LEACHING POTENTIALS OF COAL SPOIL: EFFECTS OF ROCK TYPE AND DEGREE OF WEATHERING

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Past surface mine pre-mining analytics focused on:

(1) AMD potential, and (2) Revegetation potential

Now we need to consider:

(3) TDS POTENTIAL
Figure by Carl Zipper

RECLAIMED VALLEY FILL

- Organic horizon forms at surface
- Rainfall Infiltration
- Tree roots
- Low TDS spoil
- High TDS Spoils are isolated from hydrologic flows
- Woody vegetation/mature trees
- Subsurface flow toward stream channel
- Ephemeral channel (as represented by surface contours) flows into larger channel
- Stream
OBJECTIVES

1) To characterize the potential leaching behavior of mine spoil materials, in terms of:
   • pH
   • EC
   • Major cation and anion composition

2) To evaluate leaching behavior with respect to:
   • rock type
   • degree of weathering
Column leaching conducted on 55 diverse spoil samples from lower to middle-Pennsylvanian age strata:

<table>
<thead>
<tr>
<th>ROCK TYPE</th>
<th>WEATHERING</th>
<th># OF SAMPLES</th>
<th>CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>unweathered</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(un)weathered</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>weathered</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Mudstone</td>
<td>unweathered</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(un)weathered</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>weathered</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Black shale</td>
<td>unweathered</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Mixed spoil</td>
<td>unweathered</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(un)weathered</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

(un)weathered – partially weathered or mix of weathered and unweathered material
BULK SAMPLES (2 5-gal buckets) were each:

- Spread out to air-dry.
- Passed through a 1.25 cm (0.5”) sieve.
- Coarse fraction was crushed to <1.25 cm.
- All material was thoroughly re-blended.
- Subsamples (1200 cm³, with mass recorded) were collected (cone and quarter) for column leaching, to determine pore volume (within columns), and to determine coarse particle size distribution.
- Subsamples were collected and crushed as appropriate for basic characterization including saturated paste pH/EC and total-S.
COLUMN SETUP

- Sample volume: 1200 cm$^3$
- Inside diameter = 7.5 cm
- Height of spoil = ~ 27 cm
- Inside bottom of column:
  - 5 cm (2") sand
  - Whatman #1 filter
  - 0.1 mm nylon mesh
  - perforated plastic disc
- PVC pipe nipple and Tygon tubing for drainage
• Each spoil material was run in triplicate (3 columns/material)
• Unsaturated: samples initially moistened to maximum water holding, then any amount added = amount drained.
• Leaching solution: synthetic acid rain with pH=4.6
  Contains very low amounts of CaSO$_4$, K$_2$SO$_4$, Mg$_2$SO$_4$, NaCl, NaNO$_3$, NH$_4$NO$_3$, (NH$_4$)$_2$SO$_4$, H$_2$SO$_4$, HNO$_3$, H$_3$PO$_4$)
  (Recipe from Halvorson and Gentry, 1990)
• Simulated rainfall was applied 2x/week (Mon/Thurs)
• Each rainfall event = 125 ml (~2.5 cm; 1”)
• Leachate (~125 ml) collected after ~24 hrs (Tues/Fri).
• Samples analyzed for: pH, EC, cations, bicarbonate, sulfate, and chloride
PARTICLE SIZE IN COLUMNS

- <0.25 mm (< med sand) 5 - 24%
- 2 - 0.25 mm (coarse/med sand) 5 - 49%
- > 2 mm (coarse fragments) 45 - 92%
Saturated paste EC

Number of samples per category

EC uS/cm (saturated paste)

- unweathered ss: 13
- weathered ss: 3
- unweathered ms: 11
- weathered ms: 4
- black shale: 4
- all spoils: 55
THREE REPLICATES PER MATERIAL
VERY GOOD REPLICATION

- unweathered SS
- unweathered MS
- BLACK SHALE

EC (uS/cm) vs. leach #
THREE REPLICATES PER SPOIL
VERY GOOD REPLICATION
Most samples had porosity between 25 – 45%.

Both samples <500 uS/cm at 1.8 pore volumes.

EC < 500 uS/cm at 5 vs 8 leach events
SANDSTONE: Weathered spoils tend to equilibrate at lower pH values than unweathered spoils.
MUDSTONE: Weathered spoils tend to equilibrate at lower pH values than unweathered spoils.
OVERALL NO MAJOR pH DIFFERENCES BETWEEN SANDSTONES AND MUDSTONES
HIGHLY ACIDIC pH OBSERVED ONLY FROM BLACK SHALES
SANDSTONE: All weathered and most unweathered samples equilibrated to <500 uS/cm.
MUDSTONE: All weathered and several unweathered samples equilibrated to <500 uS/cm.
Overall: finer grain size = higher EC/greater TDS.

Only one BLACK SHALE equilibrated ~500 uS/cm
TDS ELEMENTAL COMPOSITION: weathered SS

- 826 mg/L
- 293 mg/L
- 29 mg/L

% of TDS by mass

Leach #

Legend:
- Ca
- Mg
- Na
- Al
- K
- Fe
- Cations
- Sulfate
- Chloride
- Bicarbonate
L1: 4.9 mmol+/L

L39: 0.4 mmol+/L

% of TDS by mass

leach #

Ca
Mg
Na
Al
K
Fe
cations
sulfate
Cl
bicarb
TDS RELATIVE ELUTION OVER TIME: MAJOR CATIONS

weathered SS

values scaled to 100%

leach #

Ca 126 mg/L
Mg 91 mg/L
Na 27 mg/L
Al 7 mg/L
K 5 mg/L
EC 1451 uS/cm
TDS RELATIVE ELUTION OVER TIME: MAJOR ANIONS
weathered SS

values scaled to 100%

100%

sulfate 489 mg/L
Cl 77 mg/L
bicarb 23 mg/L
EC 1451 uS/cm

leach #
TDS ELEMENTAL COMPOSITION: unweathered SS

639 mg/L
425 mg/L
232 mg/L

% of TDS by mass

leach #

Ca
Mg
Na
Al
K
Fe
cations
sulfate
Cl
t bicarb
TDS RELATIVE ELUTION OVER TIME - MAJOR IONS
unweathered SS

values scaled to 100%

leach #

Ca 50 mg/L
Mg 83 mg/L
Na 11 mg/L
Al 1 mg/L
K 19 mg/L
sulfate 384 mg/L
Cl 51 mg/L
bicarb 220 mg/L
EC 1002 uS/cm
TDS ELEMENTAL COMPOSITION: Black Shale

% of TDS by mass

leach #

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39

Ca Mg Na Al K Fe cations sulfate Cl bicarb
TDS RELATIVE ELUTION OVER TIME - ANIONS
Black Shale

values scaled to 100%

leach #

100%
- sulfate: 4261 mg/L
- Cl: 42 mg/L
- bicarb: 12 mg/L
- EC: 5413 uS/cm
Summary

• TDS elution is directly related to the source strata and extent of historic weathering and oxidation.

• TDS elution appears to increase with decreasing grain size; black shales are the most problematic materials.

• Well-weathered materials typically do not appear to be problematic.
Summary

• For most samples, TDS elution was highest in the first few leach cycles, then dropped rapidly and showed little change after 10 – 15 leach cycles (about 2.5 – 5 pore volumes).

• 48 out of 55 samples evaluated in this study equilibrated to EC < 500 uS/cm.
Summary

• Elemental cation composition was dominated by Ca and Mg, with lesser amounts of Al, K, Na and Fe.

• Elemental anion composition was dominated by sulfate and bicarbonate, with lesser amounts of chloride. For several samples, sulfate was initially dominant, but over time bicarbonate became the dominant anion.
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