Evaluating acid rock drainage from road cuts in Tennessee

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In cooperation with

Tennessee Department of Transportation

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Geohazards Impacting Transportation in Appalachia
Problem

Acid rock drainage from pyrite bearing formations in road cuts and road construction

• Low pH and high trace metal concentration
• Occurrence and transport from the site
• Reduce the impact of contaminants on the environment
Objectives

- Evaluate controls on acid-rock drainage
- Define mechanisms of water and oxygen transfer
- Evaluate microbial activity that affect pyrite oxidation
Chattanooga Shale
15-30 ft thick
Trace metals
Radionuclides
Disseminated and clustered pyrite
Fentress Formation
Up to 300 feet thick
Lower unit has multiple coal/shale sequences with high pyrite -- variable
Problem primarily in NW Cumberland Plateau
Sevier Shale
Variable geochemistry
Locally high pyrite

Anakeesta Formation
abt 3,000 feet thick
Slate with sandstone
Adversely affected ecosystems in GRSM stream
Approach - Field

- Literature review
- Reconnaissance and HASP
- Identify 4 sites for sampling and evaluation
  - Access
  - Indication of ARD
  - Hydrology
  - Secondary sulfate mineralization
- Analysis for water and rock chemistry and microbial activity (sample wet and dry periods)
Approach - Lab

- Geochemical reaction tests
- Bacterial tests to determine type present
- Microcosm test to evaluate microbial effect and control on pyrite oxidations
- Storage / rinse out of metals from SSM
Approach - Lab

- Geochemical reaction tests
- Bacterial tests to determine type present
- Microcosm test to evaluate microbial effect and control on pyrite oxidations
- Storage / rinse out of metals from SSM
Fentress County
Fentress Formation

Large spoil pile / disposal area

Seeps occur along coal/underclay sequence in cut
Fentress County
Fentress Formation

Large spoil pile / disposal area

Seeps occur along coal sequences in cut
Fentress Formation
Field parameters

Low pH seep near coal seam

pH 2.7, SC 2,200

pH 2.9, SC 1,900
Fentress Formation
Field parameters

Low pH seep near coal seam

pH increase and SC varies with flow along road ditch and rip-rap

pH 7.4, SC 1,600
pH 6.0, SC 2,000
pH 2.7, SC 2,200
pH 2.9, SC 1,900
pH 3.8, S.C. 1,830

300 ft
Chattanooga Shale – Williamson Co

Long lateral exposure of shale
Vertical exposure on bench cut
Shale breakdown at base of cut
Multiple seeps;
  overlying Fort Payne
top of Chattanooga
shale rubble
underlying limestone
pH 7.6, SC 1,250
Al <20
SSM on Chattanooga Shale

Mineralization occurring as edge rind on chips and within shale plates
Chattanooga Shale - Hickman county
SSM at Hickman

Mineralization covers nearly full face of road cut.

Multi-colored – different metal accumulation (??)

Potential source of low pH and high metal

Little water – almost none in January 2014
Gypsum $\rightarrow$ Anhydrite $\rightarrow$ increasing trace metals (accumulation)

SSM Dissolution $\rightarrow$ gypsum $\rightarrow$ ?? (release)
1. Compare pH lowering potential of weathered and unweathered shales

Batch Experiment

• 150 ml of three representative shale samples used

• Weathered, shaley-limestone, and unweathered

• Electronic mixer and mounted pH probe was used
1. Compare pH lowering potential of weathered and unweathered shales
Summary

• Cooperative investigation with TDOT to evaluate ARD from road cuts.

• Primary pyrite-bearing formations are Chattanooga Shale, Fentress Formation, and Anakeesta units.

• Low pH and high trace metals, very high Al from Dc seep

• SSM can result in rapid change in pH and metals
Questions ??
Bacteria

Recharge
DO

Groundwater

Oxidation of pyrite

Acidithiobacillus sp.
Thiobacillus sp.

Acidic water

High Volume
Runoff

Low Volume
Dry Season
Evaporation

Transport of acidic water and dissolved metals

Fe, Al, and Metal Sulfate co-precipitation

Sulfate mineral dissolution
Release of acid, runoff of dissolved metal and sulfate

Rainfall

Gypsum precipitation
Highway 840

Secondary Sulfate Minerals (SSM)

Weathered

Unweathered
Flume run results

![Graph showing HYDRONIUM (H3O) IONS AND NACL over time and concentration.](image-url)
# Bacteria Types

<table>
<thead>
<tr>
<th>BACTERIA TYPE</th>
<th>SIGNIFICANCE OF BACTERIA TYPE</th>
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<tbody>
<tr>
<td>Total aerobic heterotrophic bacteria (HAB)</td>
<td>Aerobic heterotrophic bacteria are efficient at metabolizing carbon food, are desired for aerobic degradation processes and to initially deplete competing electron acceptors for anaerobic processes.</td>
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<tr>
<td>Iron-related bacteria (IRB)</td>
<td>Iron-reducing bacteria are relatively efficient at biodegrading petroleum hydrocarbons and other simple organics. Active in aerobic processes with ARD</td>
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<tr>
<td>Sulfate-related bacteria (SRB)</td>
<td>Sulfate-reducing bacteria function in strongly reducing conditions and typically use fermentation products as food. Sulfur-oxidizing bacteria use sulfide as a food source.</td>
</tr>
<tr>
<td>Acid-producing bacteria (APB)</td>
<td>Bacteria that switch to fermentation metabolism when O₂ is limiting, producing organic acids by-products, acetate &amp; lactate</td>
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<tr>
<td>Slime forming bacteria (SLYM)</td>
<td>SFB are a consortium of bacteria that tend to form biofilms by adhering to hard surfaces. This is critical for maintaining bacteria populations in the subsurface.</td>
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</tbody>
</table>
Bacteria
Identifying bacteria types – Biological Activity Reaction Test (BART)

Aerobic, facultative anaerobe

Anaerobic, facultative anaerobe

Aerobic, facultative anaerobe

Anaerobic, facultative anaerobe
XRF Lower Concentrations

![Bar chart showing concentrations of various elements in Shale with SSM and Non-weathered Shale](image-url)

- Elements: Mo, Zr, Sr, U, Rb, Th, Pb, As, Hg, Zn, Cu, Ni, Mn, Cr, V, Ba, Cs, Te, Nb, Cl, SiO2, Fe2O3, Al2O3, K2O, CaO

- Y-axis: Concentration (PPM)

- Shale with SSM
- Non-weathered Shale
Transient Storage for Flume Table

Reduced Hydronium Concentration vs. Time (seconds)
Transient Storage for Flume Table

- Reduced NaCl Concentration
- Time (seconds)

- Model
- Data