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:

Gammons C.H. and Icopini G.A., 2019, Improvements to the water quality of the acidic Berkeley Pit lake due to the combined effects of copper recovery and sludge disposal. *Mine Water and the Environment,* v. 39, p. 427-439.

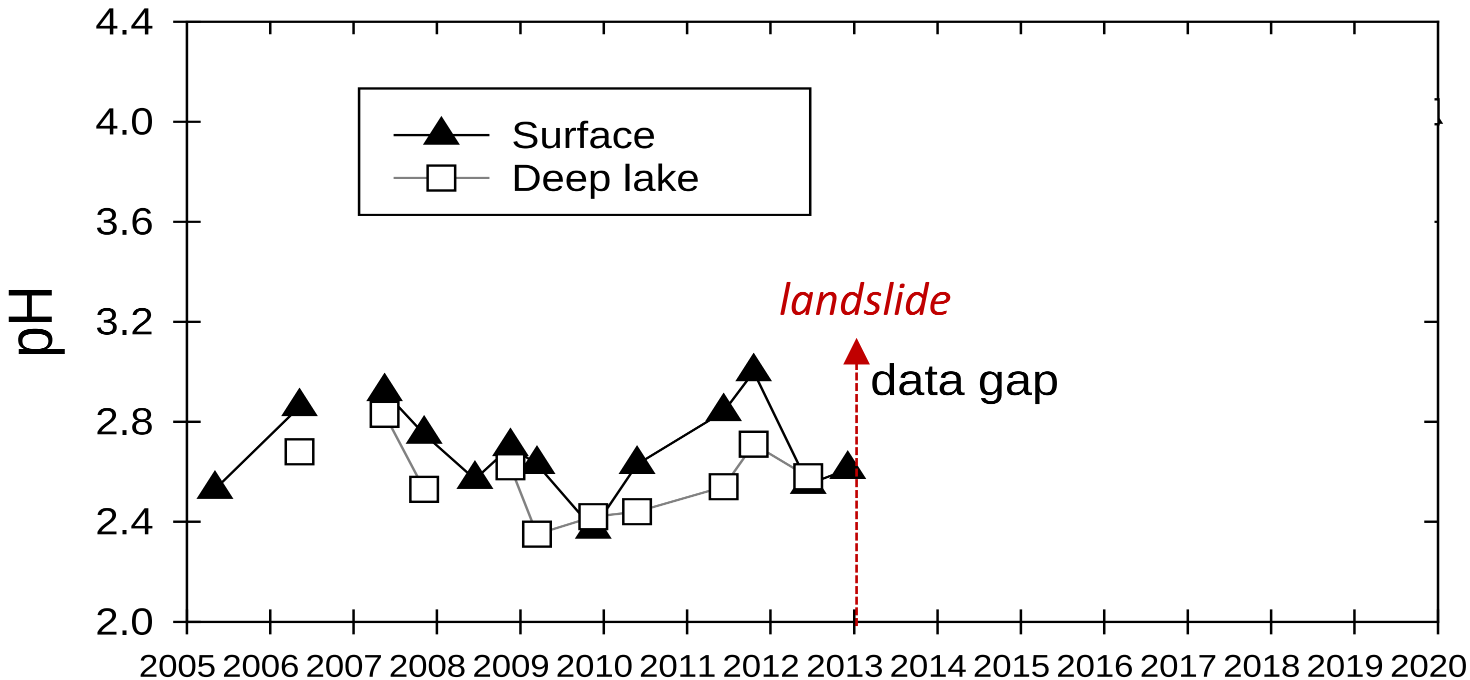
Tucci, N.J., and Gammons, C.H., 2015, Influence of copper recovery on the water quality of the acidic Berkeley Pit lake, Montana, USA: Environmental Science and Technology, v. 49, p. 4081-4088.

Gammons, C.H., and Duaime, T.E., 2006, Long-term changes in the geochemistry and limnology of the Berkeley pit-lake, Butte, Montana: Mine Water and the Environment, v. 25, p. 76-85.

Pellicori, D.A., Gammons, C.H., and Poulson, S.R., 2005, Geochemistry and stable isotope composition of the Berkeley pit lake and surrounding mine waters, Butte, Montana: Applied Geochemistry, v. 20, p. 2116-2137.

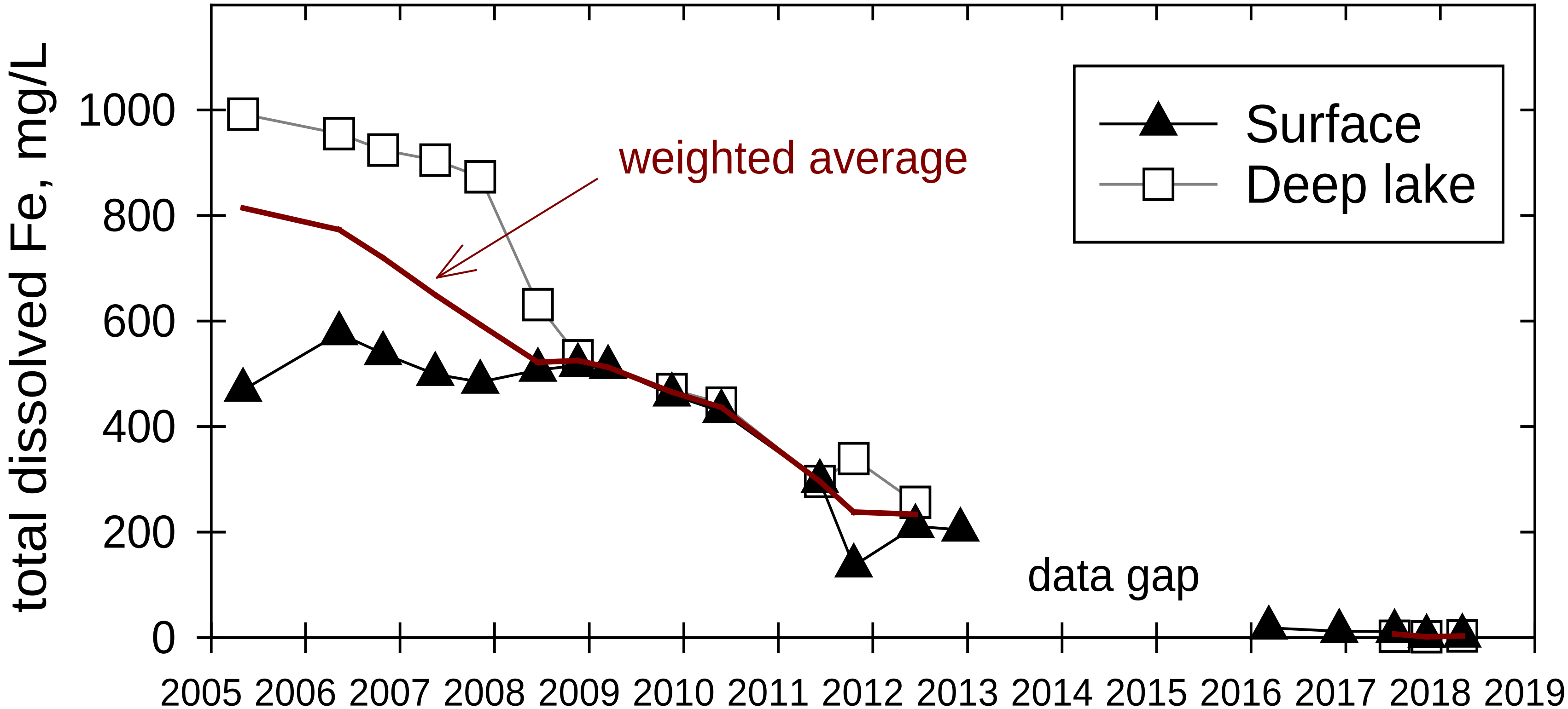
Davis, A., and Ashenberg, D., 1989, The aqueous geochemistry of the Berkeley Pit, Butte, Montana, USA: Applied Geochemistry, v. 44, p. 23-36.

Berkeley Pit: pH trends



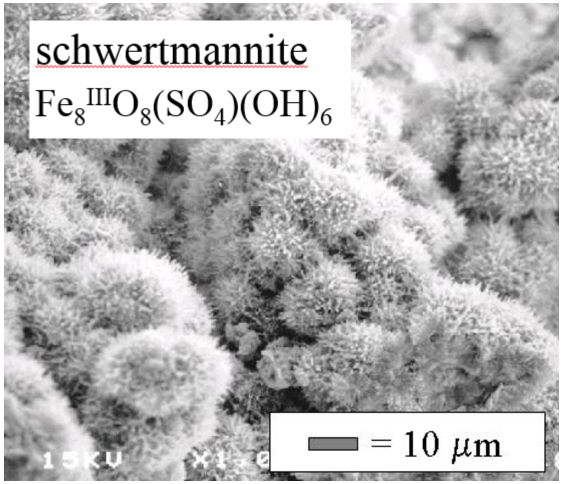
HMS Berkeley

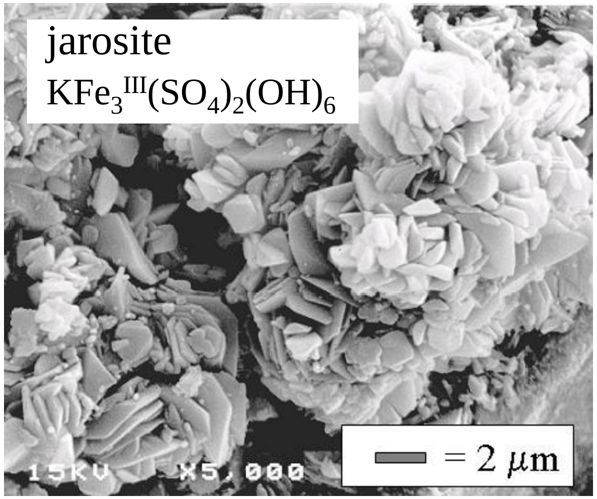
Berkeley Pit: Fe trends



Between 2003 and 2015

- Precipitation of > 400 million pounds of Fe-rich solids from the water column
- Mix of schwertmannite and jarosite



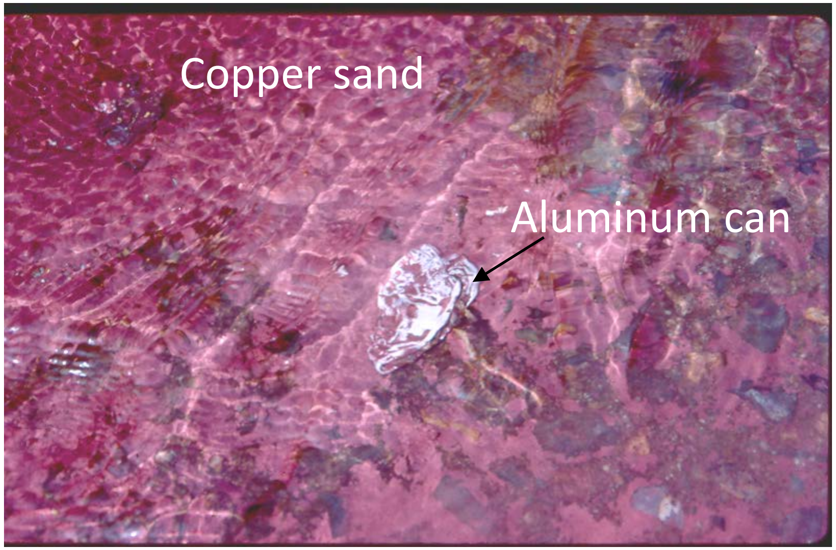


SEM photos taken by Dick Berg

What caused the changes to the lake chemistry?

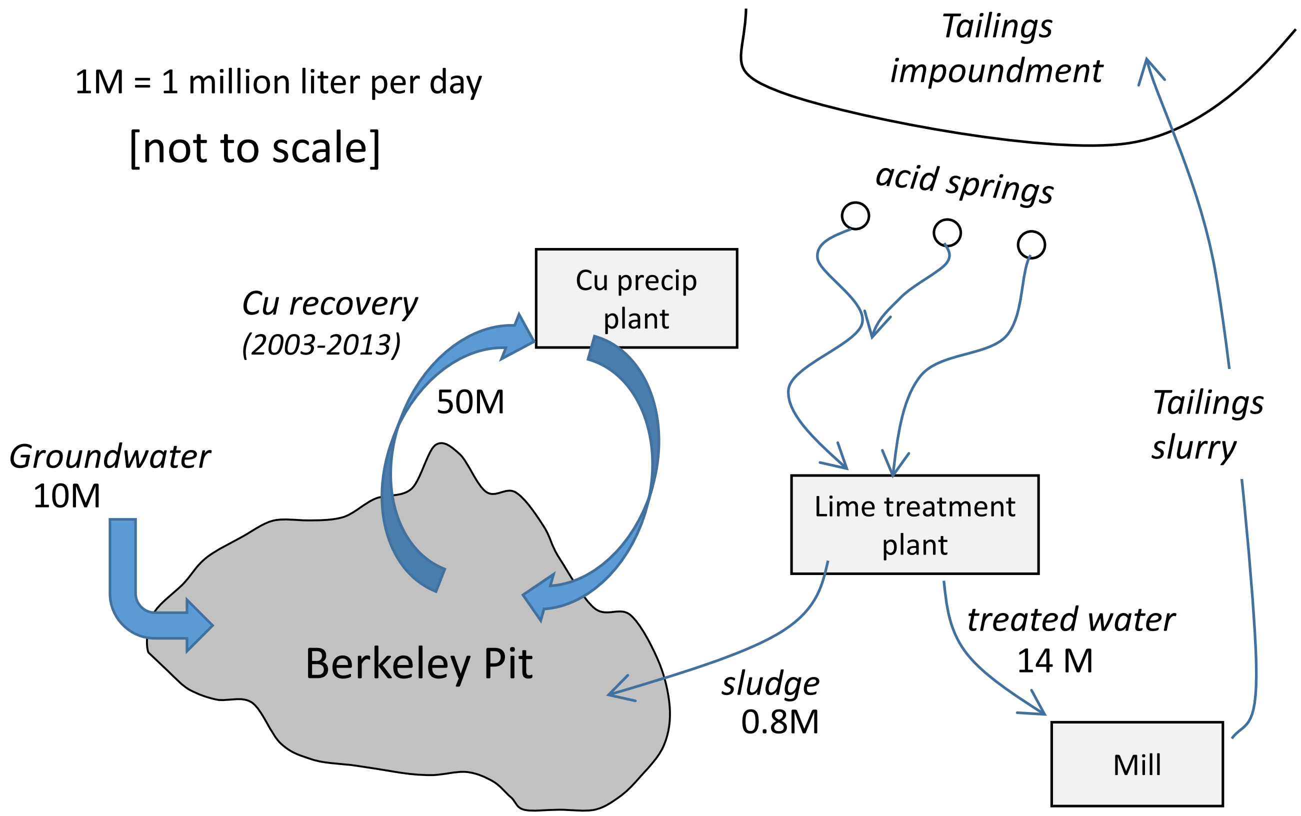
1) Copper recovery project
2) Disposal of lime-treatment sludge

Copper Recovery: Cementation



$$Cu^{2+} + Fe \rightarrow Fe^{2+} + Cu$$

Berkeley Pit, circa 2005



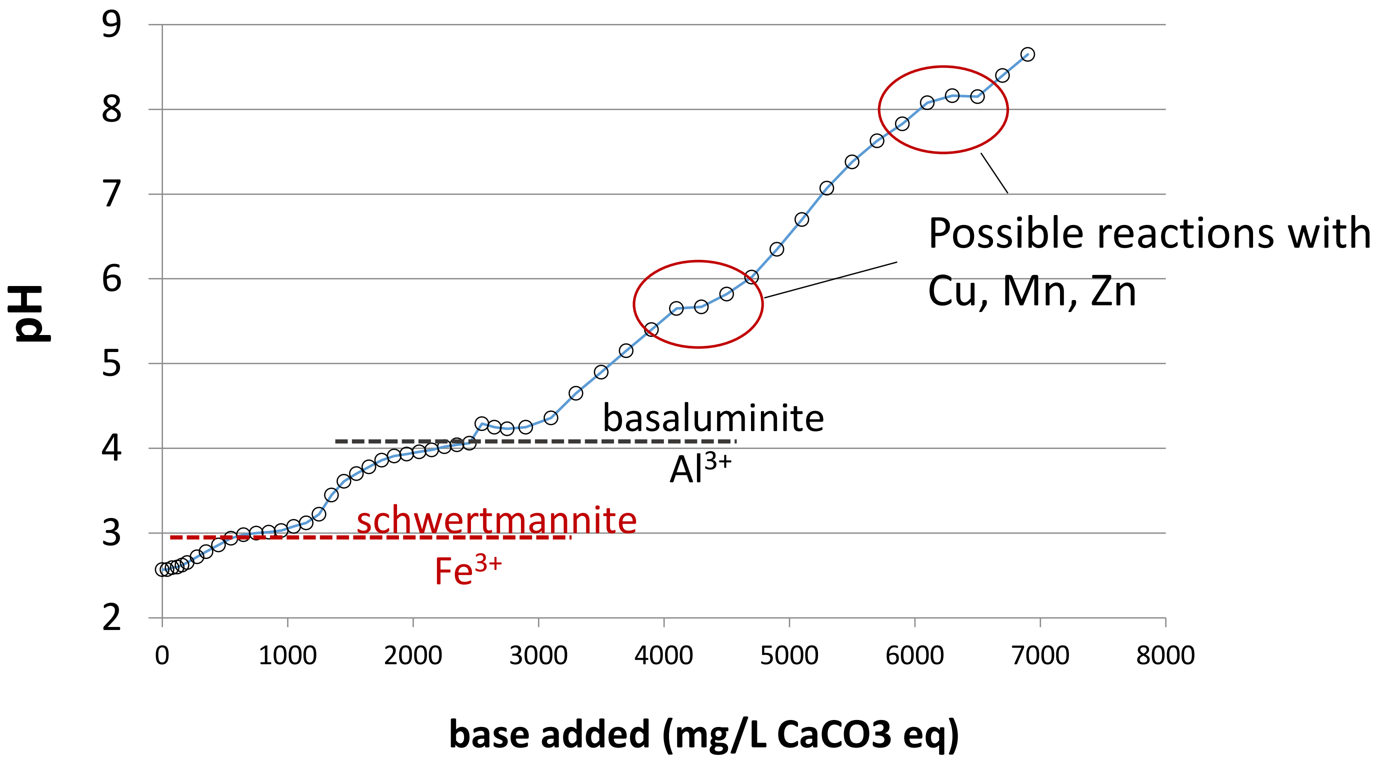
Lime Treatment: Sludge disposal

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

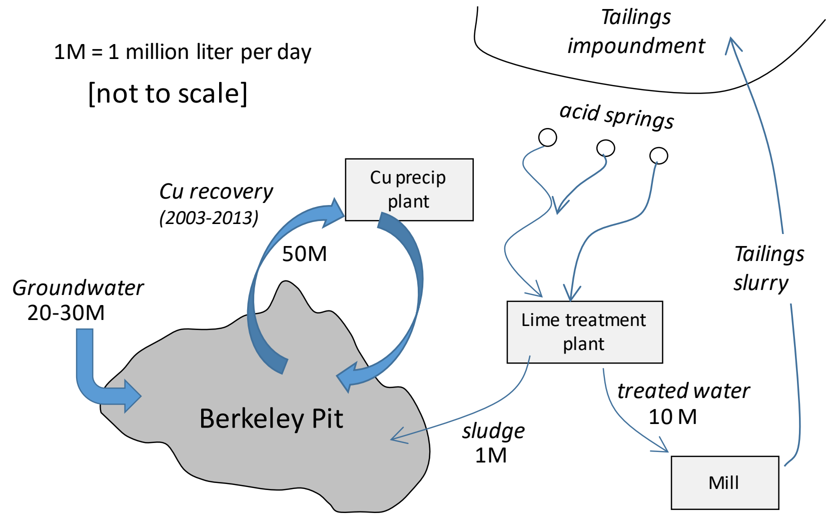
Alkalinity is stored in metal-hydroxide solids

*2018 to present: Treating Berkeley Pit
(Sludge parameters have changed)

Berkeley Pit pH titration
(in-class demonstration)



Basaluminite: $Al_4(SO_4)(OH)_{10} \cdot 5H_2O$

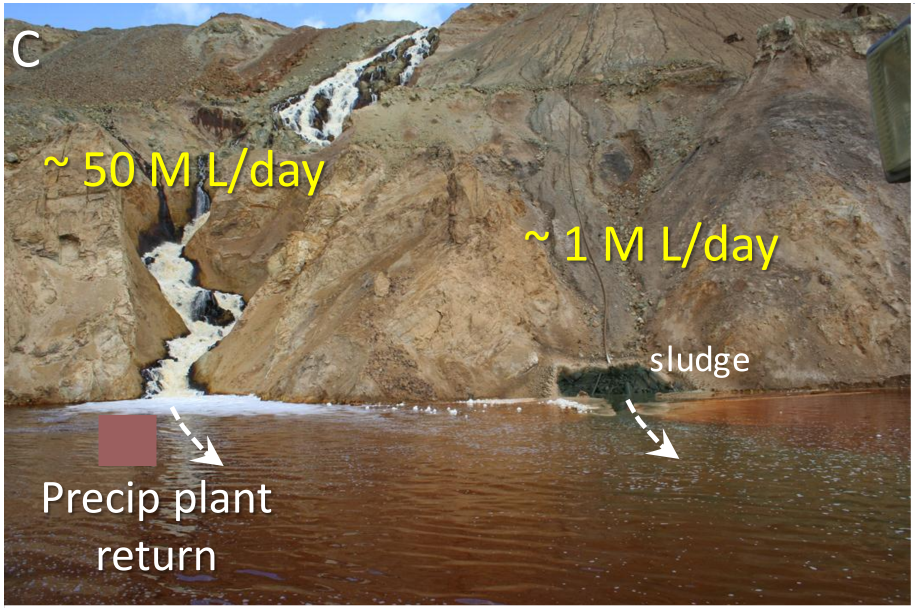


Copper Recovery

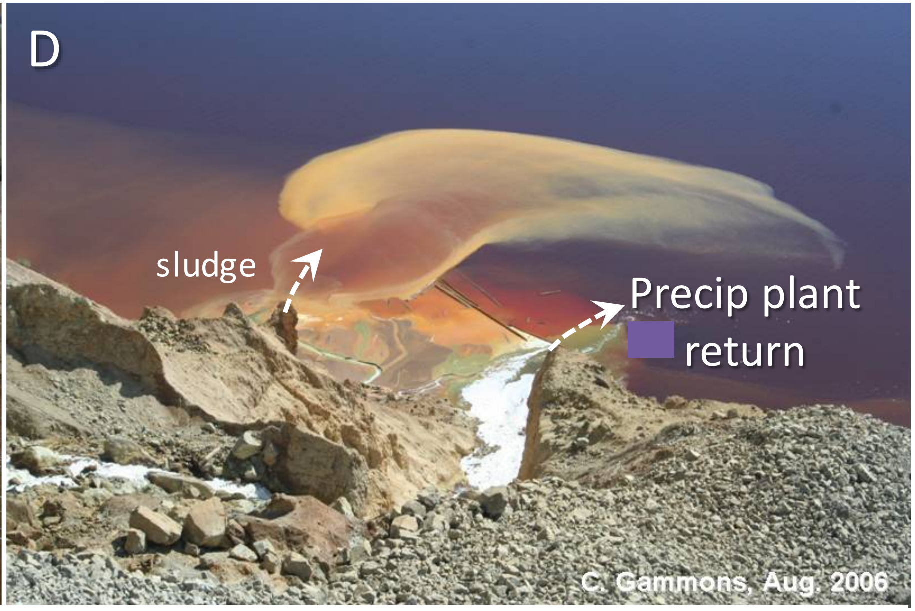
- Mixed and oxidized the lake

Sludge Disposal

- Raised pH

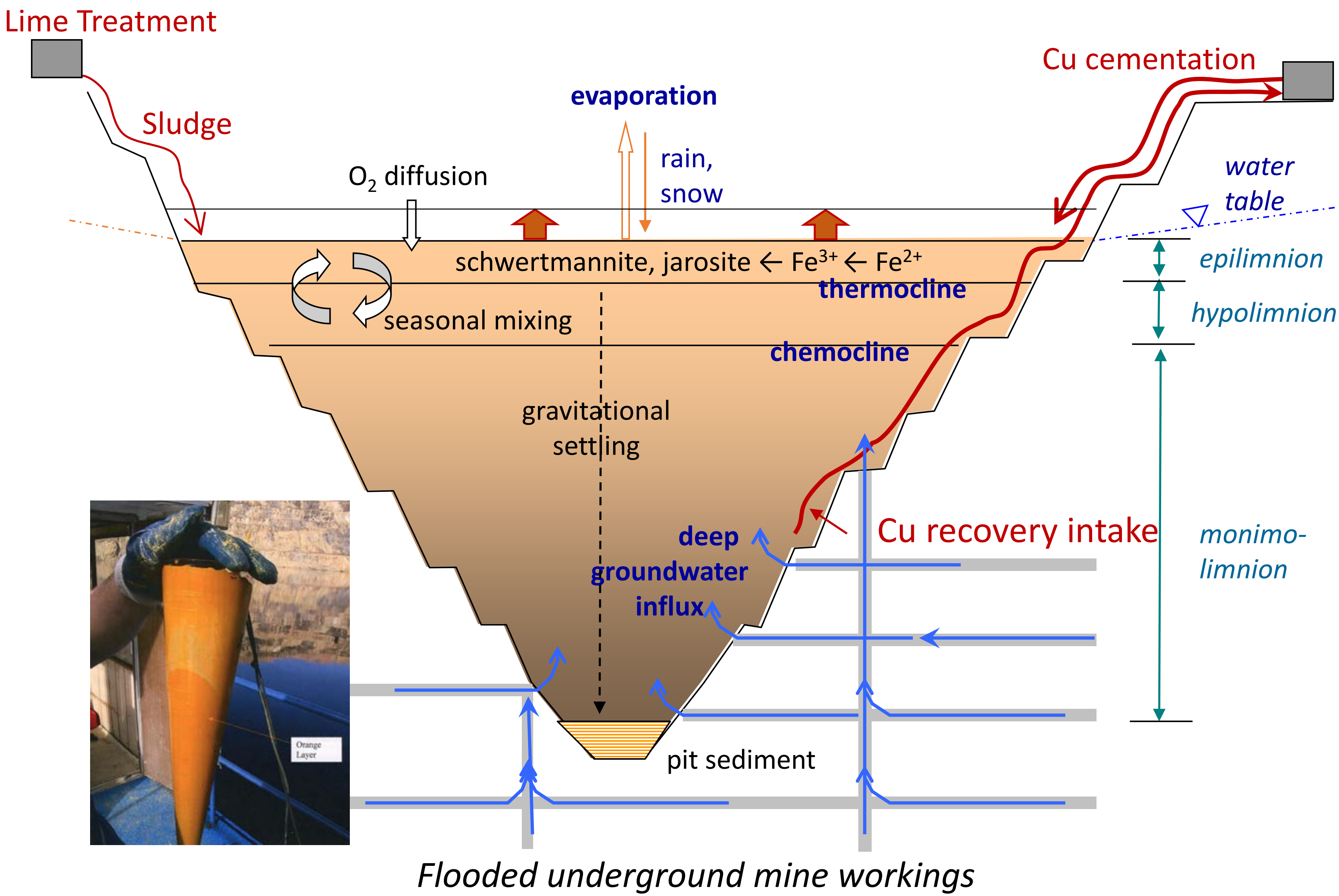


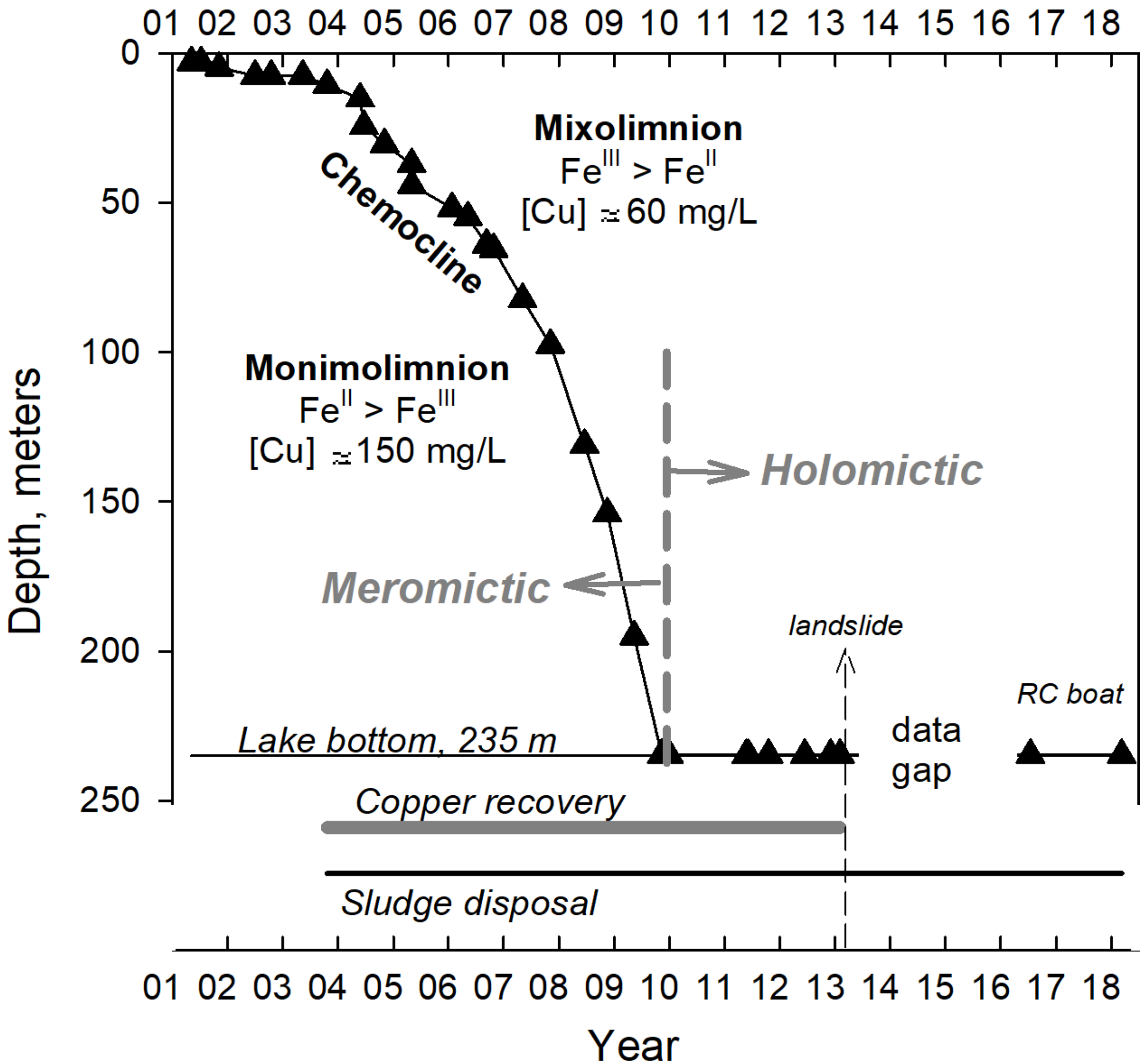
View from lake level



View from top

Berkeley Pit, circa 2005

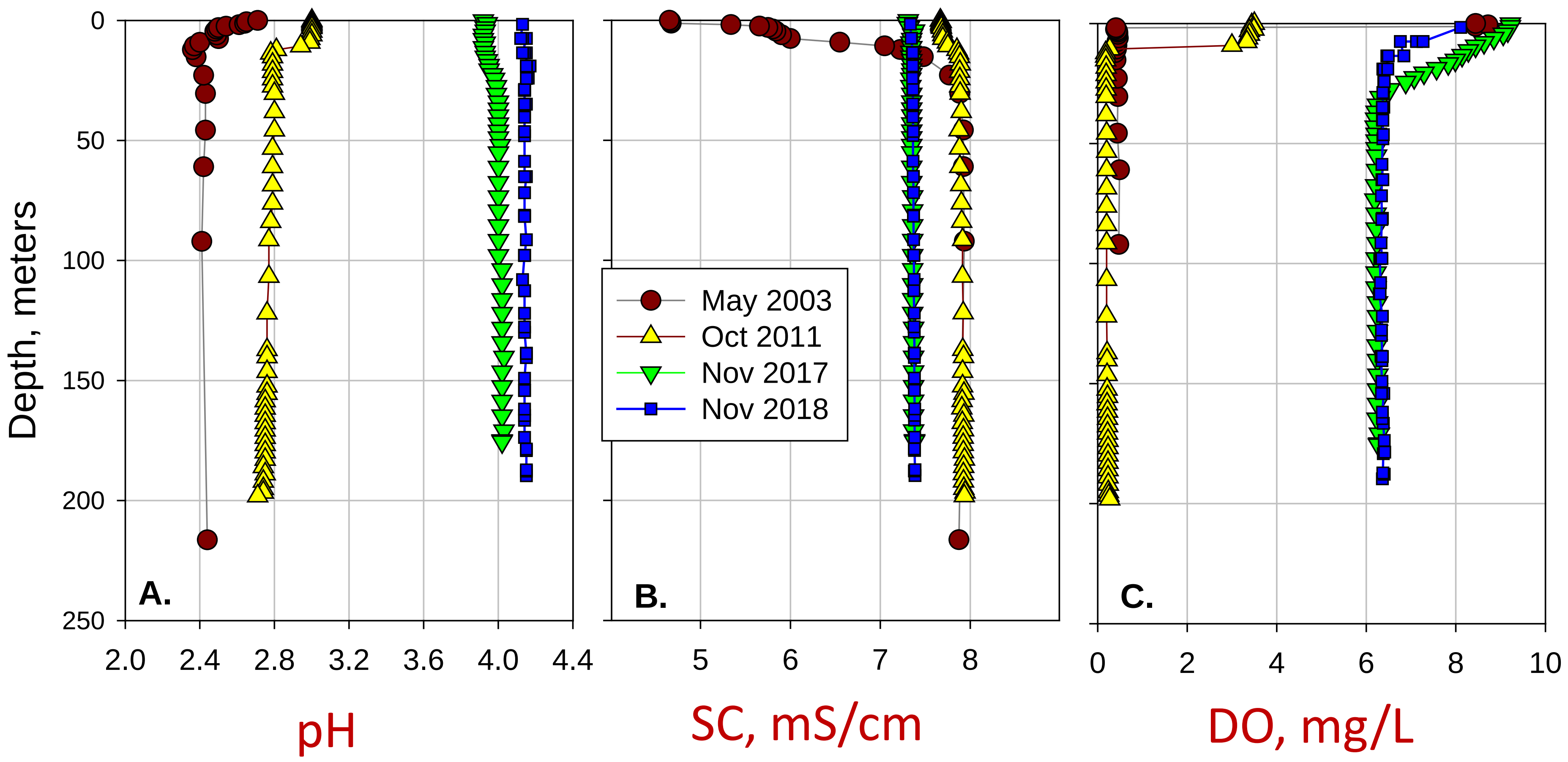


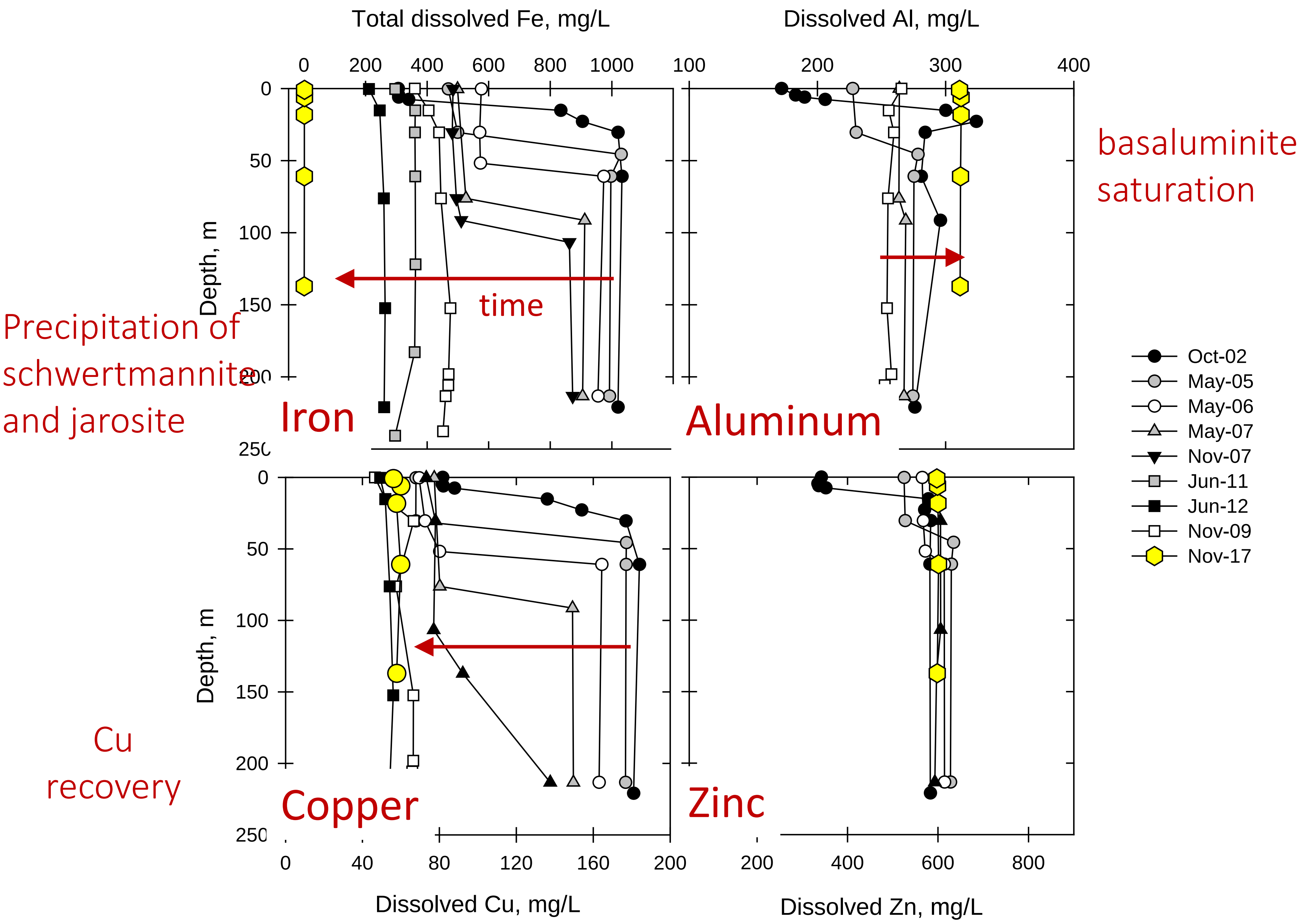


Transition from meromictic to holomictic lake

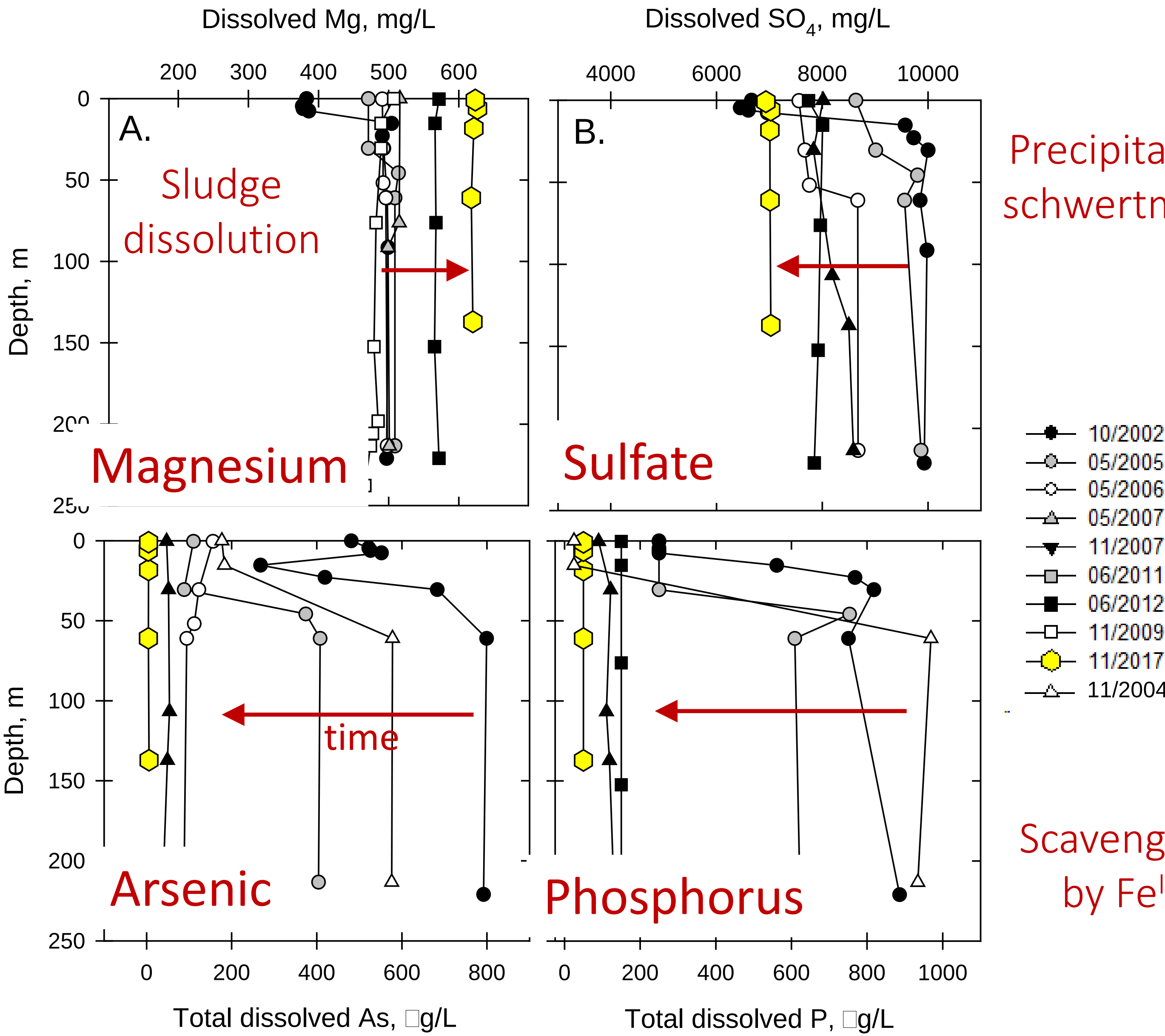
Berkeley Pit

Selected Datasonde Profiles, 2003 to 2018





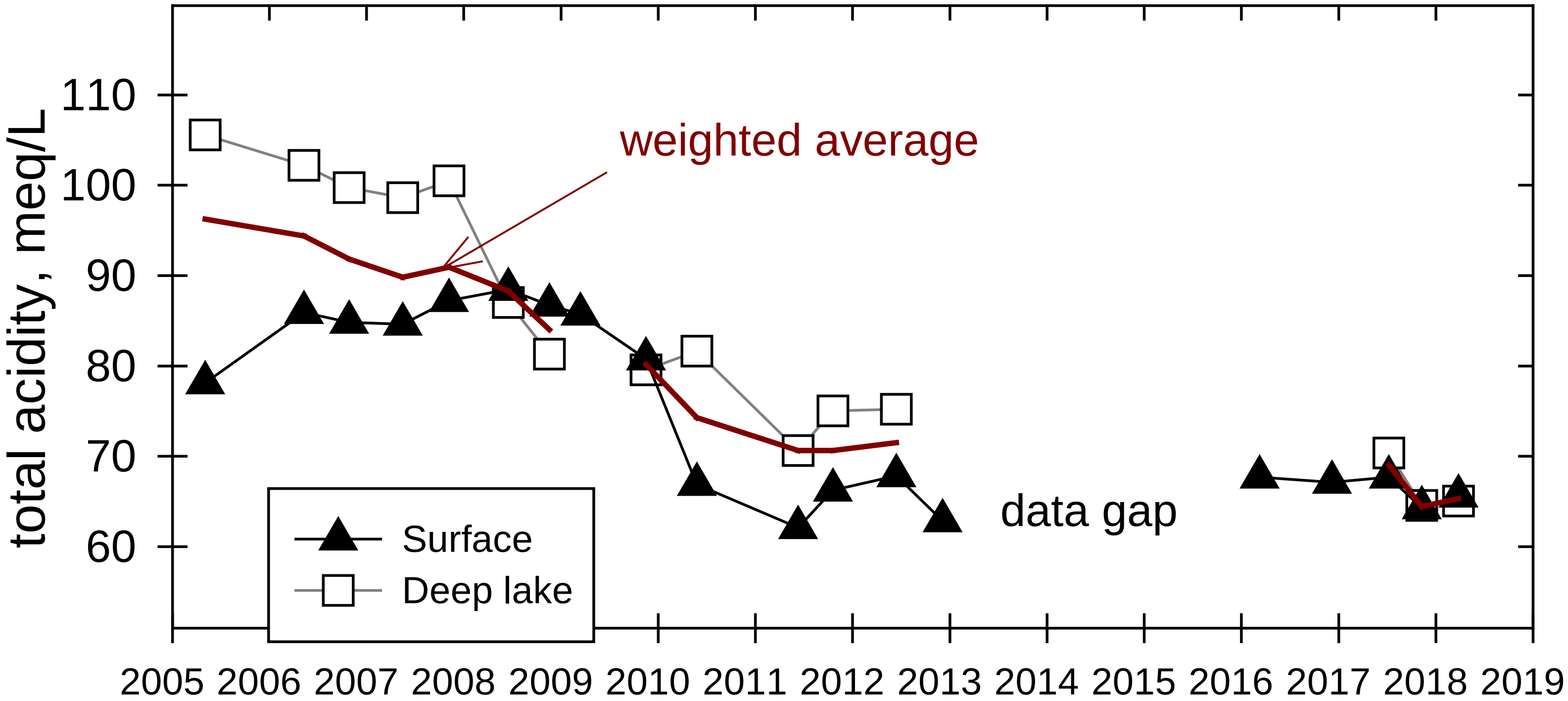
Total dissolved Fe, mg/L
Dissolved Al, mg/L
Depth, m
Dissolved Cu, mg/L
Dissolved Zn, mg/L
basaluminite saturation
Precipitation of schwertmannite and jarosite
time
Iron
Aluminum
Copper
Zinc
Cu recovery
Oct-02
May-05
May-06
May-07
Nov-07
Jun-11
Jun-12
Nov-09
Nov-17



Precipitation of gypsum, schwertmannite, jarosite

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

Berkeley Pit: acidity trends

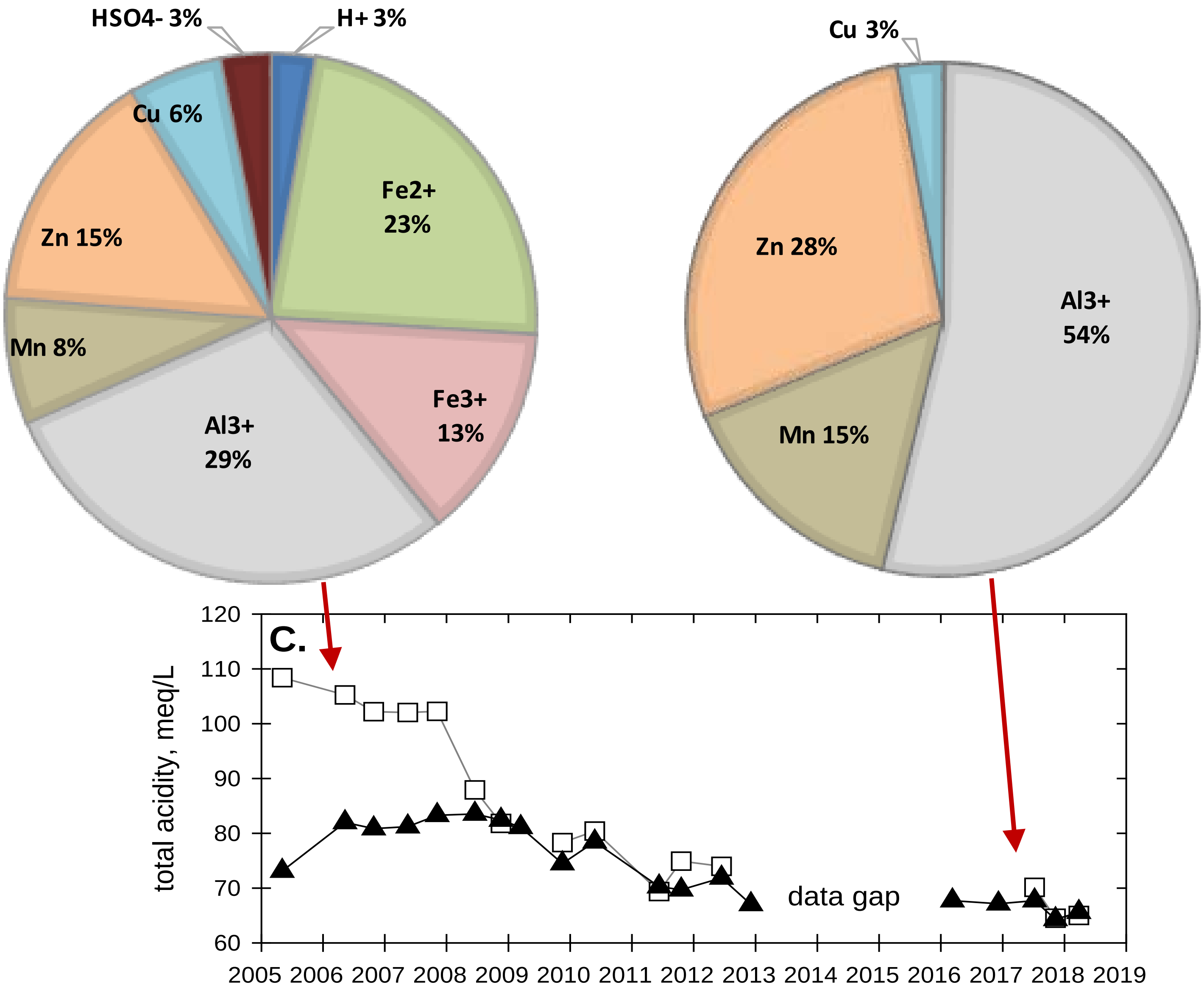


$$\Sigma\text{Acidity (mol/L)} = m\text{H}^{+}$$

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

$$+ 3\text{x}(m\text{Fe}^{3+} + m\text{Al}^{3+})$$

% total acidity as individual solutes

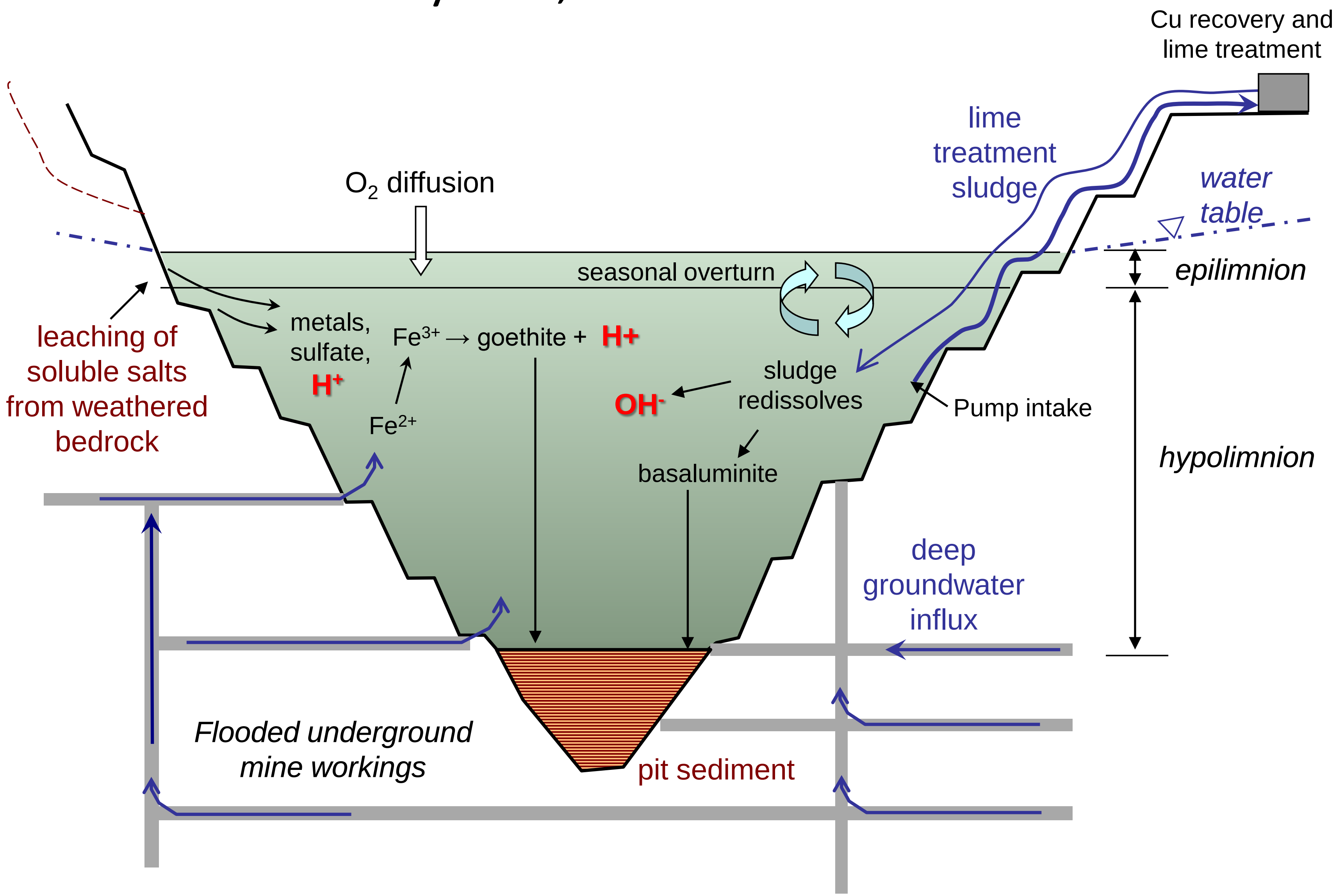


If alkaline sludge is still being dumped in the lake, why has pH and acidity of Berkeley Pit leveled off?

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

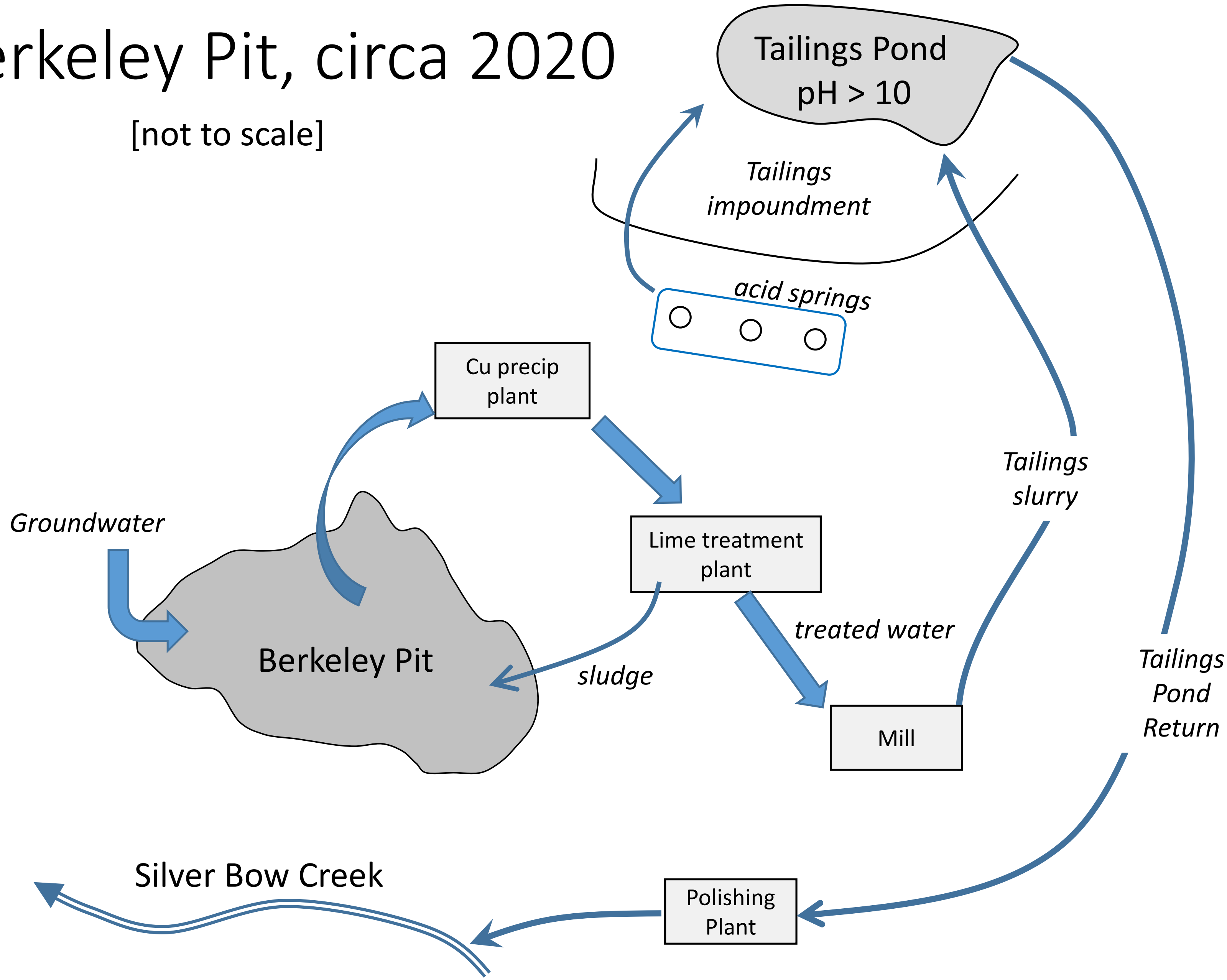
Work in progress

Berkeley Pit, circa 2020



Berkeley Pit, circa 2020

[not to scale]



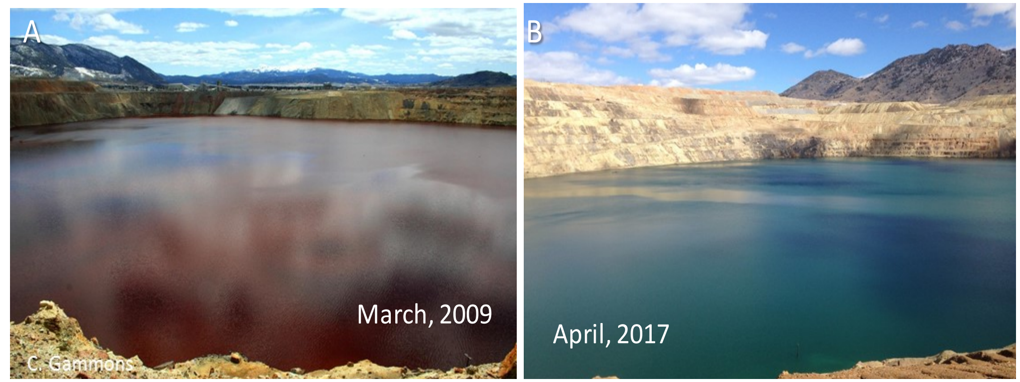
Conclusions

- 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?



Acknowledgements

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