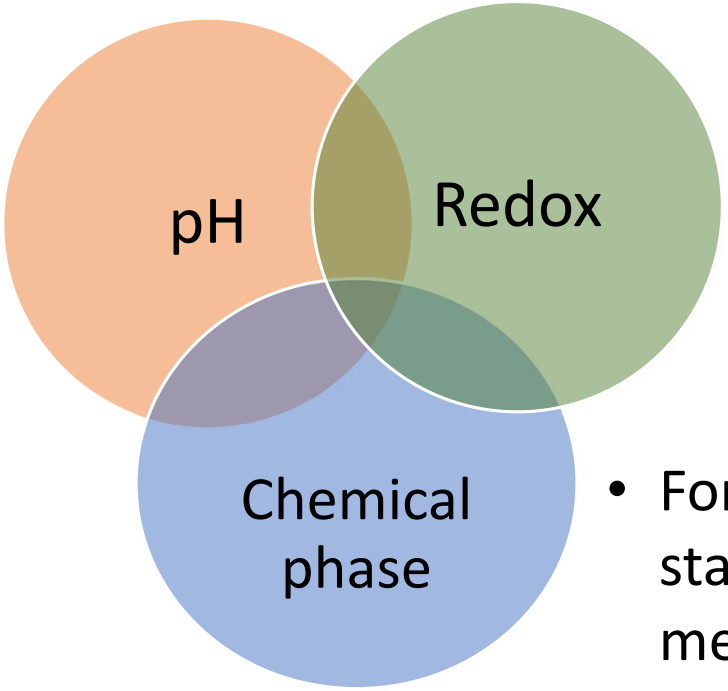
Andres, NF and Francisco, MS, 2008, Effects of sewage sludge application on heavy metal leaching from mine tailings impoundments, Bioresource Technology, Vol. 99, Issue 16.

Harwood, JJ, Koirtyohann, SR, and Schmitt, CJ, 1986, Effects of Cover materials on leaching of constituents from dolomitic lead mine tailings, Water, Air, and Soil Pollution, 34, pp 31-43.

Schwab, P, Zhu, D, Banks, MK, 2007, Heavy metal leaching from mine tailings as affected by organic amendments, Bioresource Technology, Vol. 98, pp. 2935-2941.

# Goal: Characterize Metal Mobilization from Potential Geochemical Changes Induced by Cover Amendments

- Organic acids
- Fertilizers




- Reducing conditions from organics
- Changes to oxygen flow in pile

- Formation of stable organic-metal aqueous phases

# Methods to Characterize Metal Mobilization Potential of Waste

- Elemental Composition

  Microwave assisted acid-digestion, followed by ICP-AES

- Sequential Extractions (Tessier et al. 1979)

| Fraction 1 | Fraction 2 | Fraction 3 |
|---|---|---|
| • Exchangeable<br>• 1 M $MgCl_2$ pH 7 | • Carbonate Bound<br>• 1M sodium acetate pH 5 | • Fe and Mn oxide bound (reducible)<br>• 0.04M hydroxylamine hydrochloride in 25% acetic acid |

*Modified Tessier et al. 1979 method, with F4 (bound to organic carbon) omitted

# Amendment Extraction Methods

- Leach tests with amendment solutions
  - 1 g rock + 20 mL extraction solution
- Extraction of Waste Rock + Amendments
  - 1 g rock + 0.5 g amendments
  - 1 M $MgCl_2$ at pH 7
- Analysis
  - Filter 0.45 microns
  - ICP-OES

## Amendments used in Leach Tests

| Amendment(s) | Source | Solution Description | Initial pH of Solution |
|---|---|---|---|
| None | -- | Deionized Water | -- |
| Topsoil | EarthGro Topsoil | Extraction* | 7.1 |
| Spent Brewery Grain | Green Mountain Beer Company, Lakewood, CO | Extraction* | 3.8 |
| Biochar | Biochar Solutions, Lafayette, CO | Extraction* | 9.1 |
| Compost | 3XM Grinding & Compost, Olathe, CO | Extraction* | 8.4 |
| Compost/Biochar | Biochar Solutions and 3XM Grinding & Compost | Extraction* | 8.5 |
| Soil Media** | Proganics™ Biotic Soil Media (Profile 2020) | Extraction* | 6.8 |
| Phosphate | Calcium phosphate monobasic monohydrate | 4 mmol P/L | 5.7 |

*Extraction Solution prepared by drying solids for 48 hours at 40 degrees C, followed by extraction with deionized water for 48 hours at room temperature and constant mixing.

** Soil Media is Proganics™ Biotic Soil Media, produced by Profile Products

# Waste Material Composition

## Average Elemental Composition (% by mass)

| Al | Ca | Cu | Fe | K | Mg | Mn | P | Pb | S | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.3 | 2.5 | 0.75 | 4.4 | 0.45 | 0.33 | 1.3 | 0.12 | 3.5 | 1.0 | 0.80 |

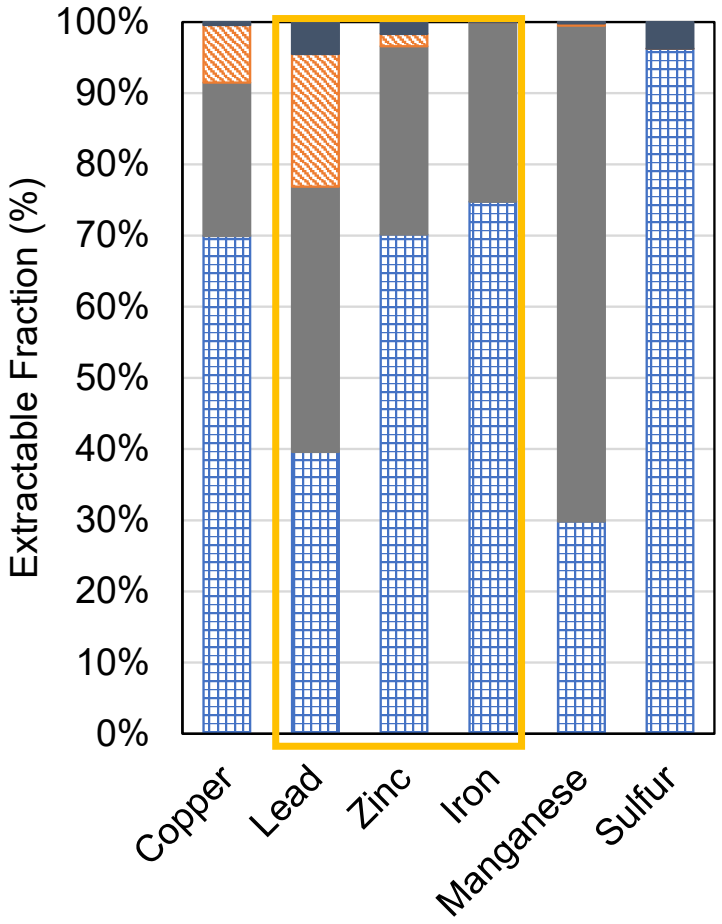
**35,000 mg/kg Pb**: in waste material

**1,000 mg/kg Pb:** typical cleanup level for industrial site (EPA 2015)

**1.8 mg/L Pb**: concentration if 1% of lead mobilized (20:1 water to waste material)

**0.01 mg/L Pb**: Chronic aquatic life standard (hardness of 400 mg/L, CCR 1002-34)

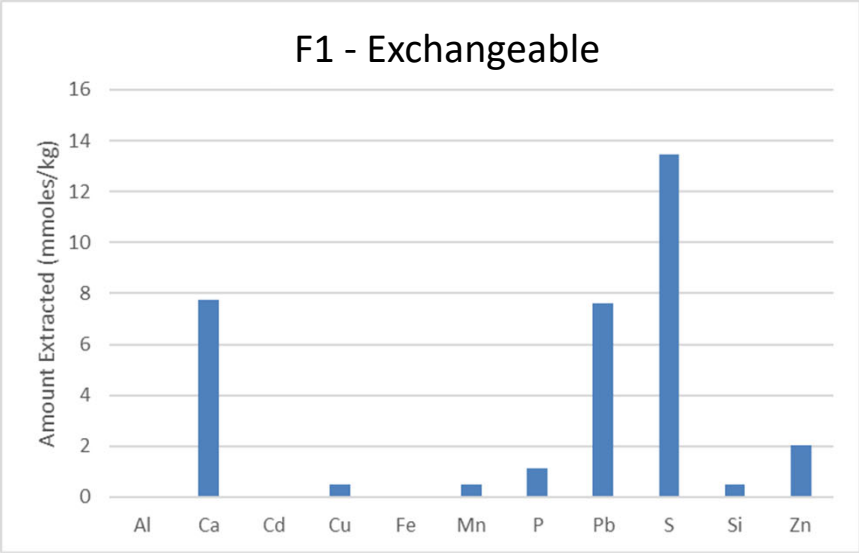
# Metal Fraction Association

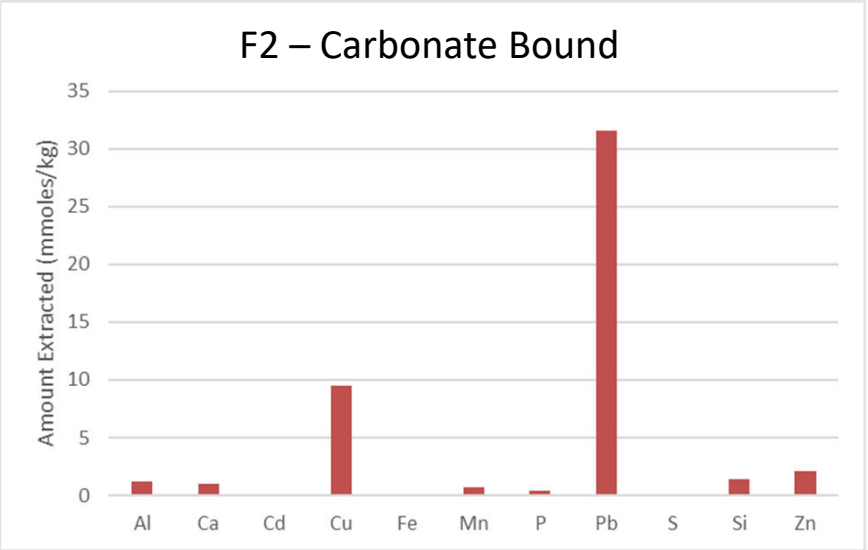


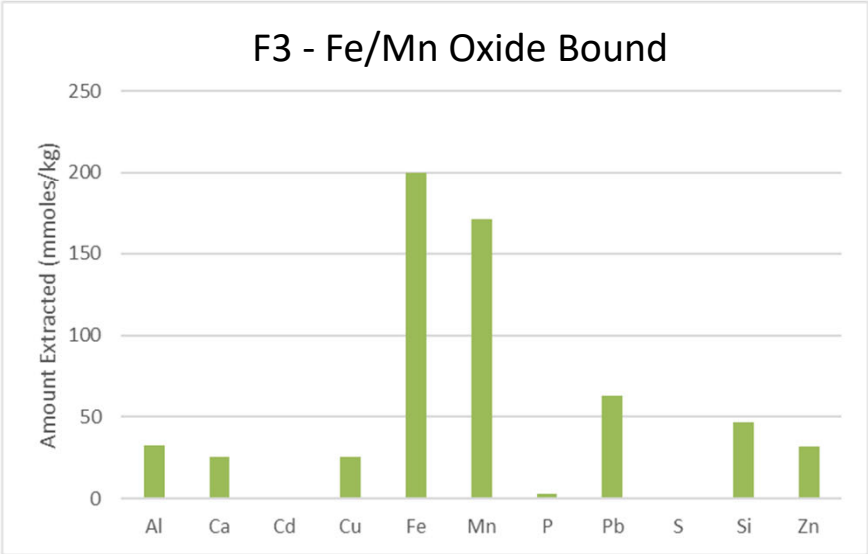

- Potential weathering impact
- Large fraction associated with Fe & Mn oxides:
  - 22% of Copper
  - 37% of Lead
  - 26% of Zinc

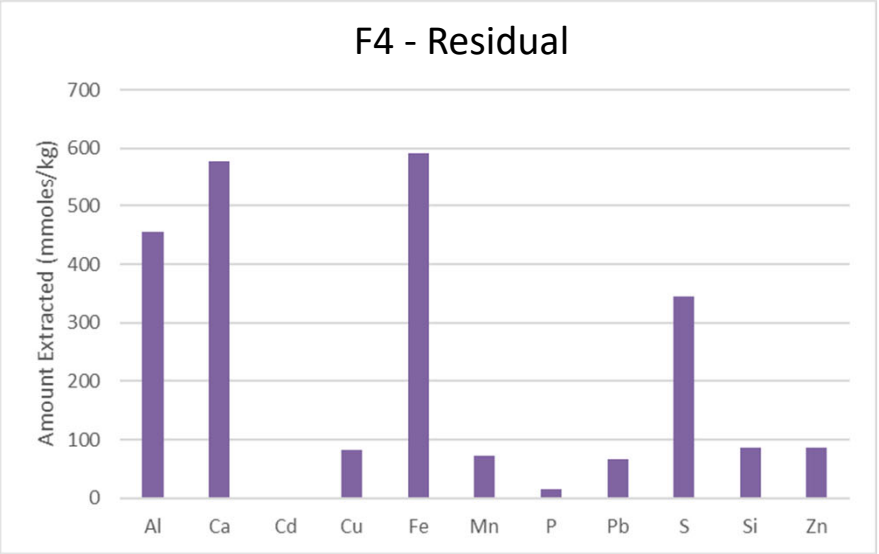
**Cover amendments that produce strongly reducing conditions will mobilize metals**

# Metal Mass Association

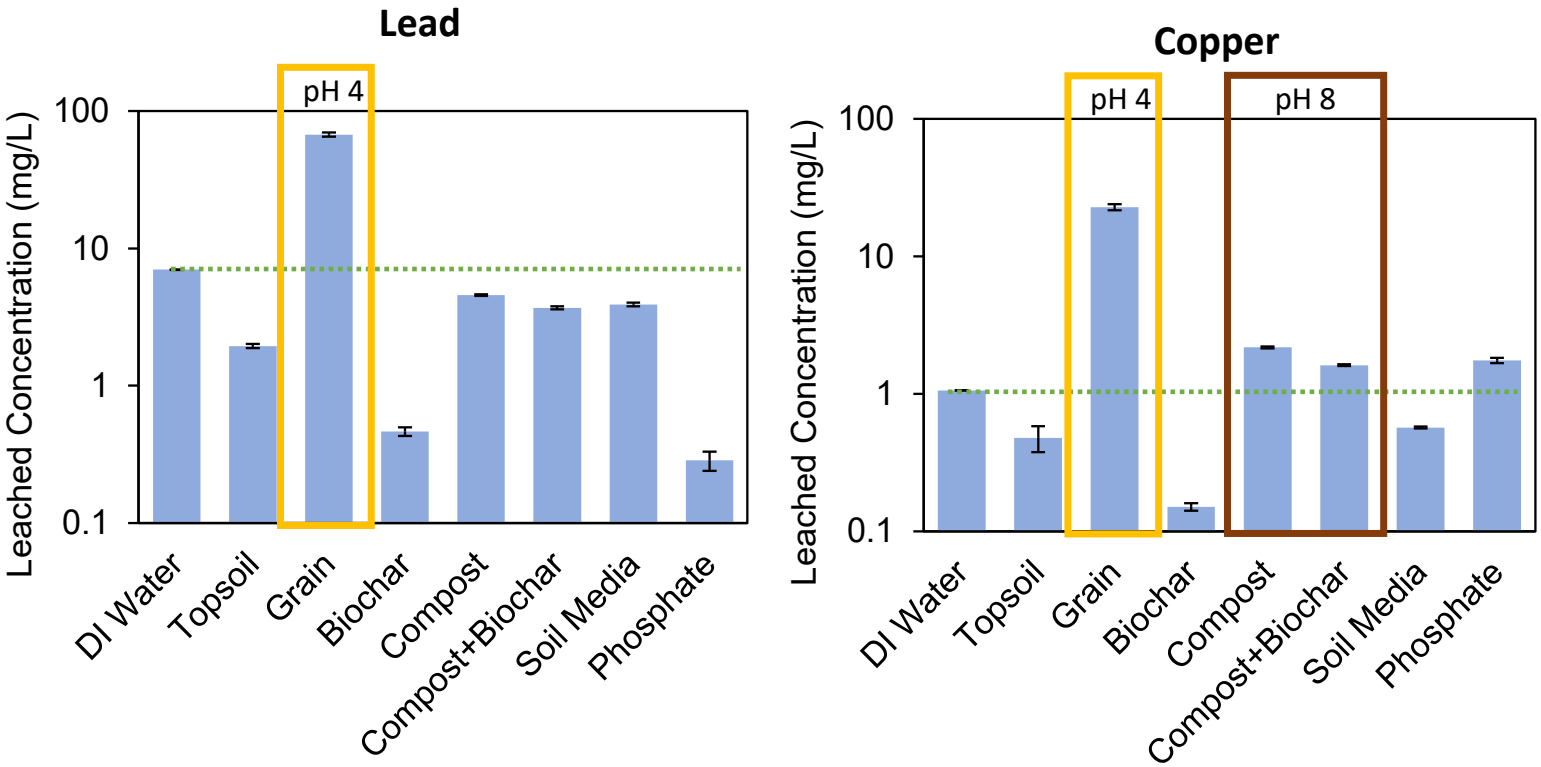


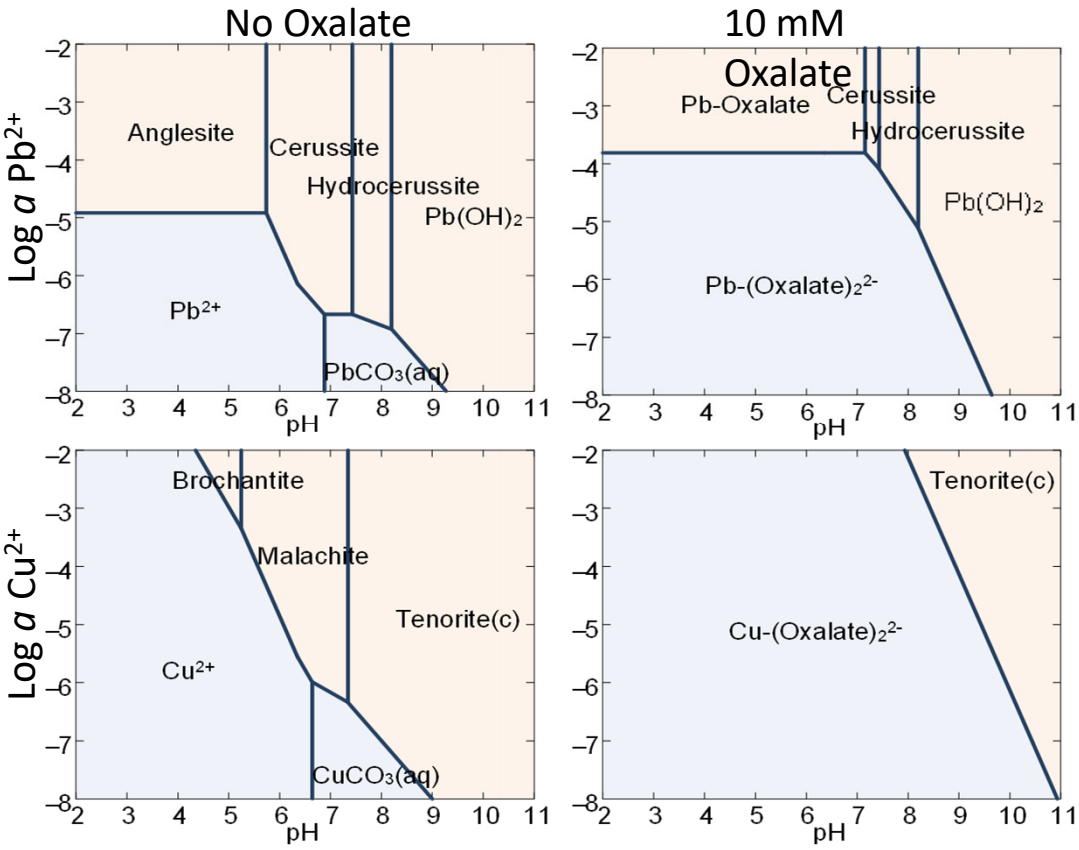
# Metals Mobilization by Amendment Leachate




**Low pH of brewery grain caused dissolution of cerussite/lead phosphates and desorption of metals from oxides**

# Controls on Metals Mobilization: Aqueous Metal-Organic Complexes

- Formation of stable aqueous metal-organic complexes possible
- Copper complexes are more stable than for Pb
- Contribute to Cu mobilized by compost



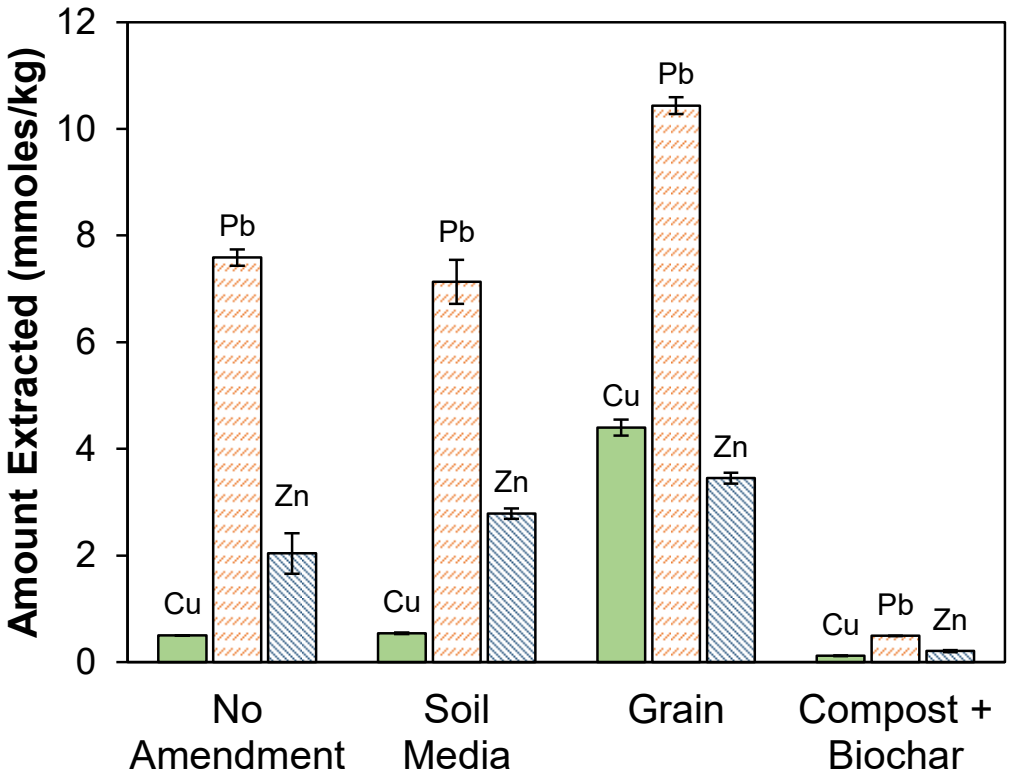

Diagrams created with Visual MINTEQ database formatted for Geochemist Workbench

# Controls on Metals Mobilization: Waste/Amendment Extracts

Biochar + compost decreased exchangeable fraction of Pb, Cu, and Zn by 87% (avg.)

Soil media did not reduce metals mobilization relative to DI control

Brewing grain increased Cu, Zn and Pb leaching compared to other treatments



# Acknowledgements


- James Ranville, Colorado School of Mines
- David Heinze, Ramboll
- Jim Gusek (retired) and Lee Josselyn with Linkan Engineering
- Tom Clark with Cemvita
- Jonah Levine with Biochar Solutions Inc.
- Green Mountain Beer Company

# Treatment Implications for Tailings and Waste Rock

- Identifying metal phases critical
- Sequential extraction effective for waste characterization
- Extraction with waste/amendment mixture critical
- Knowledge of metal phases allows for more effective field trials
- Organic amendments with low pH and high soluble carbon present the greatest risk

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