MICROANALYTICAL TECHNIQUES TO UNDERSTAND ELEMENT LEACHING FROM ORE MINERALS IN MINING WASTES

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Hemimorphite
sciencephoto.com

Hydrozincite
minfind.com

Sphalerite
surreyminerals.com

Willemit
John Schneider Photo

Smithsonite
iRocks.com
Purpose of USGS Geoenvironmental Assessment (Monomineral) Study:

Mineralogy in mining waste is complex—ore bodies host many minerals and these minerals host many individual elements. This study examines nearly pure zinc mineral phases knowing that they are not pure.

The bioavailability of a potentially toxic element is dependent on:
- element speciation in the mineral-host
- the mineral’s physical properties
- the distribution, or residence of the element of interest in the mineral
Objective of USGS Geoenvironmental Assessment (Monomineral) study:

To further understand the bioavailability of elements of concern such as As, Cd, Cu, Co, Fe, Hg, Mn, Ni, Pb, and Zn in complex mine-waste material by studies on monomineralic samples.

Demonstrate the importance of mineralogical characterization for better prediction of Acid Rock Drainage (ARD).

Direct characterization methods to identify mineralogy, locate residence of minor to trace elements, study weathering textures, and formation of secondary minerals:
## Microscopic Analytical Approach

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineralogy</td>
<td>Petrographic Microscope</td>
<td>Mineral species; acid or non-acid generating</td>
</tr>
<tr>
<td></td>
<td>Scanning Electron Microscope</td>
<td>Particle size, Mineral textures; cleavage, etching Structure Weathering features</td>
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<tr>
<td></td>
<td>X-ray Diffraction</td>
<td>Mineral species</td>
</tr>
<tr>
<td>Trace Metals</td>
<td>Microprobe</td>
<td>Exact residence of trace metals Spatial distribution of trace metals</td>
</tr>
</tbody>
</table>
Leaching Studies:

Importance:

Identify and characterize constituents that are mobilized from these minerals upon exposure to water.

The USGS Field Leach Test (FLT) provides specific answers to understand how minerals would act if leached in the natural environment.

- Utilizes DI water, a short agitation period (5 minutes), and a 20:1 leaching ratio—this allows results to be compared to results of the EPA 1311 and 1312 methods.

- Resulting leachate identifies the constituents that would be mobilized due to leaching by natural precipitation (rain, snow)
Selected Elements (FLT leachate) releases readily soluble phases

![Graph showing log leachate concentration (ug/L) for various elements at different pH values.](image)

- pH 6.6
- pH 6.1
- pH 7.1
- pH 7.2

Elements: Al, As, Cd, Co, Cu, Mn, Ni, Pb

Inset: Graph showing Zn FLT leachate concentration in log scale.
**Sphalerite**

*Creede Vein*

**Balmat SEDEX**
(sedimentary exhalative)

**Note:**
Alteration minerals along fractures. Mineral inclusions such as pyrite.

**Note:**
Mineral inclusions such as galena.
Pyrite and galena are below detection limits of XRD; therefore a variety of techniques are needed to identify all minerals—especially pyrite.
Secondary minerals and amorphous phases:

- **py**
- **FeS**
- **Fe sulfates/oxides w/ Zn, As**
- **PbS**
- **PbSO4**

Scale bar: 10 μm
Hydrozincite/Willemite

Phase ID (3)
- **Hydrozincite - Zn₅(OH)₆(CO₃)₂**
- **Calcite - CaCO₃**
- **Willemite - Zn₂SiO₄**

Pie chart showing percentages:
- **Hydrozincite** = 97.4%
- **Calcite** = 1.2%
- **Willemite** = 1.4%

X-ray diffraction patterns:
- **WPF Model**
- **Measured**
Micron-size mineral inclusions include:

- Cu, Zn mineralization
- Descloizite ($\text{Pb}_2\text{Zn}_2\text{(OH)}\text{VO}_4$)
- Ag, Sb mineralization
Zn silicates are intergrown.

Hemimorphite - Zn₄Si₂O₇(OH)₂·H₂O
Willemite - Zn₂(SiO₄)
Calcite - CaCO₃
Hematite - Fe₂O₃
Hemimorphite, cont. Zn₄Si₂O₇(OH)₂·H₂O

Fe- and Mn-oxides at edges of rhombs.

Pb, Mn oxide
Smithsonite
ZnCO₃

Phase ID (4)
- Hemimorphite - Zn₄Si₂O₇(OH)₂(H₂O)
- Smithsonite - ZnCO₃
- Clinohlore 1M1a - Mg₂.5Fe₁.65Al₁.8Si₁.8Al₁.8O₁₀(CH)₈
- Quartz - SiO₂

Pie Chart
- 6.5% Hemimorphite
- 92.4% Smithsonite
- 0.9% Clinohlore 1M1a
- 0.1% Quartz

WPF Model

Measured

Two-Theta (deg)
Smithsonite, cont.

- Zn silicates intergrown with smithsonite.
- Smithsonite exhibits Ca and Cd zoning.

- Zn silicate exhibits Pb zoning.

Cd zoning in smithsonite

Cd Map
Two Zn carbonates with elevated Cd content in leachates:
- Hydrozincite
- Smithsonite

Different physical, chemical properties of Cd-bearing source material = different solubilities

> 3 wt. % Cd in smithsonite

< 3 wt. % Cd in calcite
Summary
In general:
• Trace metals are associated with characteristic geologic settings and their mineral assemblages.

• Micromineralogic analysis is useful for better prediction of trace metal release and acid rock drainage from mine waste.

Monomineral Study:
• Water-based leach tests provide a more realistic indication of “naturally” leachable Zn concentrations in this ‘monomineral’ set.

• The data we acquire on the mobility of elements and degree of solubility of minerals will be assembled in a database for use in predictive acid rock drainage models and contribute to the broader understanding of minerals in natural systems and their importance in environmental and human health studies.

Future monomineral set/study: Pb and As
Coming soon: “Techniques for Predicting Metal Mine Influenced Water”

The Acid Drainage Technology Initiative (ADTI) and Society for Mining Metallurgy and Exploration (SME) developed a series of workbooks covering the generation and prevention of acid rock drainage.

Management Technologies for Metal Mining Influenced Water Volumes:
- Basics of Metal Mining Influenced Water
- Mitigation of Metal Mine Influenced Water
- Mine Pit Lakes: Characteristics, Predictive Modeling and Sustainability

The Prediction Volume (Dave Williams, BLM, senior editor):

“Techniques for Predicting Metal Mine Influenced Water” is next in this series and presents a summary of the various predictive technologies available, as well as establishing criteria for use in evaluating some of the most commonly used predictive tests.