Geochemistry of the Berkeley pit lake, Butte, Montana

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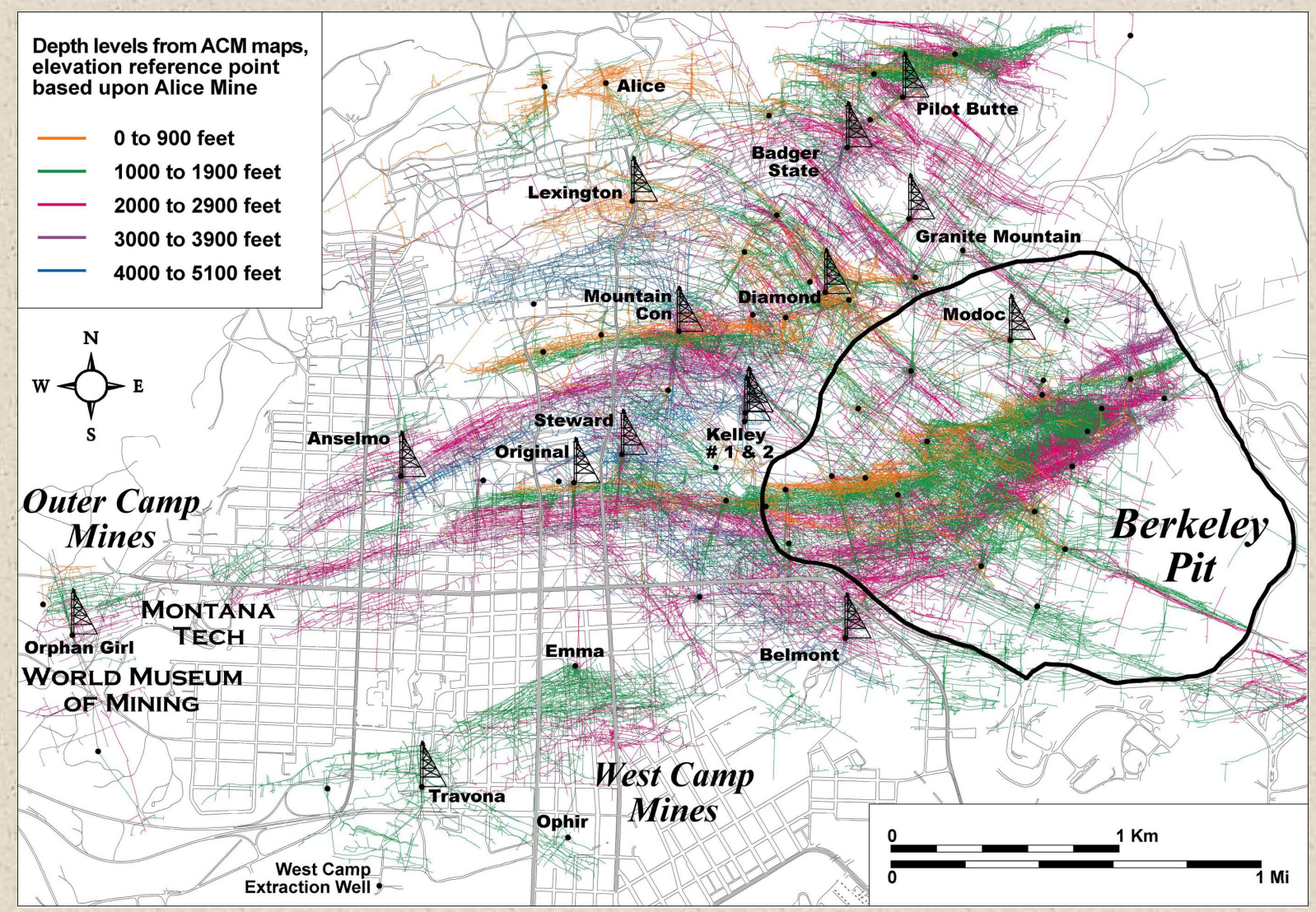
Talk overview

- Site orientation
- History of mine flooding
- Geochemical profiles in space and time
- Why is water quality so bad?
  - Geological controls
  - Evapoconcentration
  - Bad influent groundwater
  - Subaqueous pyrite oxidation
- Conceptual limno-bio-hydro-geo-chemical model

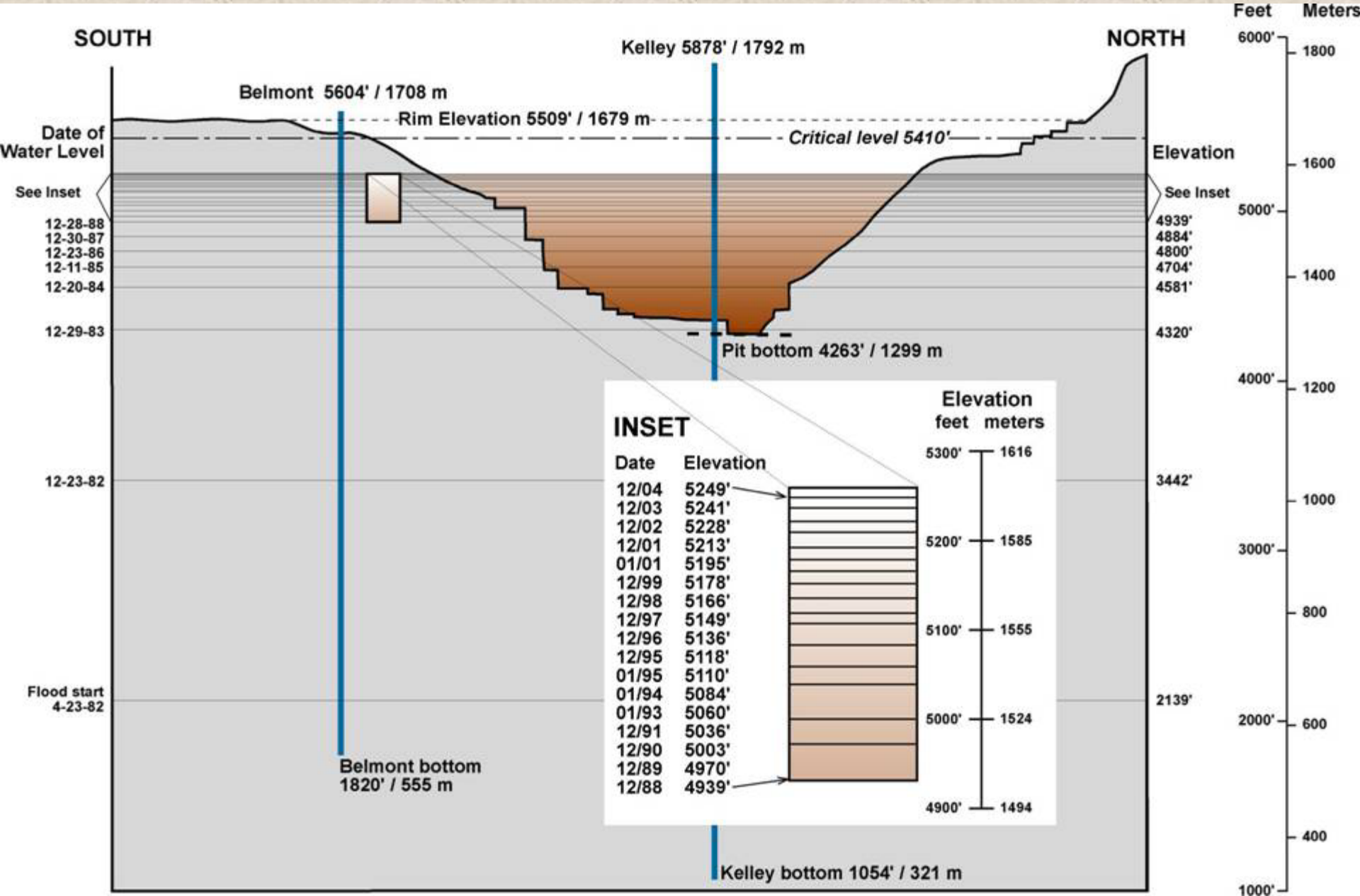
Extent of Butte mine workings (as of 1980)



Over 15,000 km of underground mine workings


Tailings Pond
old leach pads
Continental Pit
U
D
HSB
Berkeley Pit
Image courtesy of NASA

History of mine flooding



Water balance

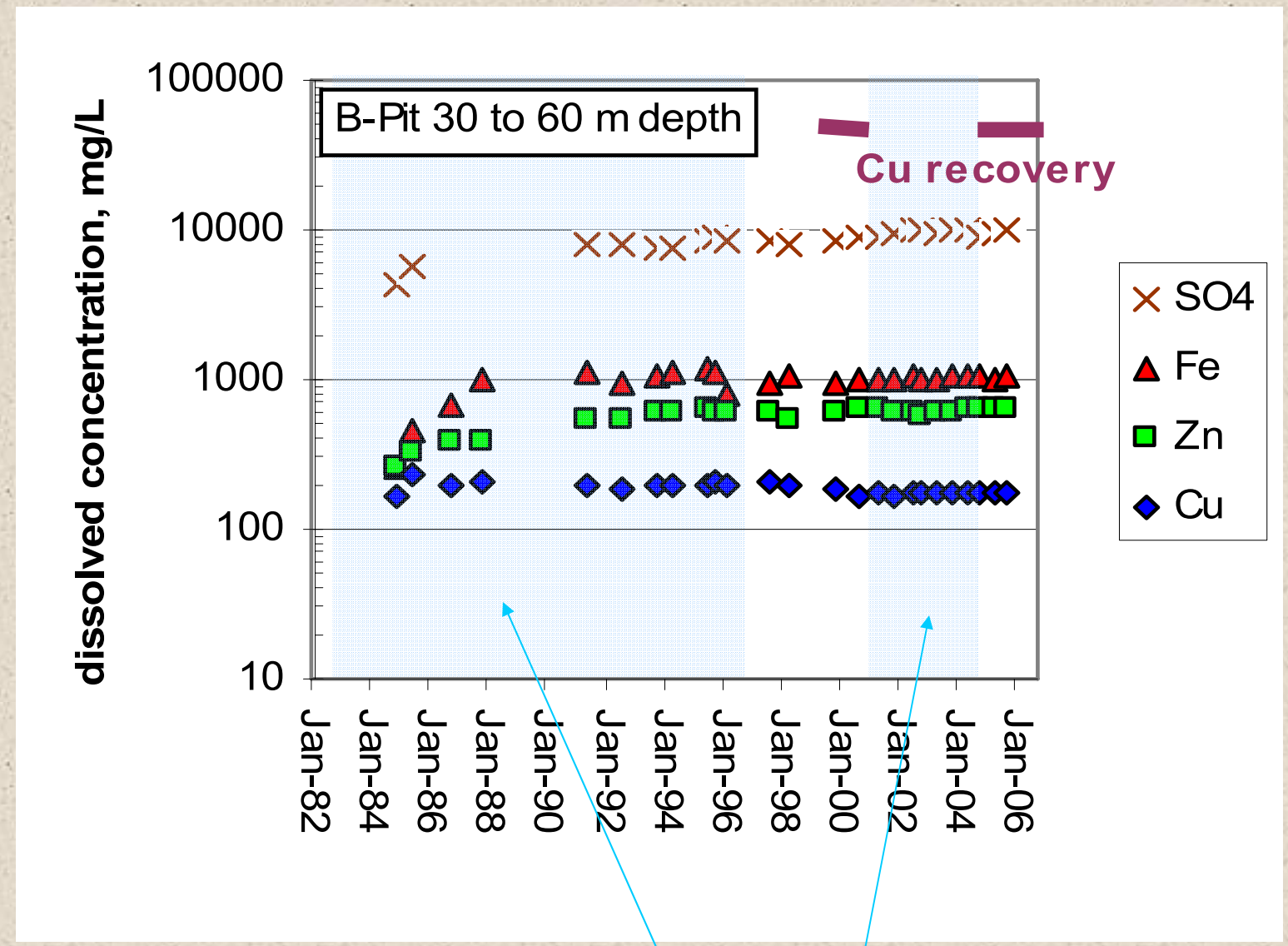
Water inputs

- Direct precipitation
  - Only ~ 12”/yr
- Pitwall runoff
  - Not quantified, believed to be minor
- Groundwater seepage
  - ~ 10 million L/day
- Surface water inputs
  - Horseshoe Bend
  - Diverted storm water

Water outputs

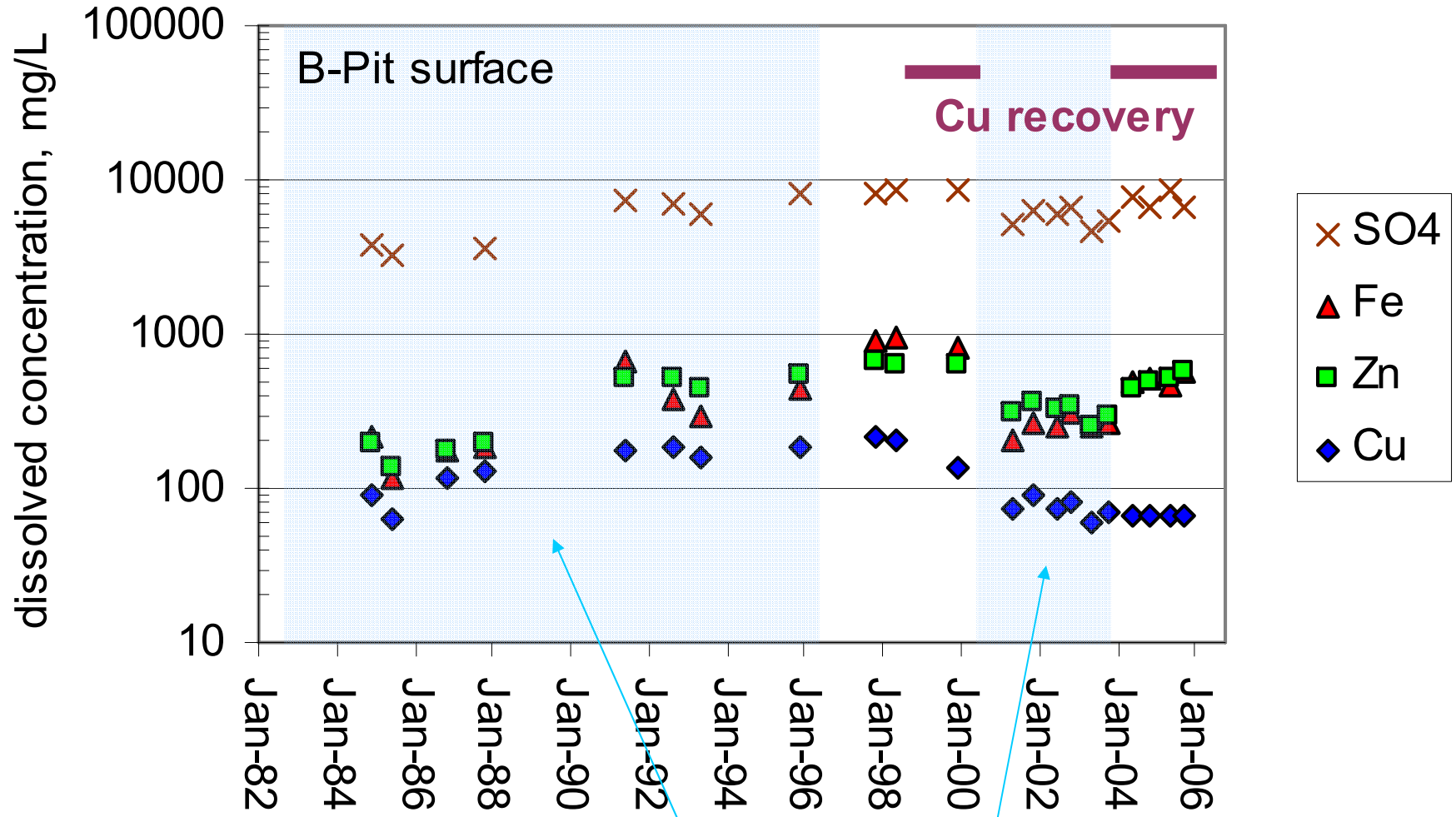
- Evaporation
  - Roughly 24”/yr

deep Berkeley Pit chemistry… changes with time



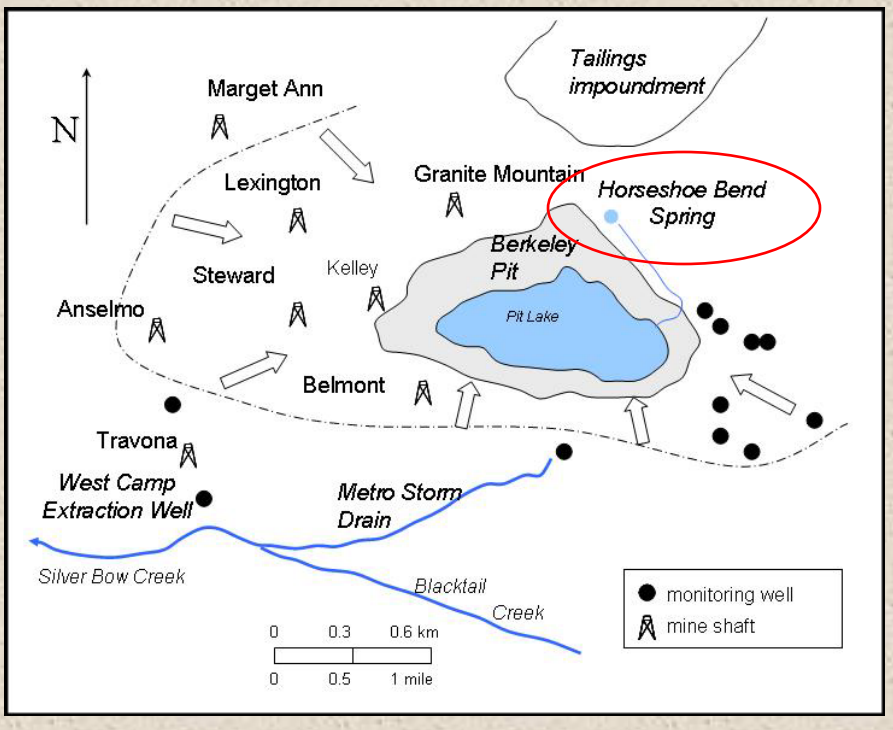
Shaded regions show when HSB dumped into pit

Shallow Berkeley Pit chemistry… changes with time



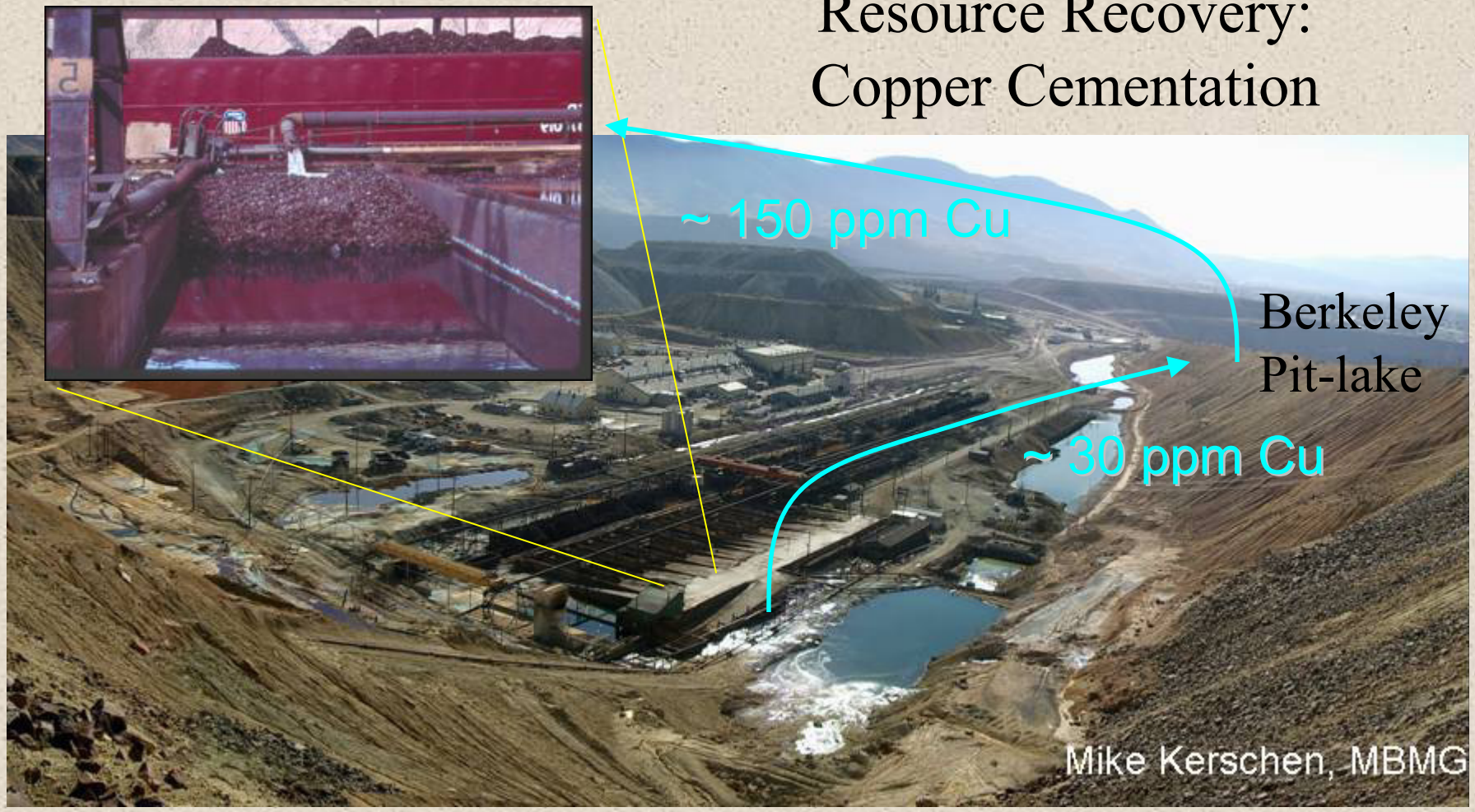
Shaded regions show when HSB dumped into pit

Horseshoe Bend Springs



- 5 to 10 million L/day (more during active mining)
- pH ~ 3.1, SC = 4.6 mS/cm, Cu = 62 mg/L, Fe = 200 mg/L
- Lower SC, so floats on top of deep pit lake
- Origin is disputed (almost certainly from tailings dam)

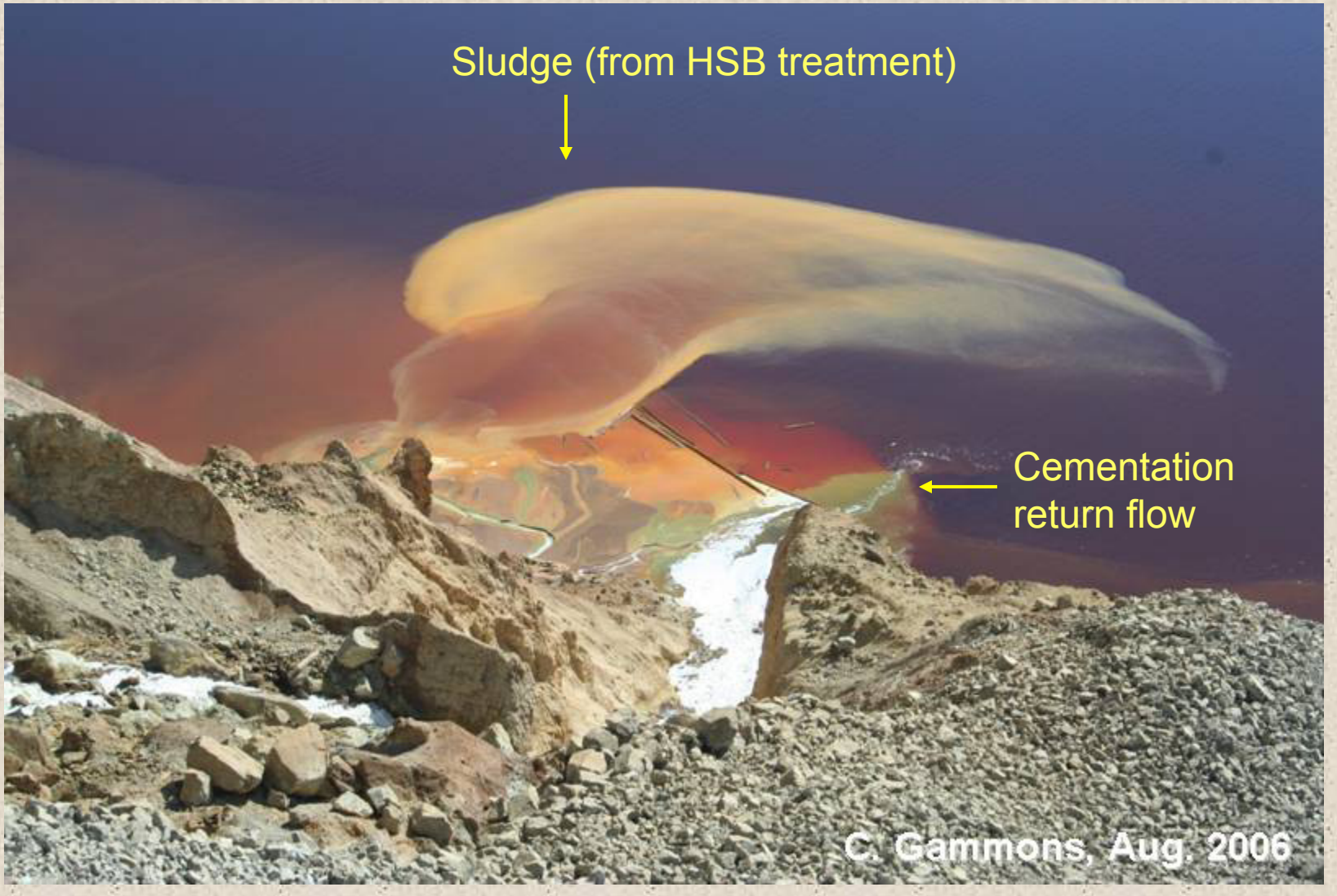
Resource Recovery: Copper Cementation



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

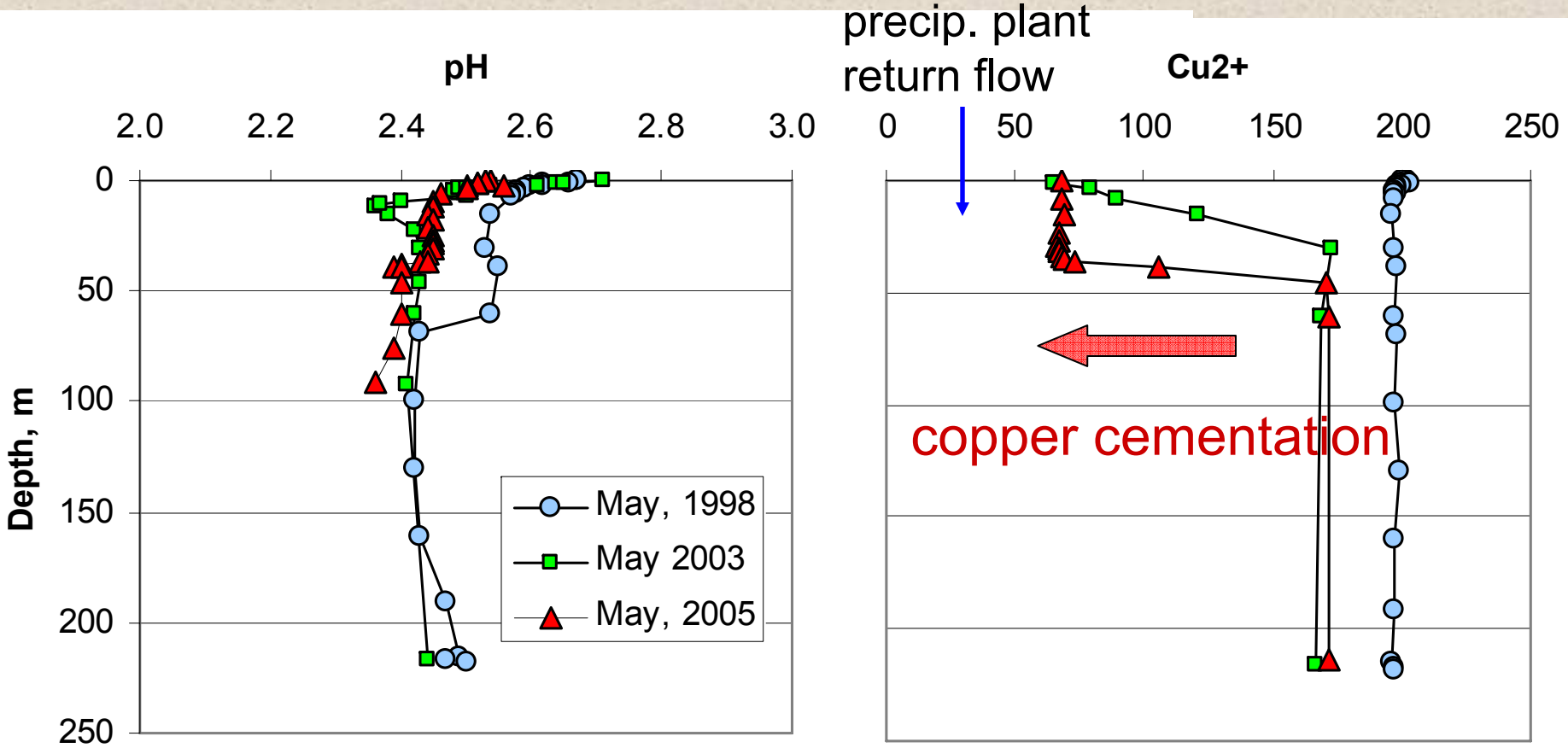
Over 40M lbs Cu dissolved in B-Pit!

Process is 75 - 90% efficient

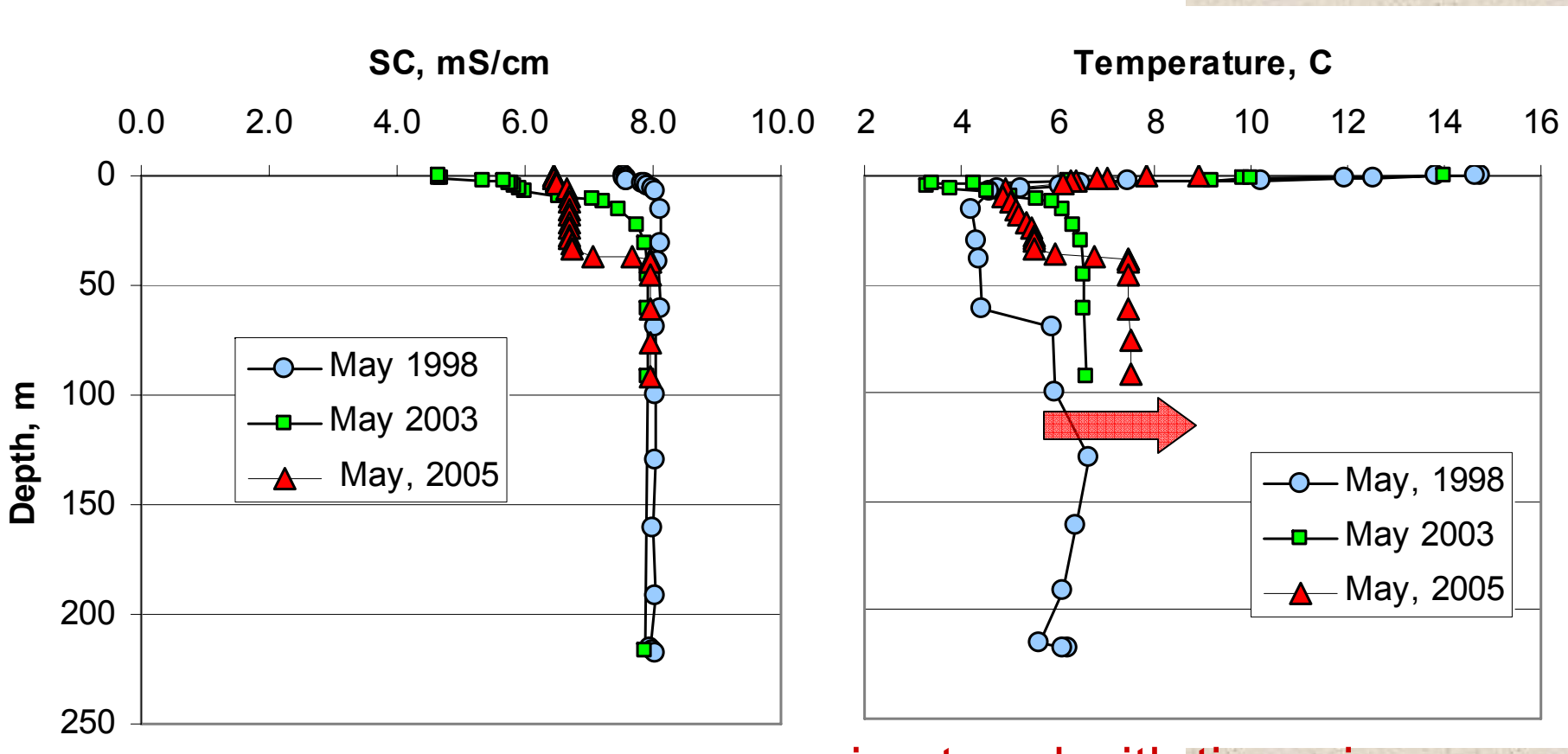


Copper cementation circuit and lime treatment sludge returning to surface of pit lake

Berkeley Pit: pH and Cu profiles over time



Berkeley Pit: SC and Temp profiles over time

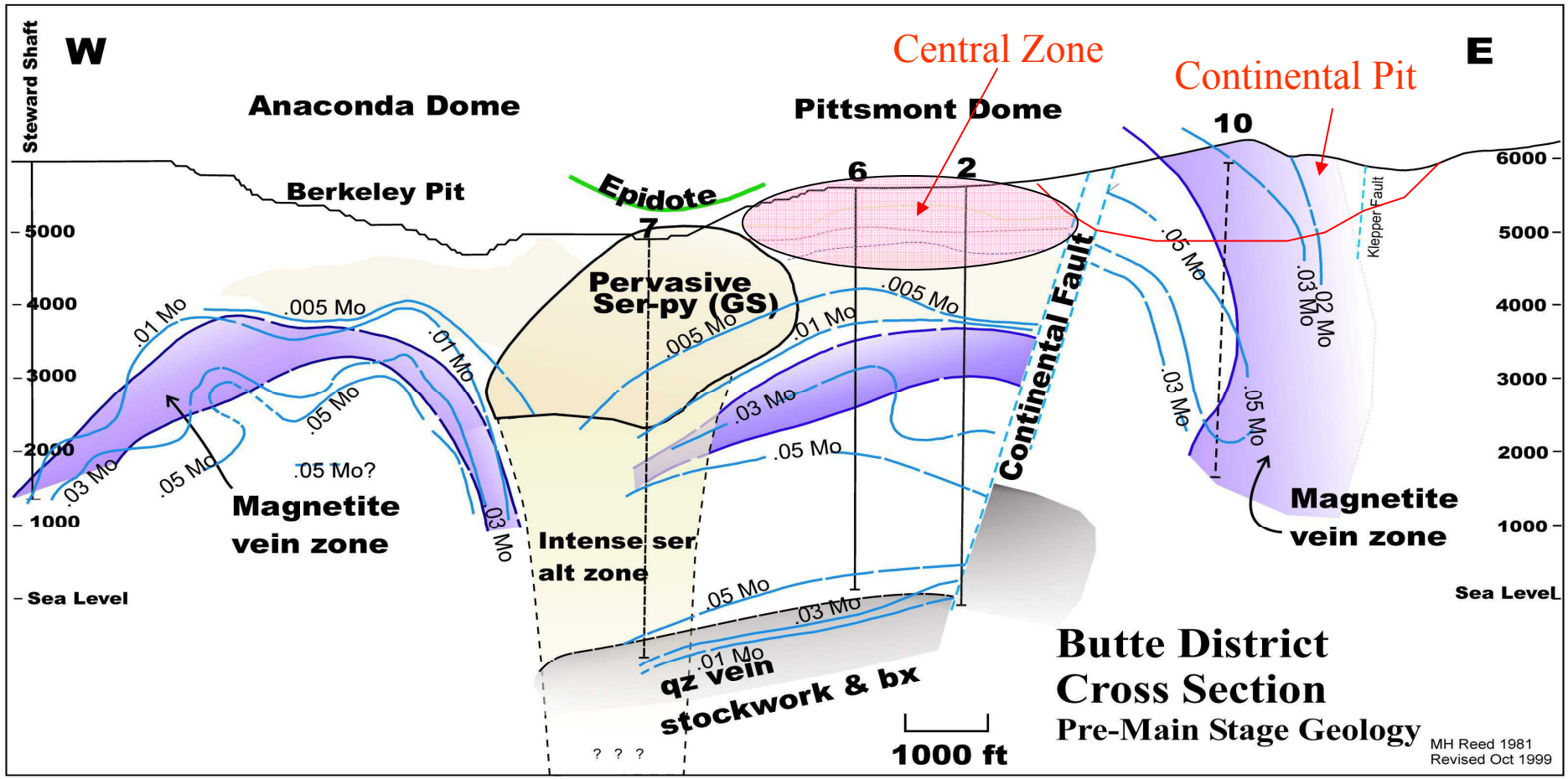


warming trend with time since last top-to-bottom turnover

Why is Berkeley pit lake so bad?

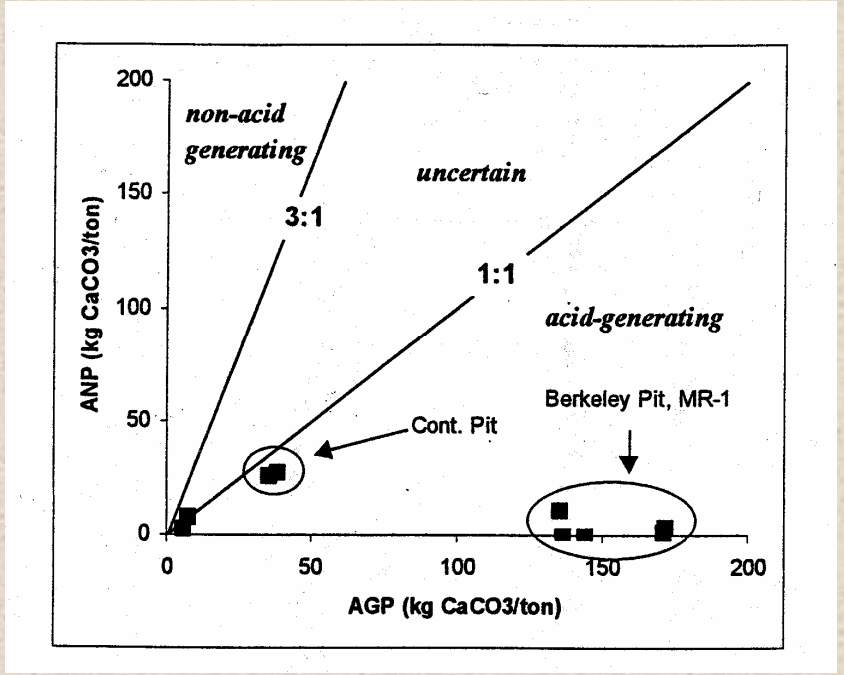
- Geology
  - Leaching of acid and metals from wallrock
- Evapoconcentration
  - Stable isotopes to quantify E
- Input of deep groundwater from undetermined source with poor water quality
- Subaqueous pyrite oxidation

Geologic cross-section

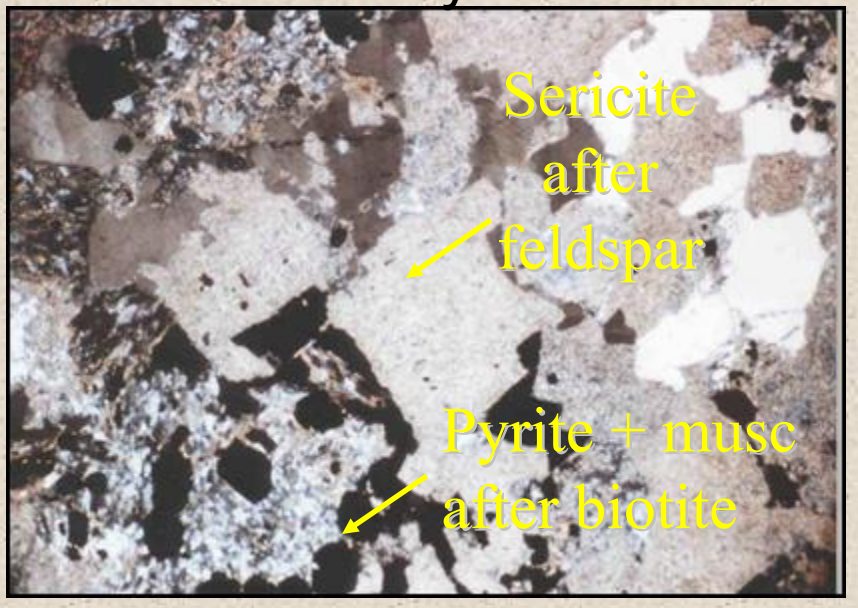


Mark Reed, Univ. of Oregon

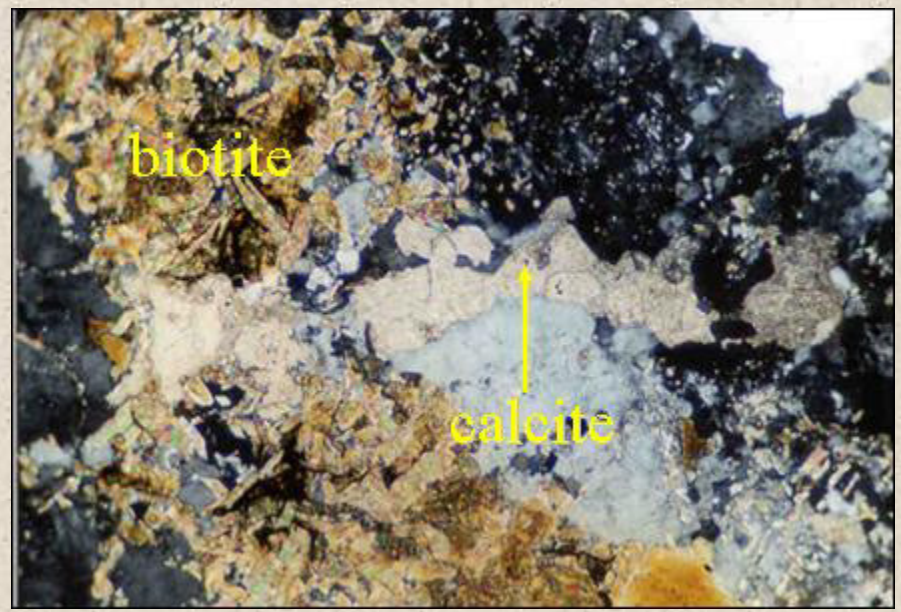
(Newbrough & Gammons, 2002)



Berkeley Pit

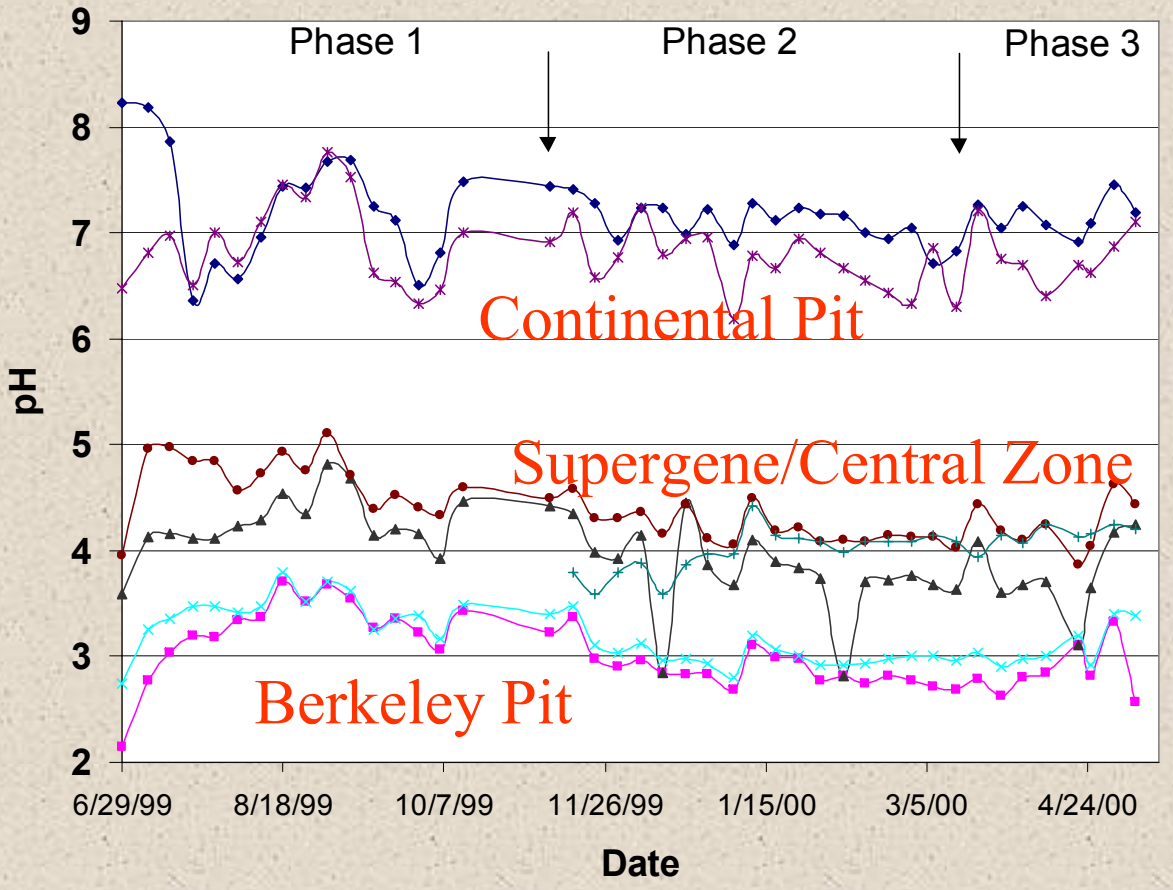


Continental Pit

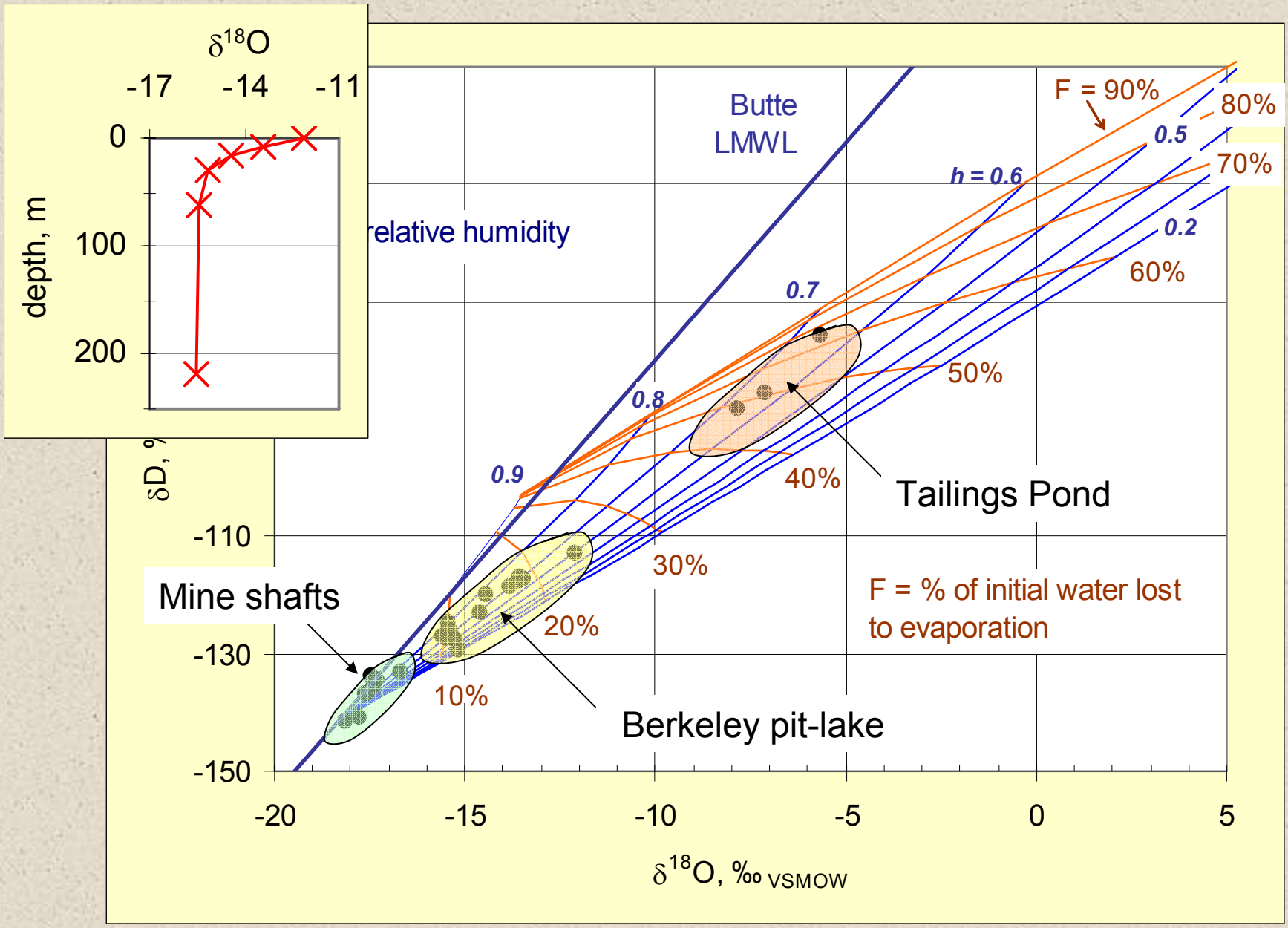


Humidity cell experiments on crushed wallrock

(Newbrough & Gammons, 2002
Environmental Geology 41, 705-719)

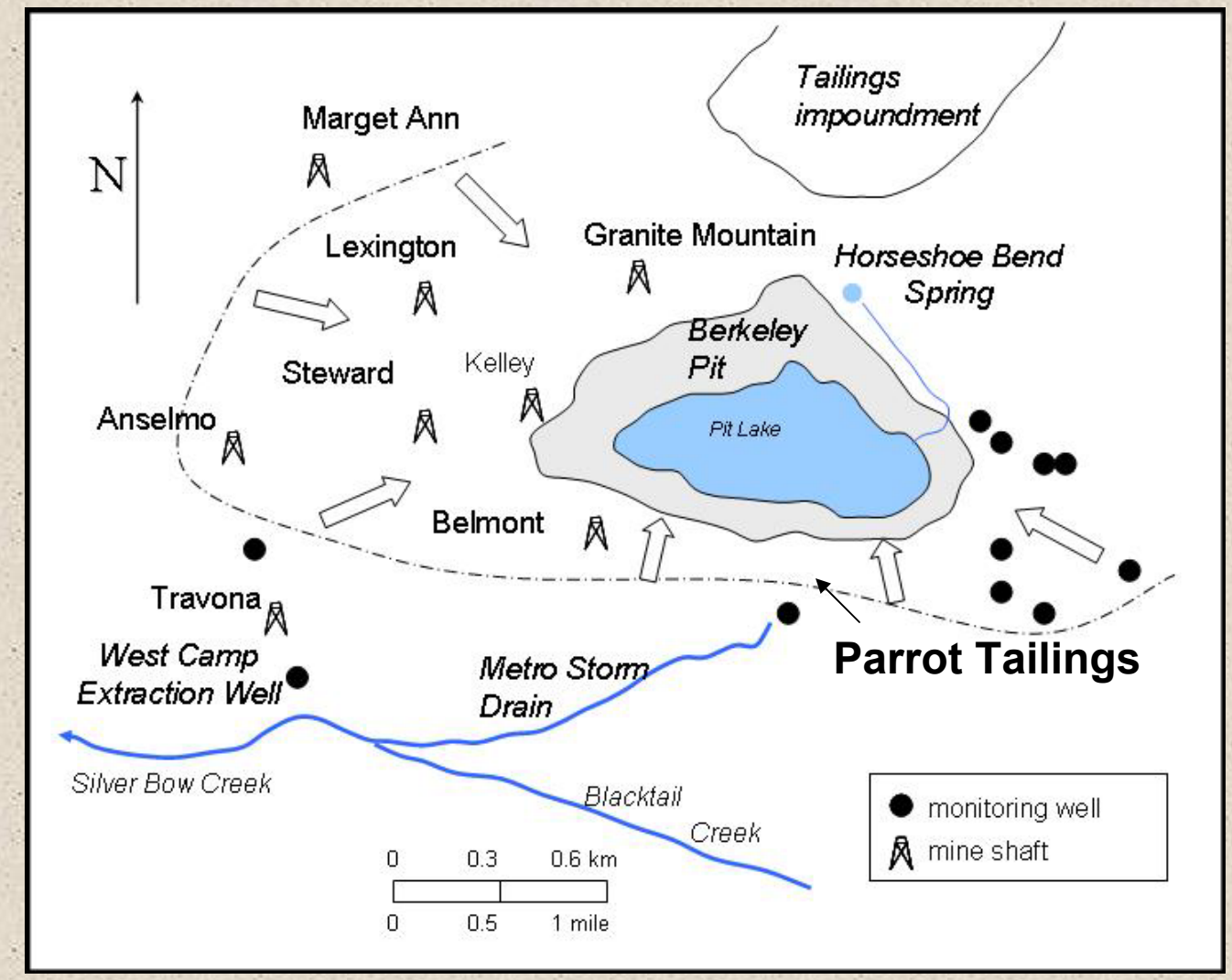


Evaporation calculations: Butte mine waters



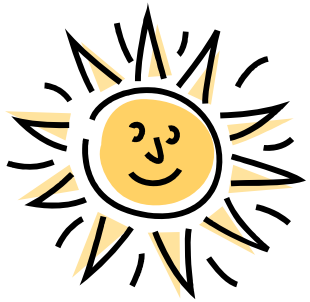
Gammons et al., 2006, J. of Hydrology

Where is groundwater coming from?



Aerial view of Butte, looking East

Subaqueous pyrite oxidation



Above water line

1) $FeS_2 + 7/2O_2 + H_2O \rightarrow$

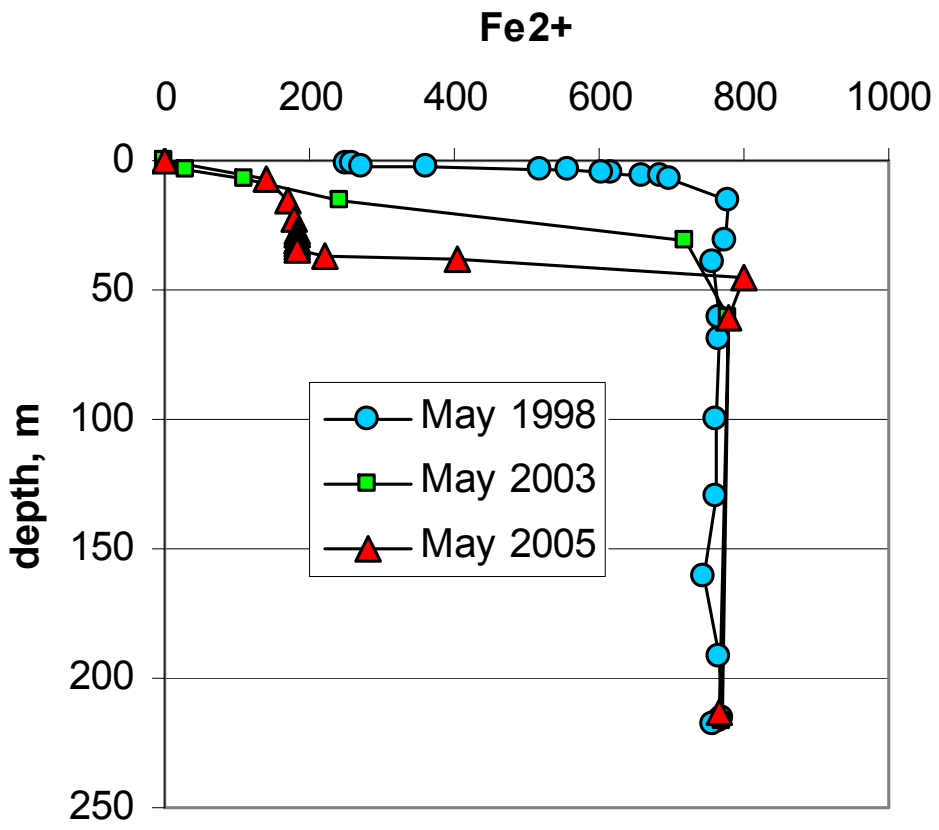
$Fe^{2+} + 2SO_4^{2-} + 2H^+$

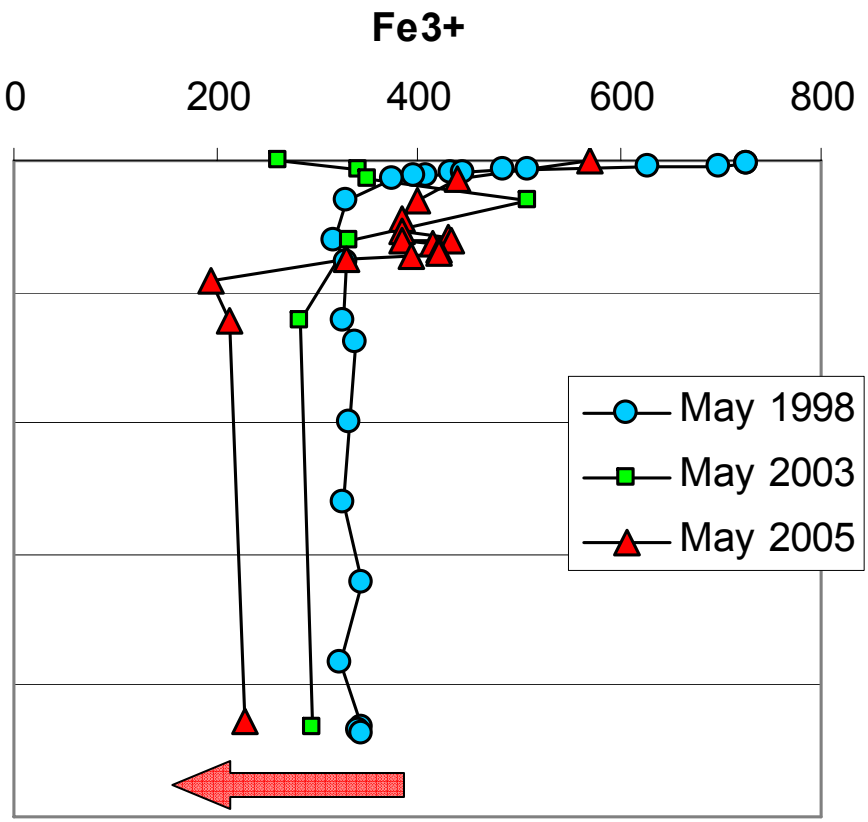
Below water line

2) $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow$

$15Fe^{2+} + 2SO_4^{2-} + 16H^+$

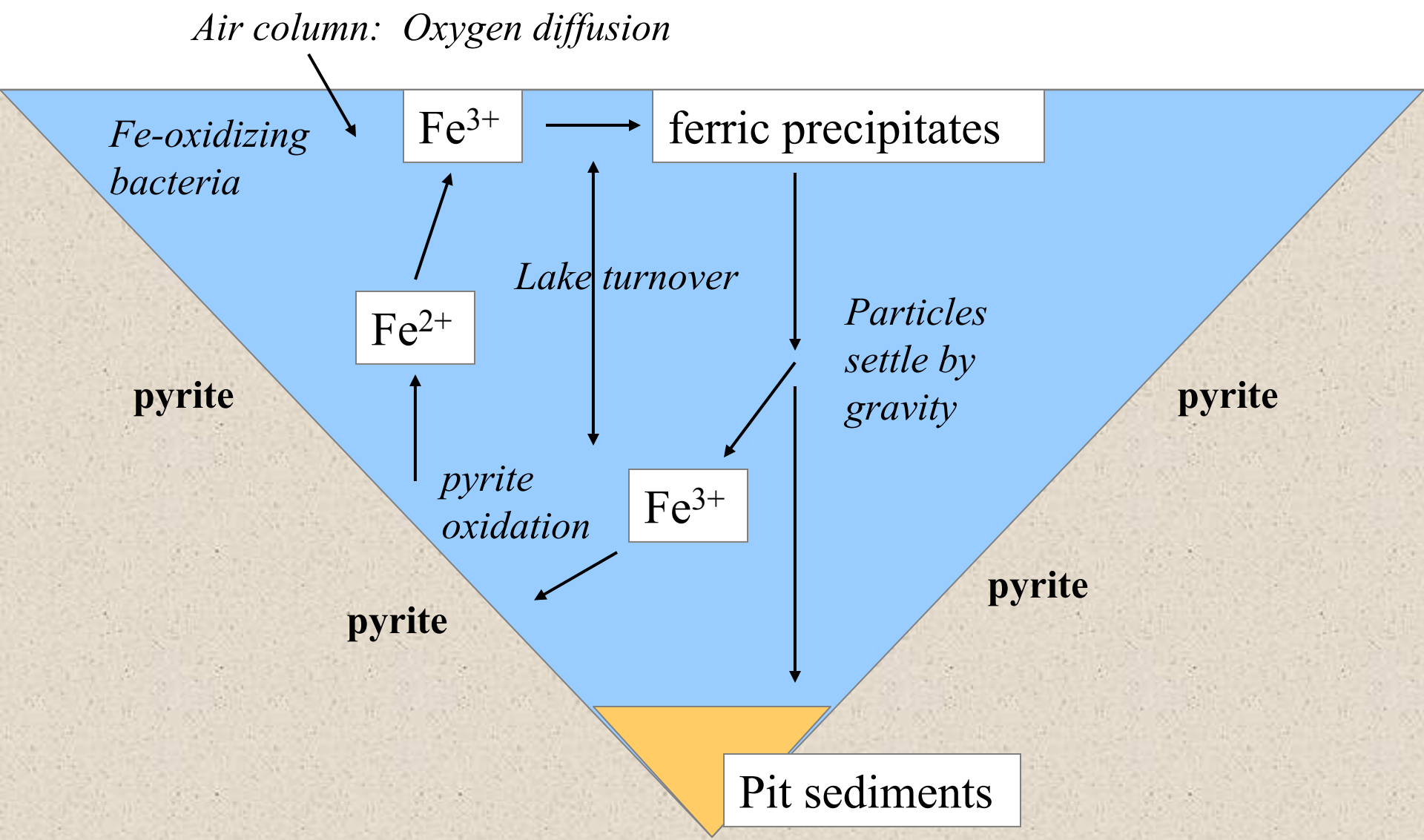
Berkeley Pit: Fe profiles over time





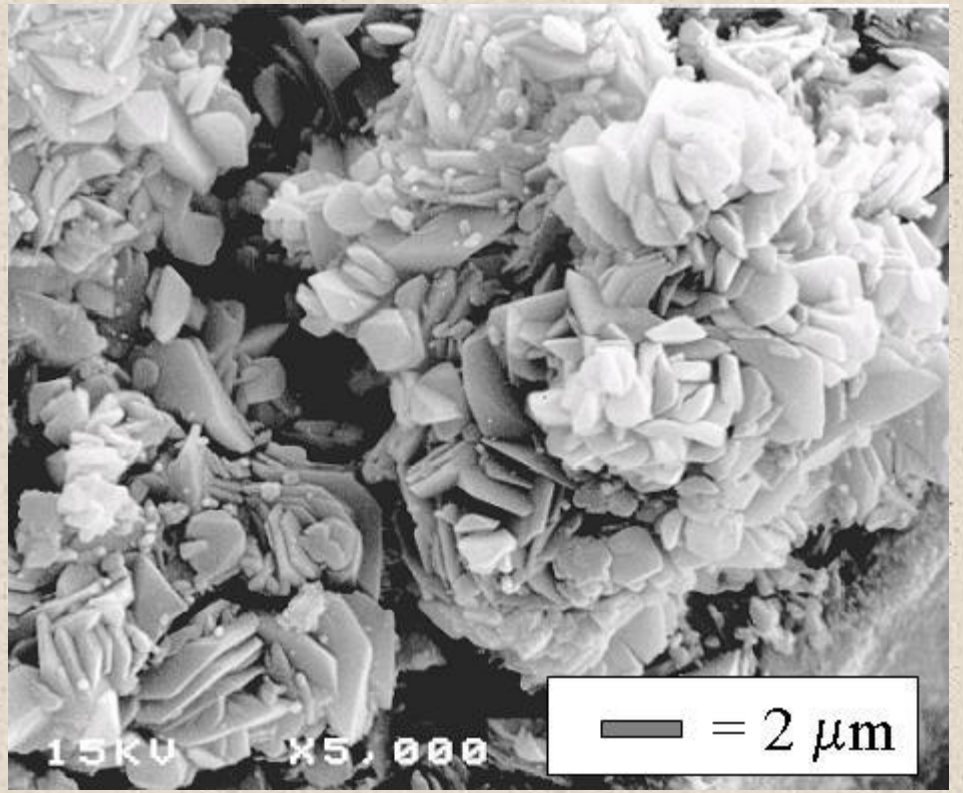
downwards shift with time: subaqueous pyrite oxidation?

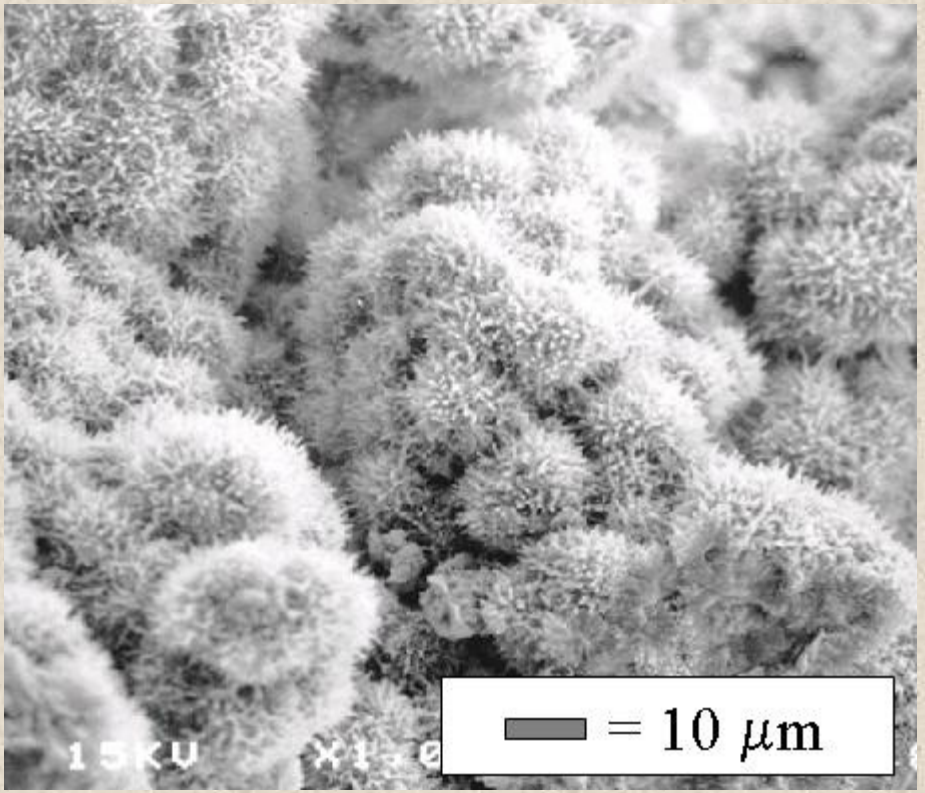
Iron Cycling Model: Berkeley Pit



Berkeley pit-lake minerals

SEM photos taken by Dick Berg at ICAL, Montana State Univ.





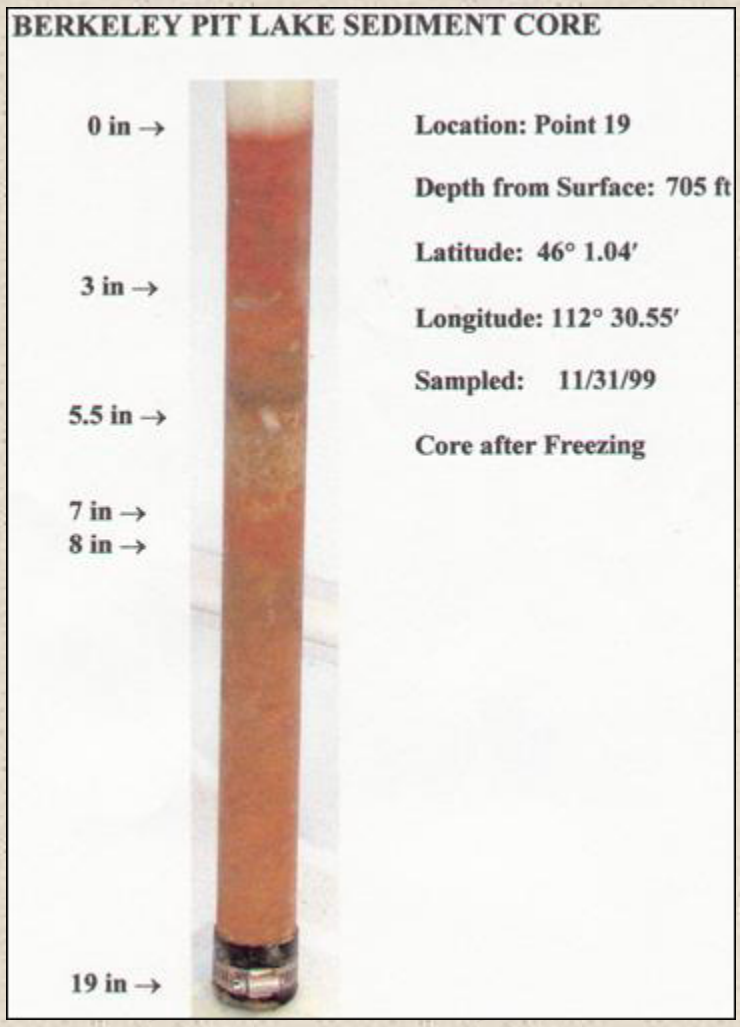
jarosite

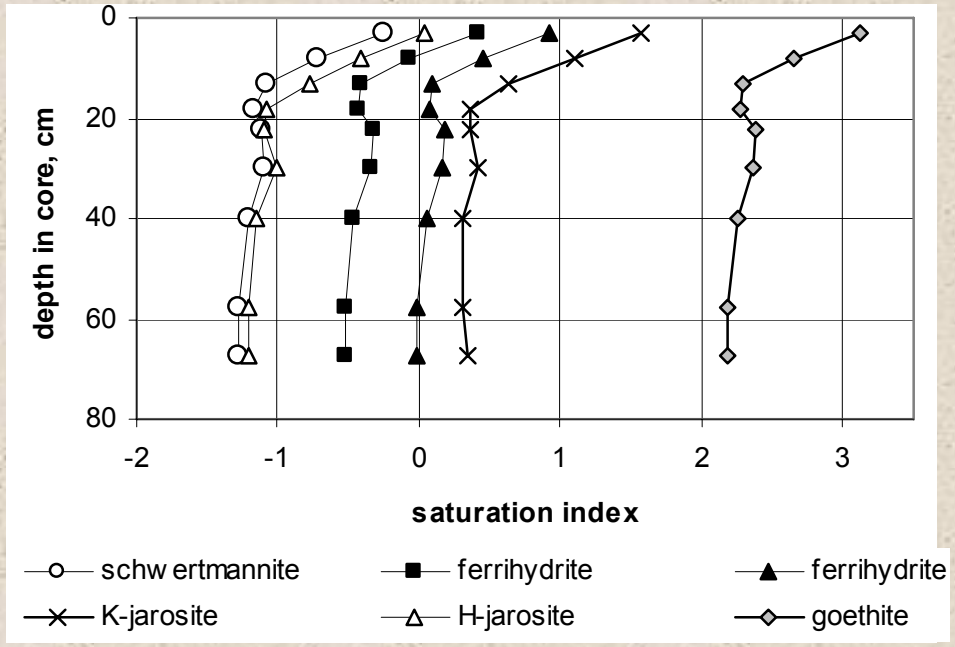
$KFe_3^{III}(SO_4)_2(OH)_6$

schwertmannite

$Fe_8^{III}O_8(SO_4)(OH)_6$

Pit lake sediment

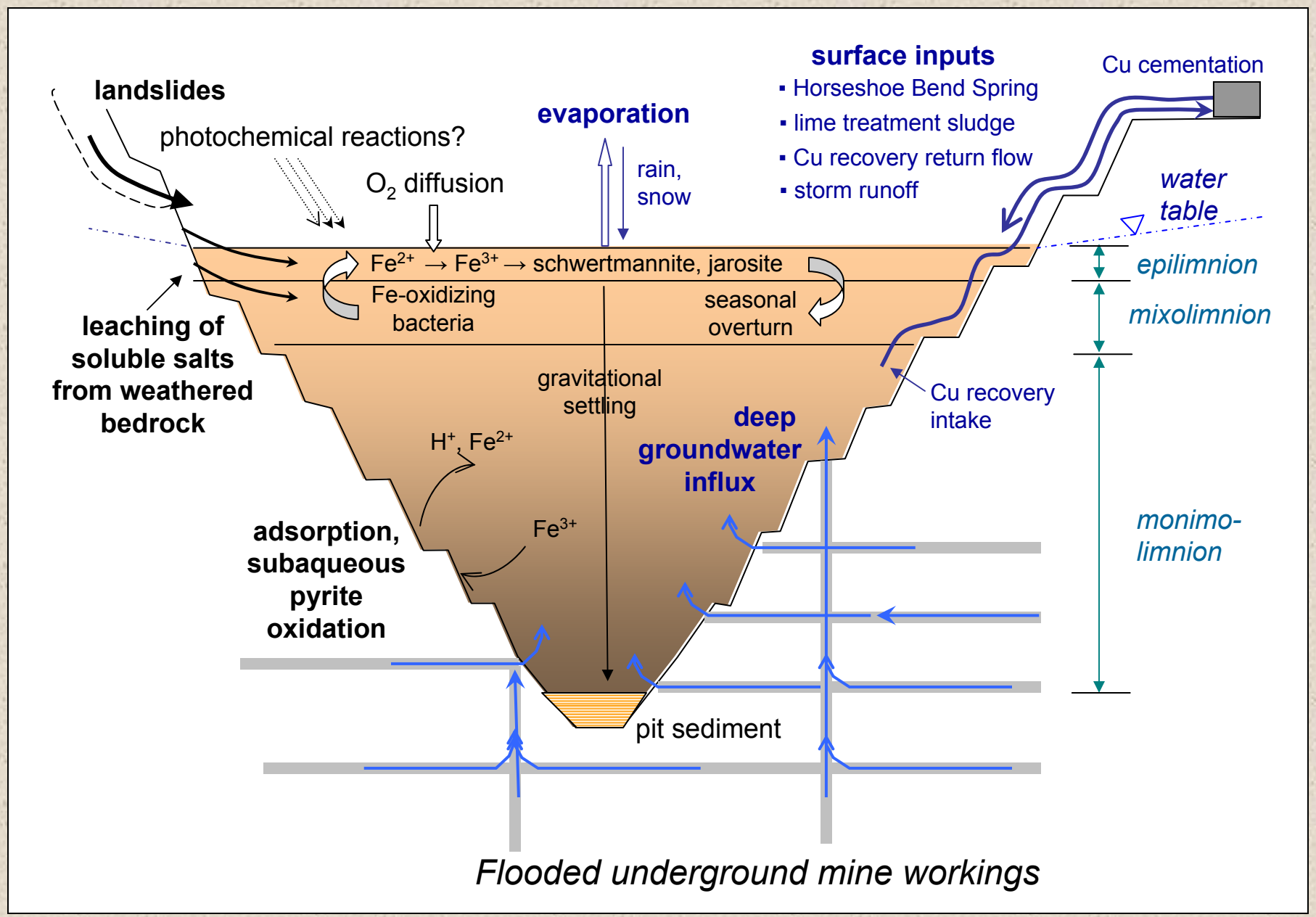




- Pit lake sediment is oxidized to depth of 1 m
- Possible transformation of schwertmannite to “aged” ferrihydrite and K-jarosite

Twidwell et al., 2006

Berkeley pit lake: Conceptual Model



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- Montana Resources
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- US-EPA, US-DOE
- Montana Tech Mine Waste Technology Program
- Montana Tech graduate students

Mike Kerschen, MBMG

References

Cameron D., Willett M., Hammer L. (2006) Distribution of organic carbon in the Berkeley Pit Lake, Butte, Montana. *Mine Water and the Environment* 25(2), 93-99.

Gammons C. H., Wood S. A., Jonas J. P. and Madison J. P. (2003) Geochemistry of rare earth elements and uranium in the acidic Berkeley Pit lake, Butte, Montana. *Chemical Geology*, 198, 269-288.

Gammons C. H., Metesh J. J. and Duaime T. E. (2006) An overview of the mining history and geology of Butte, Montana. *Mine Water and the Environment* 25(2), 70-75.

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* 25(2), 76-85.

Gammons C. H., Metesh J. J., and Snyder, D. M. (2006) A survey of the geochemistry of flooded mine shaft water in the Butte District, Montana. *Mine Water and the Environment* 25(2), 100-107.

Gammons C. H., Poulson S. R., Pellicori D. A., Roesler A., Reed P. J., Petrescu E. M. (2006) The hydrogen and oxygen isotopic composition of precipitation, evaporated mine water, and river water in Montana, USA. *Journal of Hydrology* 328, 319-330.

Madison J. P., Gammons C. H., Poulson S. R. and Jonas J. P. (2003) Oxidation of pyrite by ferric iron in the acidic Berkeley pit lake, Montana, USA. Proc. 6th International Conf. on Acid Rock Drainage, Cairns, Australia, July 14-17, 2003, Australian Inst. of Mining & Metall., Publ. Series 3/2003, 1073-1078.

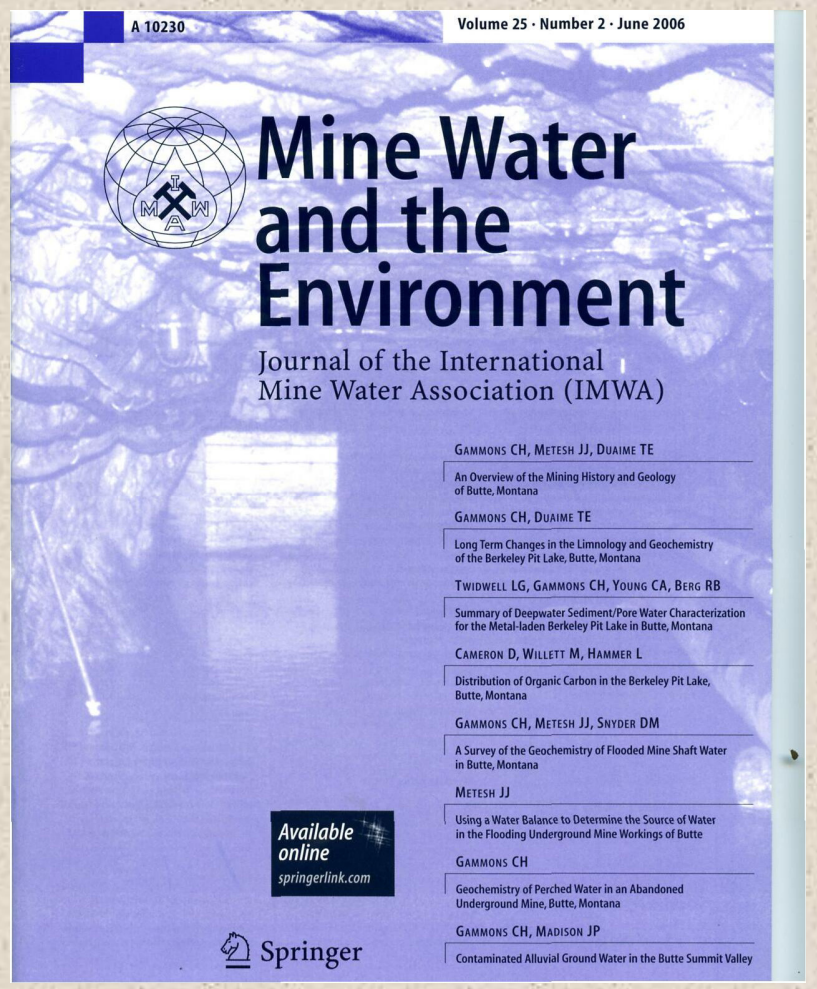
Newbrough P. and Gammons C. H. (2002) Experimental investigation of water-rock interaction and acid mine drainage at Butte, Montana. *Environmental Geology* 41(6), 705-719.

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* 20, 2116-2137.

Twidwell L., Gammons C. H., Young C., and Berg R. (2006) Deepwater sediment/pore water characterization of the metal-laden Berkeley pit lake in Butte, Montana. *Mine Water and the Environment* 25(2), 86-92.

References in **bold** are included on the MEND workshop CD

Questions?



Frozen lake surface with strange gypsum (?) concretions