Improvements to the water quality of the Berkeley Pit lake, Butte, Montana

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Talk outline

• Trends in pit-lake chemistry, 2005 to present
• Changes to how the pit has been managed
• Changes to vertical structure of the lake
• Geochemical processes
• Possible future trends
Berkeley Pit: Sources of Info

• Pitwatch website: www.pitwatch.org/
• MBMG GWIC database: http://mbmggwic.mtech.edu/
  Search by name: Berkeley Pit, Silver Bow County, “show all sites”
  Vast amount of chemistry and water level data stored on this site
• Montana Bureau of Mines & Geology publications
  Go to http://www.mbmg.mtech.edu/mbmgcat/catmain.asp and type in keyword: “Berkeley Pit”

Selected journal articles:


Berkeley Pit: pH trends

HMS Berkeley

landslide

data gap
Berkeley Pit: Fe trends

- **Surface**
- **Deep lake**

The graph shows the total dissolved Fe (in mg/L) over the years 2005 to 2019. The data indicates a decreasing trend in the concentration of dissolved Fe in both the surface and deep lake samples. The weighted average is highlighted, showing a consistent decrease over the years. There is a noticeable data gap from 2015 to 2016.
Between 2003 and 2015

• Precipitation of > 400 million pounds of Fe-rich solids from the water column
• Mix of schwertmannite and jarosite
What caused the changes to the lake chemistry?

1) Copper recovery project
2) Disposal of lime-treatment sludge
Copper Recovery: Cementation

\[ \text{Cu}^{2+} + \text{Fe} \rightarrow \text{Fe}^{2+} + \text{Cu} \]

Scrap iron

Copper sand

Aluminum can

Cu-plated rails in Lexington Tunnel
Berkeley Pit, circa 2005

Cu precip plant

Lime treatment plant

Tailings impoundment

acids springs

Tailings slurry

treated water

14 M

Mill

Cu recovery (2003-2013)

Groundwater

10M

50M

sludge

0.8M

1M = 1 million liter per day

[not to scale]
Lime Treatment: Sludge disposal

- 2003 to 2018*: Treated Horseshoe Bend Springs
- Two stage, high-density sludge
  - Sludge alkalinity: \(~ 1.1 \text{ eq/L}\)  
  - Discharge rate \(~ 1 \text{M L/day}\)
- Treated water re-used by active mine

*2018 to present: Treating Berkeley Pit  
(Sludge parameters have changed)
Berkeley Pit pH titration
(in-class demonstration)

Possible reactions with Cu, Mn, Zn

Basaluminate: $\text{Al}_4(\text{SO}_4)(\text{OH})_{10} \cdot 5\text{H}_2\text{O}$
Copper Recovery
• Mixed and oxidized the lake
Sludge Disposal
• Raised pH

1M = 1 million liter per day
[not to scale]

Groundwater 20-30M

Berkeley Pit

Cu precip plant

Cu recovery (2003-2013)

50M

Lime treatment plant

treated water 10 M

Tailings slurry

Tailings impoundment

acid springs

Mill

1M = 1 million liter per day

~ 50 M L/day

~ 1 M L/day

Precip plant return

View from lake level

View from top

C. Gammons, Aug. 2006
Berkeley Pit, circa 2005

- **Lime Treatment**
  - **Sludge**

- **O₂ diffusion**
  - **evaporation**
  - **rain, snow**

- **schwertmannite, jarosite ↔ Fe³⁺ ↔ Fe²⁺**
  - **thermocline**
  - **chemocline**

- **gravitational settling**
  - **seasonal mixing**

- **deep groundwater influx**

- **Cu recovery intake**

- **Cu cementation**

- **water table**
  - **epilimnion**
  - **hypolimnion**
  - **monimolimnion**

- **Flooded underground mine workings**
Transition from meromictic to holomictic lake.
Berkeley Pit
Selected Datasonde Profiles, 2003 to 2018

pH
SC, mS/cm
DO, mg/L

Depth, meters

A.  B.  C.

May 2003  Oct 2011  Nov 2017  Nov 2018
Precipitation of schwertmannite and jarosite. Basaluminate saturation and copper recovery.
Precipitation of gypsum, schwertmannite, jarosite

Scavenging of $PO_4^{3-}$, $AsO_4^{3-}$ by Fe$^{III}$ oxy-hydroxides

Sludge dissolution
\( \Sigma \text{Acidity (mol/L)} = mH^+ \)

\[ + 2x(m\text{Fe}^{2+} + m\text{Cu}^{2+} + m\text{Mn}^{2+} + m\text{Zn}^{2+}) \]

\[ + 3x(m\text{Fe}^{3+} + m\text{Al}^{3+}) \]
% total acidity as individual solutes

- HSO4- 3%
- H+ 3%
- Cu 6%
- Zn 15%
- Mn 8%
- Al3+ 29%
- Fe2+ 23%
- Fe3+ 13%
- Mn 15%
- Zn 28%
- Cu 3%
- Al3+ 54%

Total acidity, meq/L

Data gap

If alkaline sludge is still being dumped in the lake, why has pH and acidity of Berkeley Pit leveled off?

- Aluminum buffering
- Buffering by water-rock reactions on the pit walls?
- Alkalinity of sludge balanced by influent acidity of deep groundwater?

Work in progress
Berkeley Pit, circa 2020

- **Epilimnion**
- **Hypolimnion**
- **Deep groundwater influx**
- **Pump intake**
- **Seasonal overturn**
- **Leaching of soluble salts from weathered bedrock**
- **O₂ diffusion**
- **Fe³⁺ → goethite + H⁺**
- **Basaluminite**
- **Sludge redissolves**
- **OH⁻**
- **H⁺**
- **Cu recovery and lime treatment sludge**
- **Pit sediment**
- **Flooded underground mine workings**
Berkeley Pit, circa 2020

[not to scale]

- Tailings Pond pH > 10
- Tailings impoundment
- Acid springs

Flow:
- Groundwater
- Berkeley Pit
- Cu precip plant
- Lime treatment plant
- Mill
- Treated water
- Tailings Pond slurry

Additional:
- Silver Bow Creek
- Polishing Plant
Conclusions

• Sludge disposal has reduced acidity and raised pH of Berkeley Pit from ~ 2.5 to ~ 4
• Circulation during copper recovery eliminated lake stratification. Lake is now well-mixed vertically
• Presence of dissolved oxygen from top to bottom
• Dissolved Fe concentrations dropped from ~ 1000 mg/L to < 10 mg/L
• Phosphate, arsenate stripped out of water column
What lies ahead?

- Pumping and lime-treatment of Berkeley Pit lake began in 2018 and will continue for a long time
  - Pit-lake surface elevation no longer rising
  - Sludge disposed in Berkeley Pit

- Continued disposal of sludge should cause precipitation of Al-solids and a slow rise in pH

- Concentrations of Cu, Zn, Cd not expected to decrease in foreseeable future
  - the lake is still toxic to waterfowl
Questions?

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