Geochemical Predictions of the Landusky Spent Ore Heap Leach Pads & Implications for Water Management.

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Objectives

• Site description
• Leach pad history and geochemical characteristics
• Current water management
• Water quality & management changes over time
The Landusky gold mine is located adjacent to the Zortman gold mine in the Little Rocky Mountains in Phillips County (~155 miles north of Billings)
The first mill was built in 1904 and underground mining continued off and on through to the 1970’s
A mining boom occurred in the district from 1923 - 1942. In 1942 production was shut down by the war production board.
Open pit heap leach operations began in 1979 and continued until 1996 when the proponent went bankrupt.
Reclamation is currently being done under the direction of the Montana DEQ and US BLM using the funds from the established Reclamation Bond.

Zortman Mine
L87/91 LP is one of the largest valley-filled leach pads holding ~120 million tonnes of spent ore.
Reclamation Issues

- The most significant reclamation issue is that of water management.
- There are essentially 3 water types on the site:
  1. Clean water discharge
  2. ARD - treated with HDS lime treatment
  3. Spent ore leachate - currently land applied
Spent Ore Leachate

- Heap leach pads were operated at pH conditions of ~10.
- A significant amount of sulfidic ROM ore was placed on the leach pads - which is potentially acid generating
- After operations, the leach pads were rinsed to drop the pH to circum-neutral conditions and H₂O₂ was added to the leachate to break down CN
- The solutions were then land applied in a Land Application Disposal (or LAD) area - currently still in use
Spent Ore Leachate

- The LAD relies on the cation exchange in the soils and plant uptake of constituents.
- Solutions are irrigated over the surface to enhance evaporation and minimize surface water discharge.
LAD Issues

• Need to land apply close to 100 Million Gallons of water a year - on a seasonal basis (early spring to late fall),

• Approaching the agronomic limits for NO$_3$ and Na

• Issues related to increasing concentrations of Se, SO$_4$ and other constituents in the water have lead to the evaluation of potential pre-treatment technologies

• An ARD study implied that the leach pad is potentially acid generating, current water quality suggests sulphides are oxidizing (high SO$_4$) and solutions are being buffered (pH ~6.5) therefore the metal concentrations (other than Se) have remained low
Landusky Mine Annual Total Sulfate Loads by Facility

- L-91
- L-87
- UPPER MONTANA GULCH
- LOWER MONTANA GULCH
- GOLD BUG DISCHARGE
- SULLIVAN GULCH
- L-83
- MILL GULCH
- L-85-86
- L-84
- L-79,80,81,82
- SWIFT GULCH (mine area only)
- KING CREEK (mine area only)
- X-03
- X-02
- MT-09 + MT-11
- X-01

**lbs per year**

Scale: 0 200,000 400,000 600,000 800,000 1,000,000 1,200,000 1,400,000 1,600,000 1,800,000
Landusky Mine Annual Total Metals Loads by Facility

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lbs per year
Distribution of Landusky Mine Sub-Surface Sulfate Load

- IT to GW: 24%
- IT to LAD: 9%
- IT to WTP: 1%
- IT to Sfc: 66%
Distribution of Landusky Mine
Sub-Surface Metals Load

- IT to GW: 2%
- IT to LAD: 0%
- IT to WTP: 18%
- IT to Sfc: 80%
Future Water Quality Changes?

• It is obvious that the water chemistry in the leach pad is changing
• An investigation was completed to help predict what the future changes may be in order select the best pre-treatment technology to accommodate the changes
The Field Survey Consisted of:

- paste pH and paste TDS measurements
- visual identification of:
  - rock type
  - degree of oxidation
  - degree of alteration
  - surface precipitates and staining
  - presence of visible sulfides
  - any ‘unusual’ textures
In general, samples with low pH have high TDS values due to the presence of soluble minerals on the grain surfaces. The exception is the leach pad samples for which the added alkalinity (during leaching) is maintaining near neutral pH values and contributing to TDS.
Surface ‘salts’

• Color on the leach pads was highly variable and in general not indicative of pH trends
Surface ‘salts’ - Mineralogical Analysis

- Powder XRD analyses confirm the presence of:
  - Calcite (CaCO₃)
  - Huntite (CaMg₃(CO₃)₄)
  - Jarosite (KFe₃(SO₄)₂(OH)₆)
  - Copiapite (Fe₅(SO₄)₆(OH)₂.20H₂O)
  - Akaganite (β-FeOOH)

- Single crystal XRD analyses suggest:
  - Celadonite (K(Mg,Fe)(Fe,Al)[Si₄O₁₀](OH)₂)
  - Calcanthite (CuSO₄·5H₂O)
  - Melanterite (FeSO₄).7H₂O
  - Dumortierite (Al₇(BO₃)(SiO₄)₃O₃)

Mineralogical analysis being done by B. Sheriff and H. Jamieson at Queen’s University.
Laboratory ARD Testing

- During the field reconnaissance survey, samples were collected for lab testing. Lab tests included:
  - Paste pH and conductivity on the ‘as received’ fines
  - modified acid base accounting (ABA) tests
  - inorganic carbon analyses
  - leach extraction analyses
  - forward acid titration tests
  - multi-element ICP analyses
  - net acid generation (NAG) tests, and
  - seive analyses
Modified Acid Base Accounting

![Graph showing relationships between Field Paste pH and Total Sulfur for different types of samples: Dike samples, Leach Pad Samples, Pit Samples, Tailings Samples, Waste Rock Samples.](image)
Modified Acid Base Accounting

Acid Potential (AP) in kg CaCO3/tonne equivalent vs. Neutralization Potential (NP) in kg CaCO3/tonne equivalent

- Dike samples
- Leach Pad Samples
- Pit Samples
- Tailings Samples
- Waste Rock Samples

Dike samples: 3:1
Leach Pad Samples: 1:1
Forward Acid Titration Tests

Sample pH

Volume of H2SO4 added (mL)

- Leach Pad Sample
- Tailings Sample
- Partially Oxidized Pit Sample
- Oxidized Pit Sample
- Unoxidized Pit Sample
Drilling Program

• A Becker hammer-type drill rig was used in order to minimize sample crushing and the geochemical disturbance of the samples
Instrumented boreholes installed with slotted PVC, thermistors every 15 ft & pore gas sampling tubes every 15 ft
Drill Cuttings Sampling

Samples were collected every 10 ft & paste pH and EC measured. A sub-set of samples were submitted for laboratory testing.
Paste pH Results

Field Paste pH (on 'fines') vs. Laboratory Paste pH (on 'as received fines')

Legend:
- DHL80LP
- DHL83LP
- DHL84LP
- DHL87/91LP
- DHL85LP
- DHL87LP
- DHZ84DK
- DHZ85LP

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Mining, Geotechnical and Environmental Engineers
Modified ABA Results

Acid Potential (kg CaCO3 equivalent)

Neutralization Potential (kg CaCO3 equivalent)

DHL80LP  DHL83LP
DHL84LP  DHL85LP
DHL87LP  DHL87/91LP
DHL91LP  DHZ85LP
DHZ84DK
Geochemical Characteristics With Depth

**pH**

![Graph for pH](#)

**CONDUCTIVITY (µS/cm)**

![Graph for Conductivity](#)

- Depth intervals (5 foot starting)
- DHL87/91LP
O₂, & CO₂ Characteristics With Depth (Lower elevation hole)
O$_2$, & CO$_2$ Characteristics With Depth (higher elevation hole)
Temperature Characteristics With Depth

Lower elevation hole

Higher elevation hole
Results from Instrumented Boreholes suggest:

- Leach pads are nearly fully oxygenated - i.e. O$_2$ not limited.
- Very small build up of CO$_2$ - indicating either little buffering reactions or continual flush of air through the pad.
- Temperatures close to ambient - indicating no substantial build up of heat or continual flush of air through the pad.
LAD  ? + LAD  HDS LIME TREATMENT

- Operating
- Leach Pad Rinsing and Mine Closure
- Post-Closure

- Leach Pads
- Waste Rock (highly acid generating)
- Waste Rock (moderately acid generating)

pH vs. TIME
• Pre-treatment prior to LAD is required before Spring 2002
  – Removal of NO$_3$, Se & CN
• Applied Biosciences out of Salt Lake were selected
• Technology utilizes reducing bacteria that are relatively temperature tolerant
• Pilot plant studies completed in late 2000
• Full scale plant now commissioned - however…
• Water quality has changed since pilot plant studies
• An aluminum precipitate is now causing problems - must be sorted out before Spring 2002
Se Trends Over Time in Landusky Leach Pads

Concentration of Se (mg/L) vs. Date

- L-87
- L-91

Date:
- 3/11/1997
- 9/27/1997
- 4/15/1998
- 11/1/1998
- 5/20/1999
- 12/6/1999
- 6/23/2000
- 1/9/2001
- 7/28/2001
- 2/13/2002
Trying to define the Al problem

Concentration (mg/L)

L87 (pH=6.53)
L91 (pH=6.55)
Trying to define the Al problem

Phase boundaries after Nordstrom (1982)
Trying to define the Al problem

Phase boundaries after Nordstrom (1982); $a_{SO_4^2-} = 10^{-2}$
Conclusions & On-going Work

• It appears to be assumed that once rinsed the spent ore leachates will be dischargeable
• The water quality predictions associated with potentially acid generating spent ore are complex
• Likely to become more complicated by reclamation measures such as regrading, placing covers etc.
• At Landusky, most of the water to be managed comes from one large leach pad that does not behave predictably and is extremely variable and dynamic
• Water management strategies must therefore also be dynamic
Conclusions & On-going Work

• More frequent and detailed water quality will be taken
  – continuation of in-situ measurements of pH, SC, DO2 and Temp
• Adaptations to the biotreatment plant are being evaluated to remove Al prior to treatment
• Potential *in-situ* (i.e. in the pad) treatments are being assessed that may increase the pH within the pad until such time as the Se and NO₃ can be reduced
  – These potential treatments cannot use caustic due to near agronomic limits of Na on the LAD