

Mining Pit Lakes: An Overview of their Characteristics with Emphasis on Northern Climates



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Overview of talk

- Geology & limnology
 - Definitions
 - Lakes in northern climates
- Geochemical processes
 - Redox structure of pit-lakes
 - Metals and metalloids
- Biological processes
- Potential for beneficial use
- Diamond mines and pit lakes



Sampling the Berkeley Pit

Two Montana examples: Geological controls



Good lake

- Calvert tungsten mine
- Low pyrite & assoc. metals
- Marble host rock

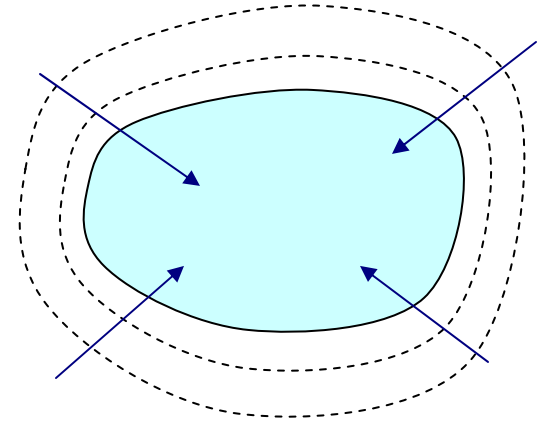
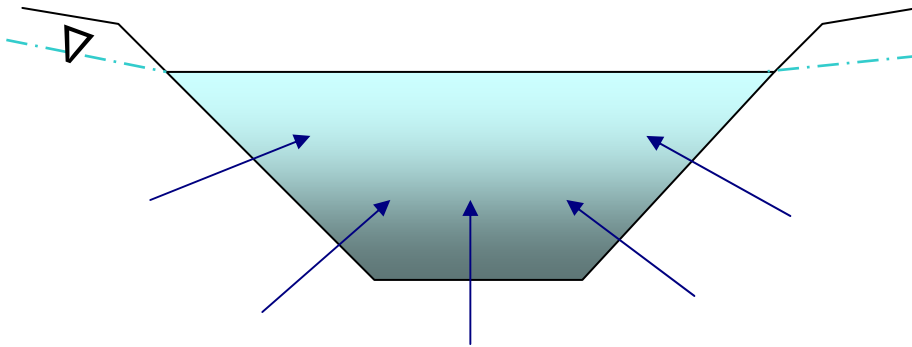


Bad lake

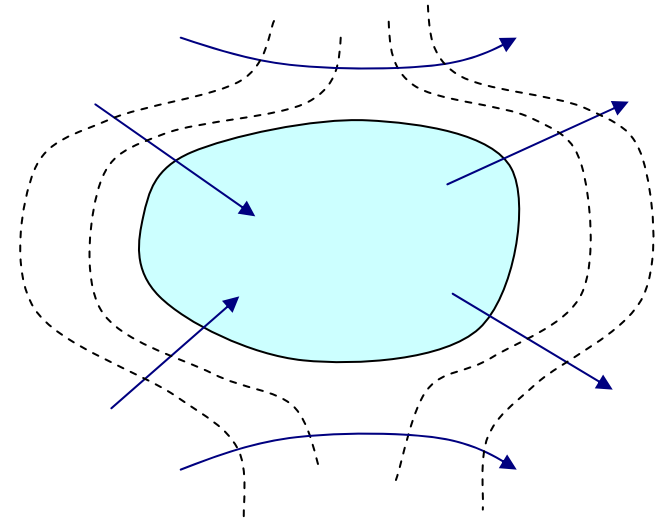
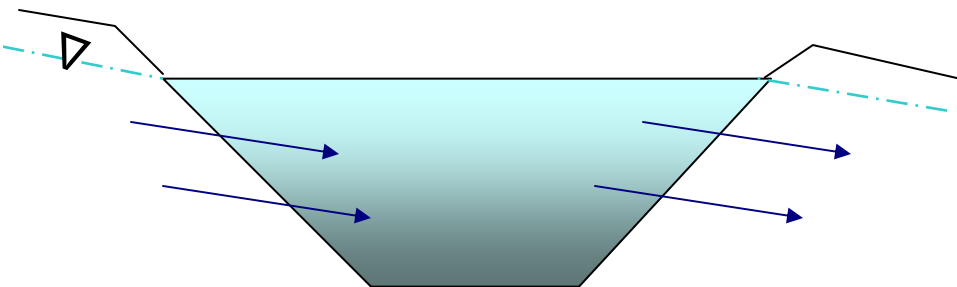
- Berkeley Pit copper mine
- High pyrite & metals
- Clay-altered granite

Lake-Groundwater Interactions

Terminal Lake

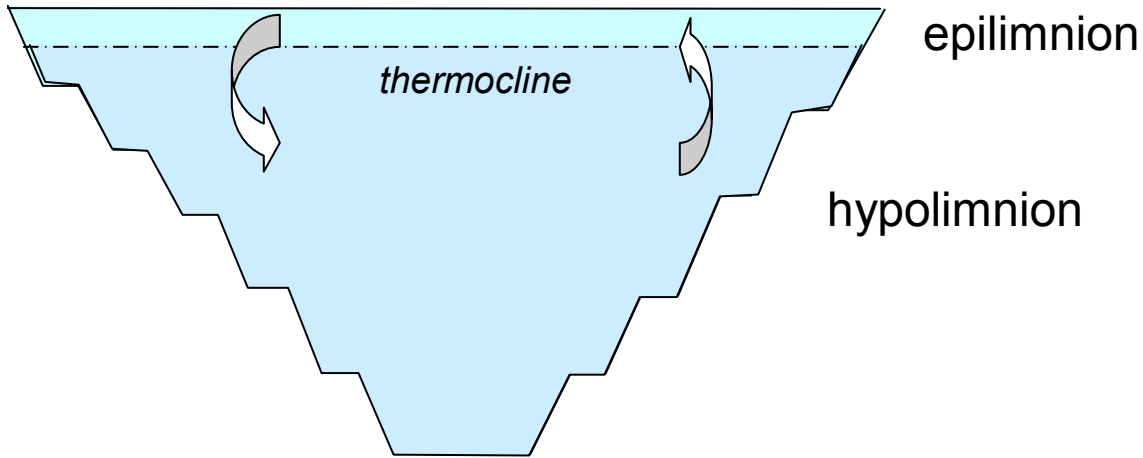


Flow-through Lake

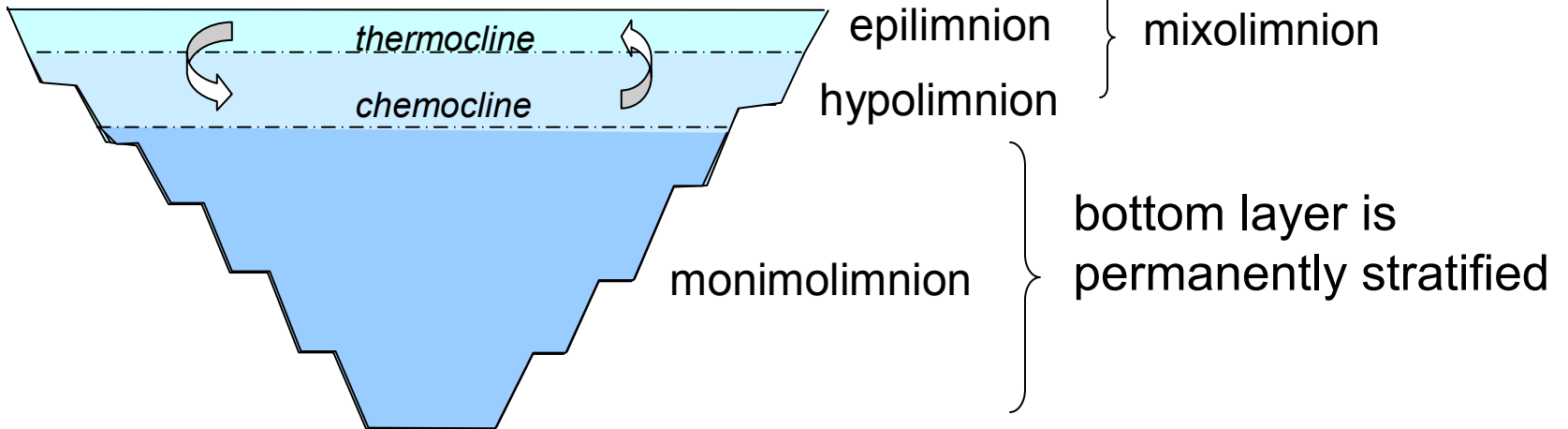


Limnology

a. Holomictic lake



b. Meromictic lake



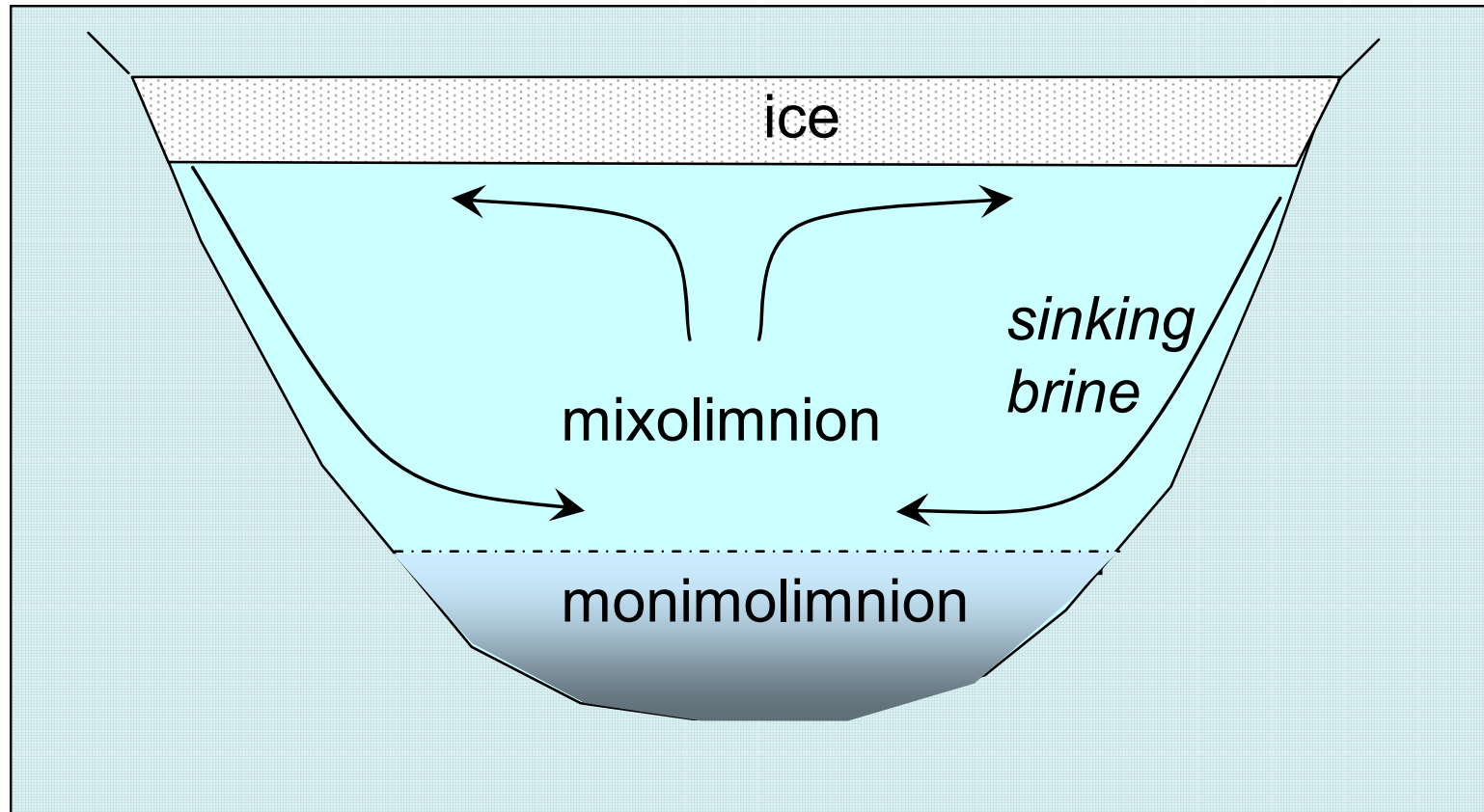
Meromixis is favored by:

- High-TDS water at depth
 - Saline groundwater
 - Diverted ocean water or AMD
- High depth/width aspect ratio
 - aka “relative depth”
- Absence of strong wind
- Thick ice → salt-exclusion

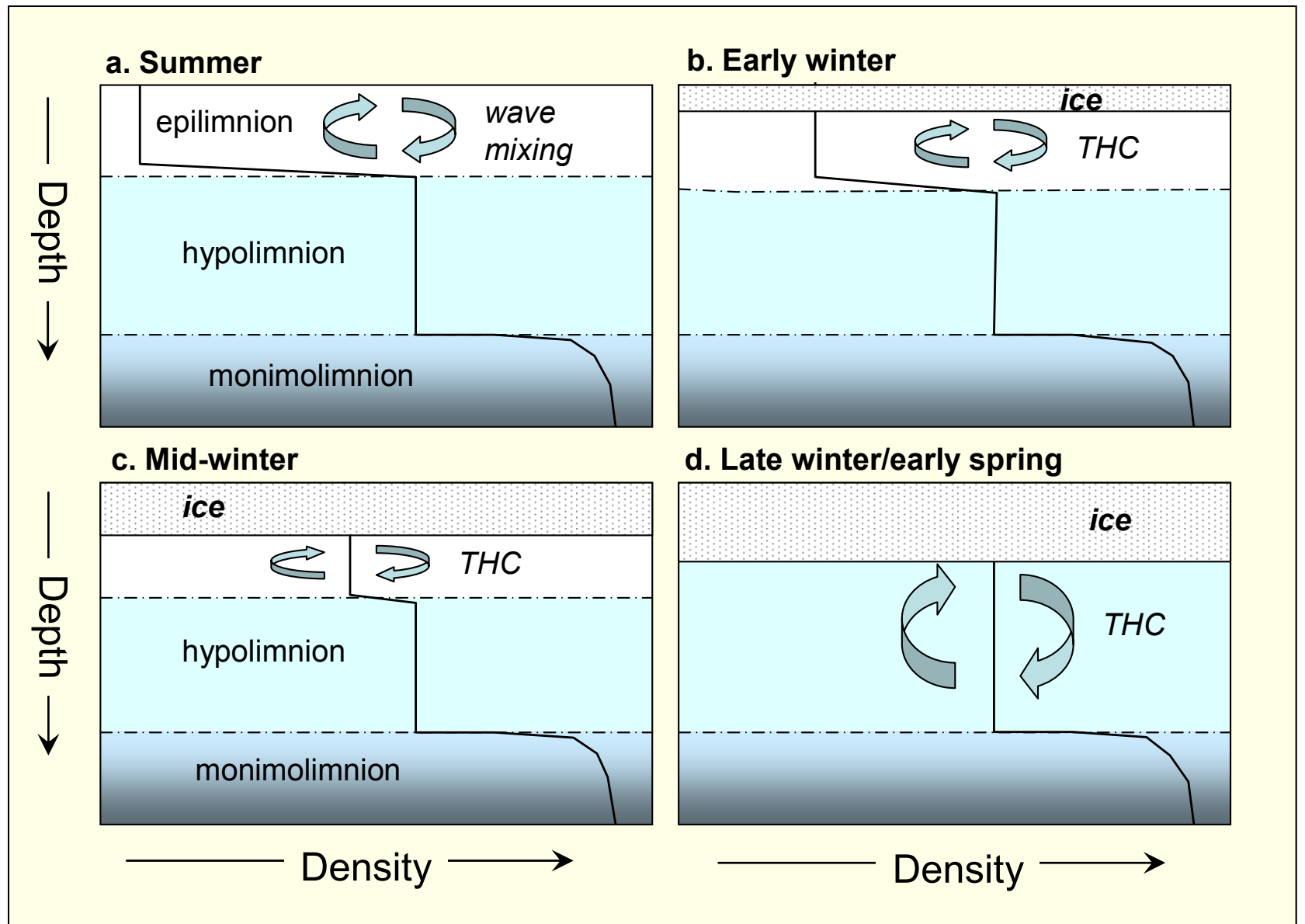


Rings of salt (gypsum?) in ice
Berkeley Pit lake

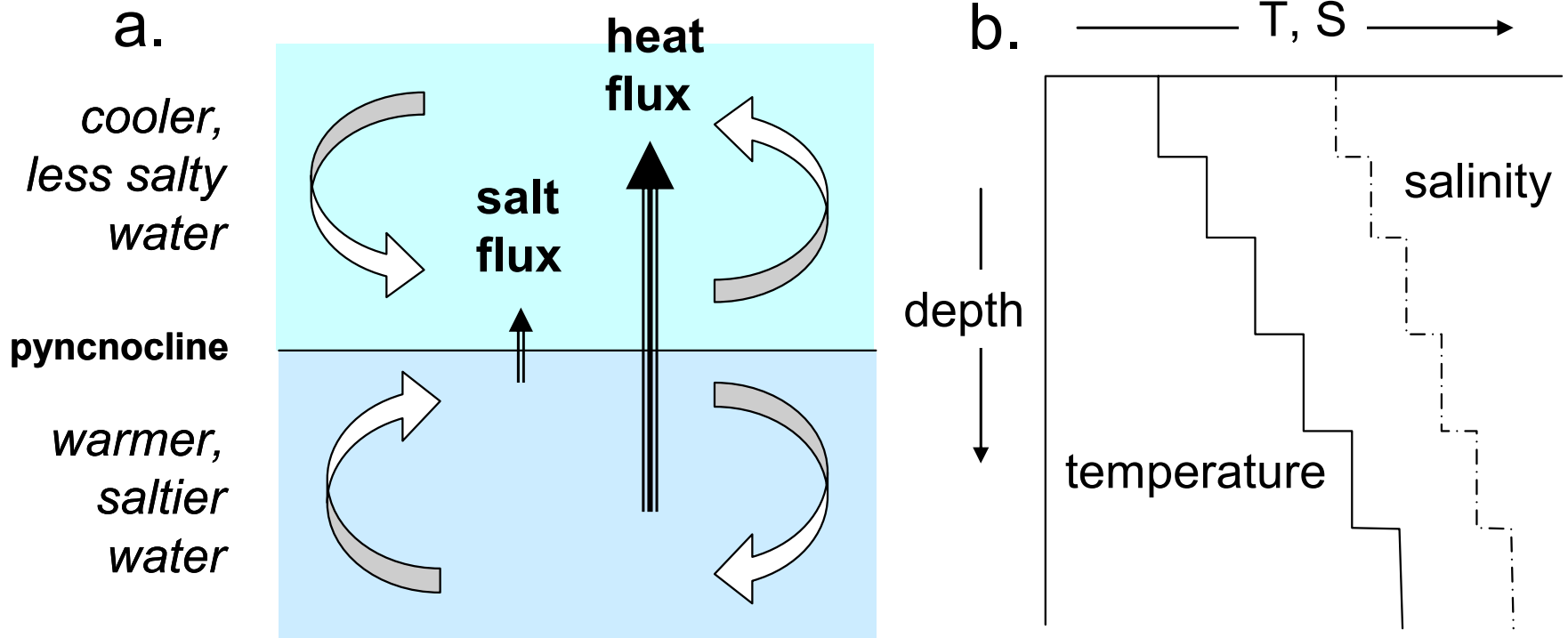
Thermohaline convection



Common phenomenon in polar oceans



Double diffusion convection

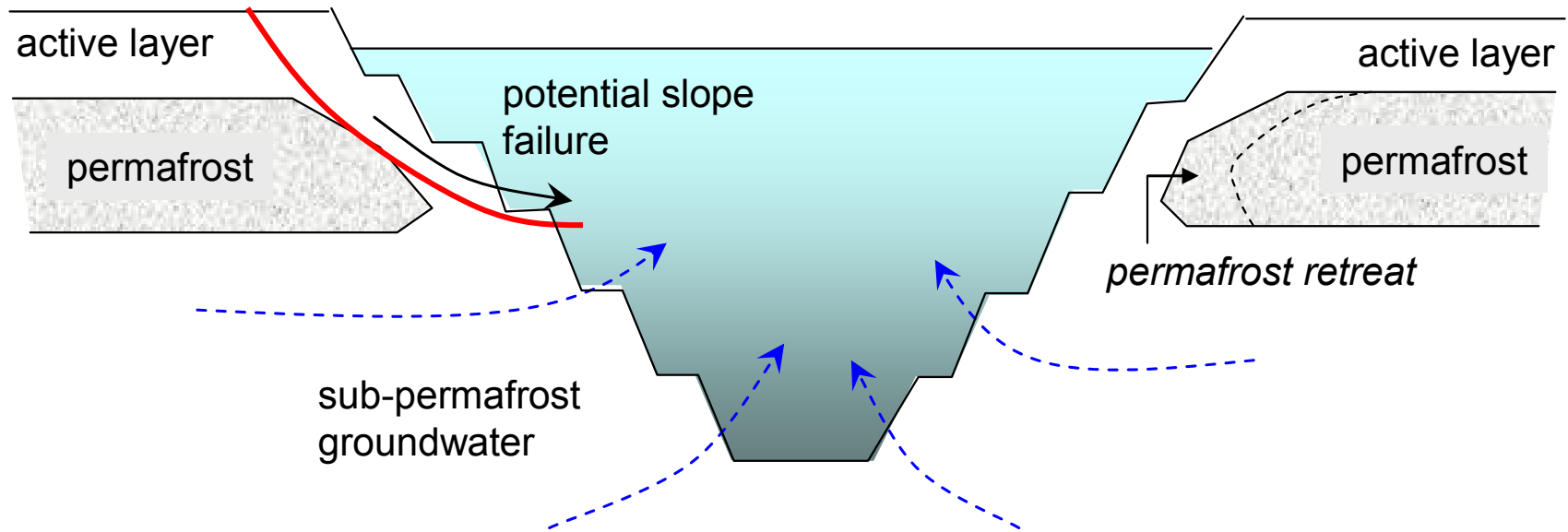


First described in Antarctic lakes

Consequences of meromixis

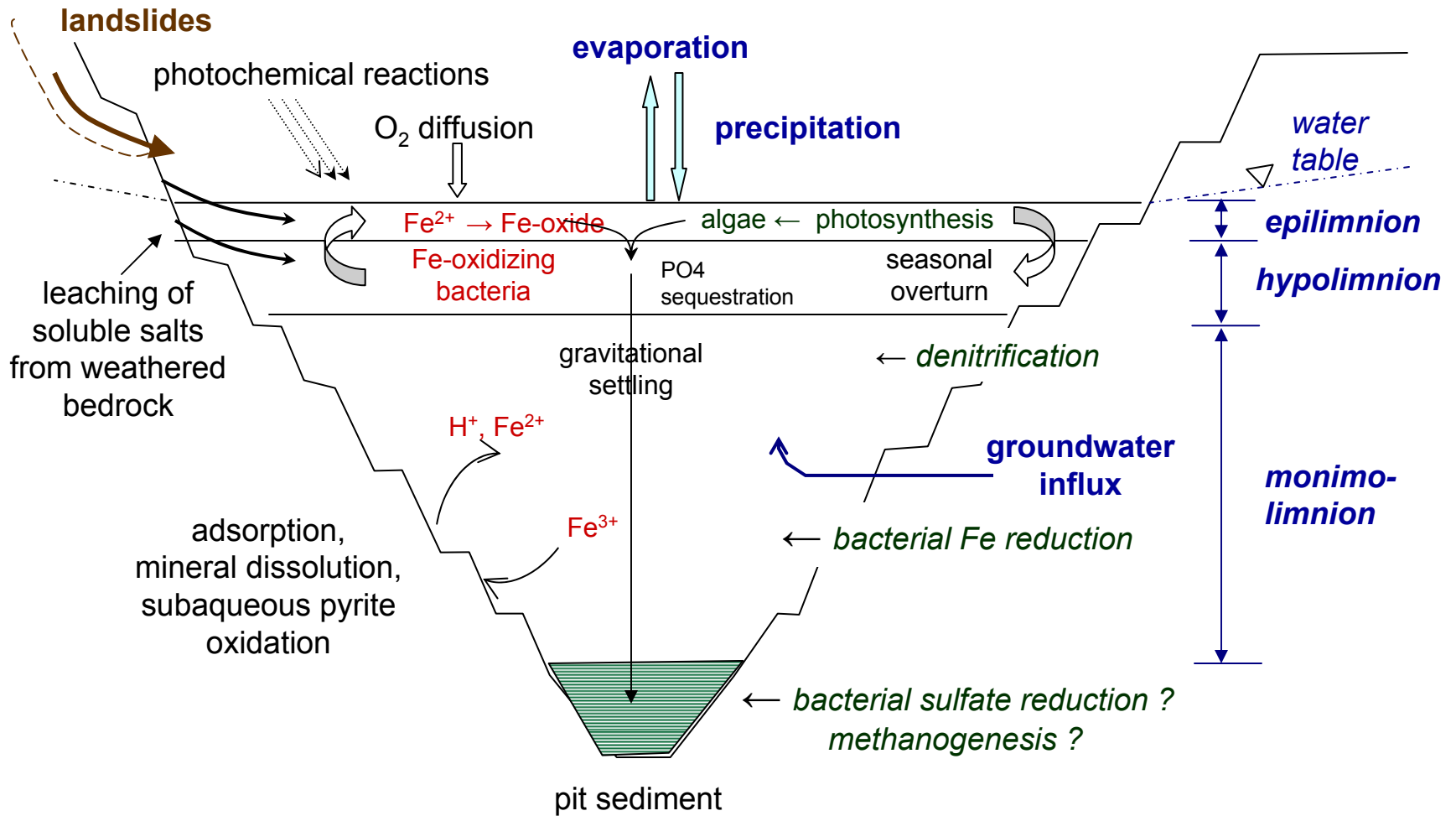
- Poor water quality in monimolimnion
 - Dissolved oxygen low or absent
 - High salinity, high metals
 - High CO₂, H₂S (?)
- Mixolimnion may or may not be good water quality. Problems:
 - “Entrainment” of deep water during seasonal turnover
 - Possible mixing during landslides

Permafrost retreat and slope failure

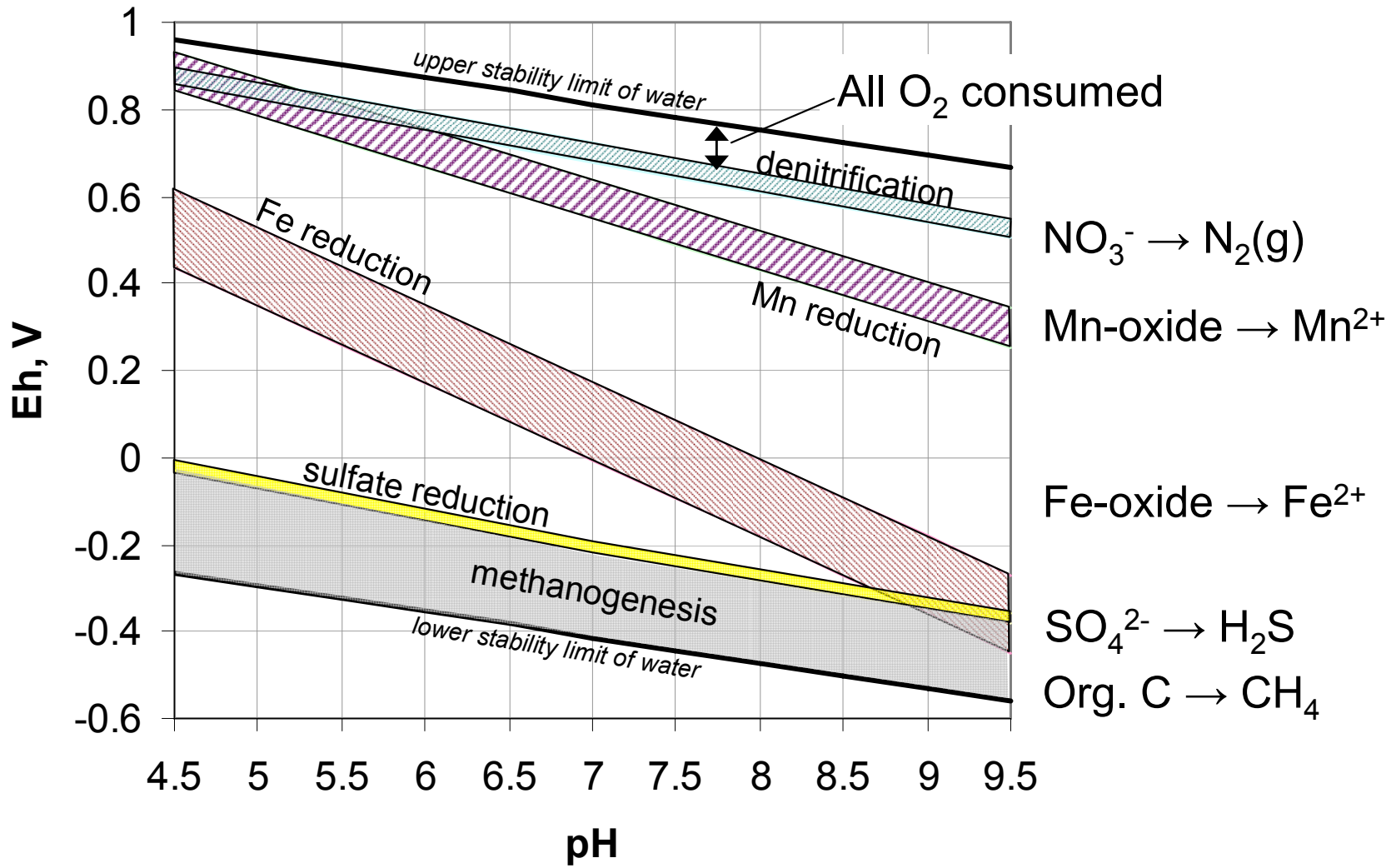


Attention! A large slope failure can completely overturn a lake

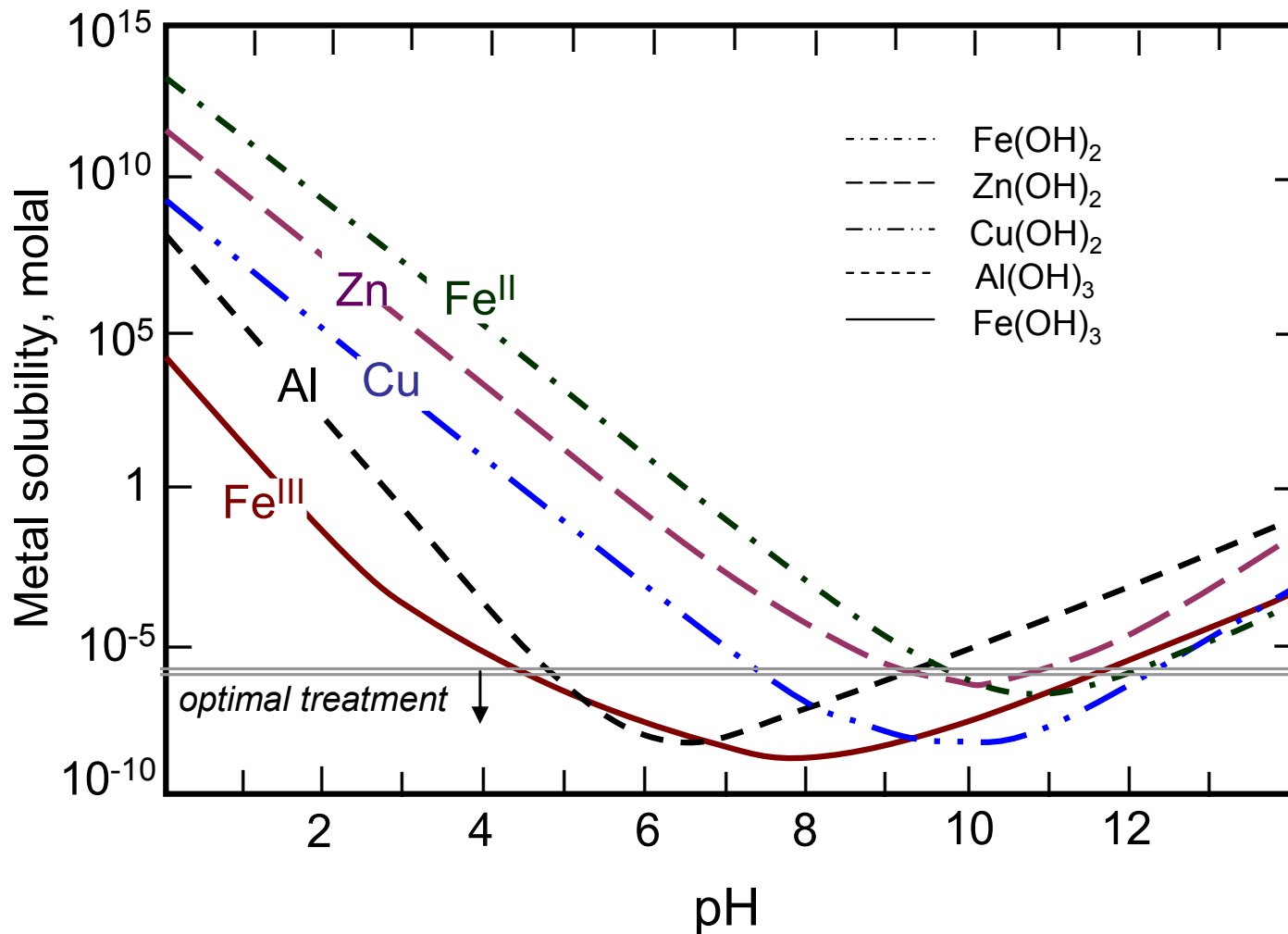
Pit-lake processes



Bacterial reduction sequence

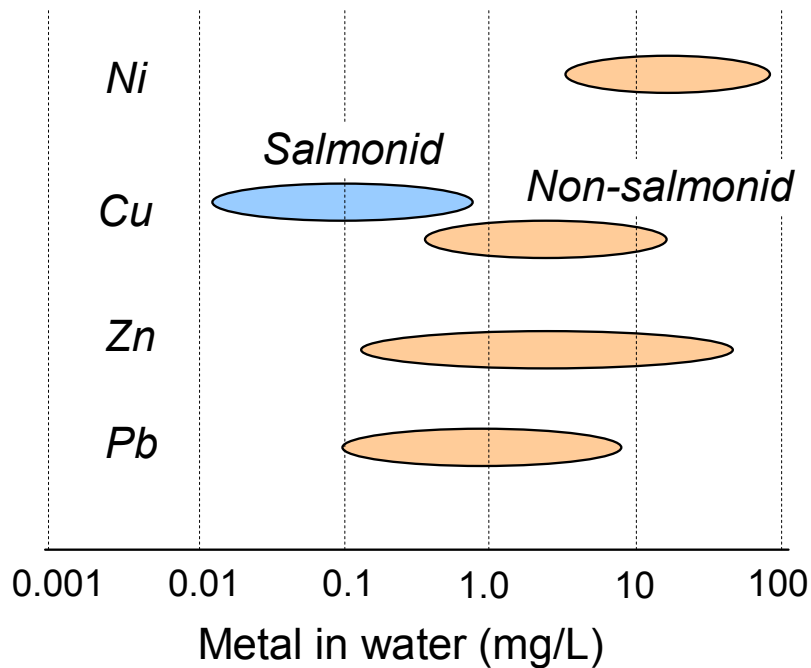


Metal solubility vs. pH



Problem: mobility of metalloids (As, Se) increases at high pH

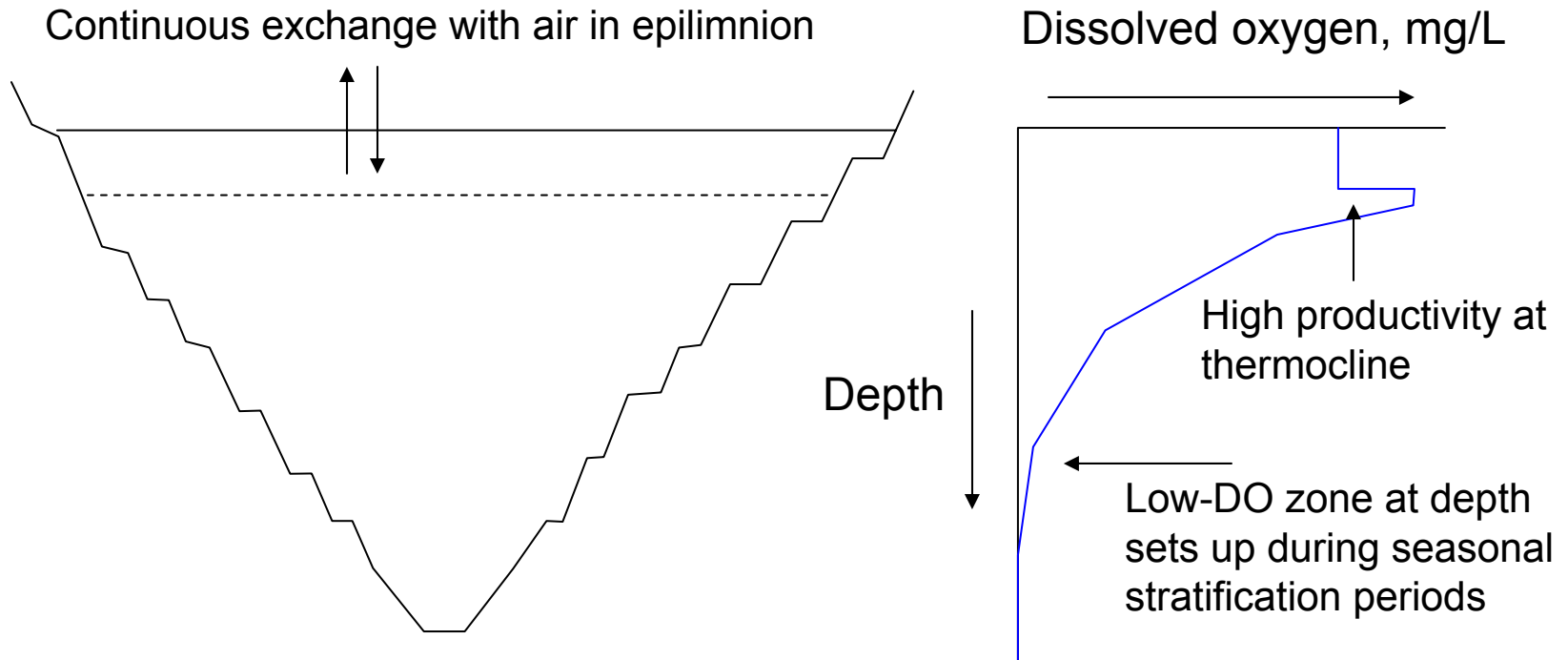
Metal toxicity to fish



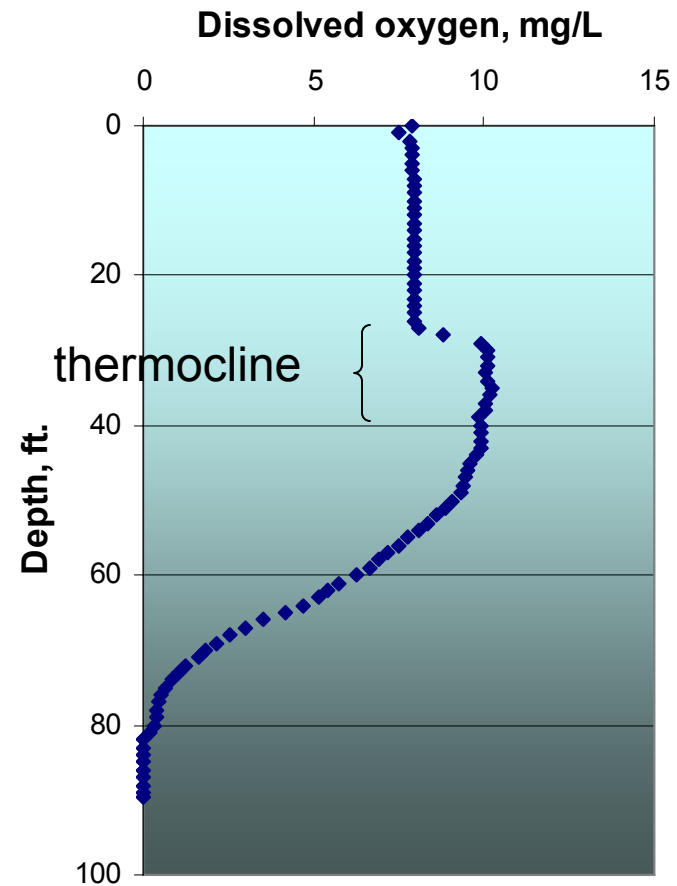
- Toxicity decreases if metal is bound with dissolved organic carbon
- Toxicity decreases as concentration of $\text{Ca}^{2+} + \text{Mg}^{2+}$ (i.e., hardness) increases
- Toxicity increases in presence of other stressors (e.g., temperature, pH)

Dissolved oxygen profiles of pit lakes

1. holomictic lake

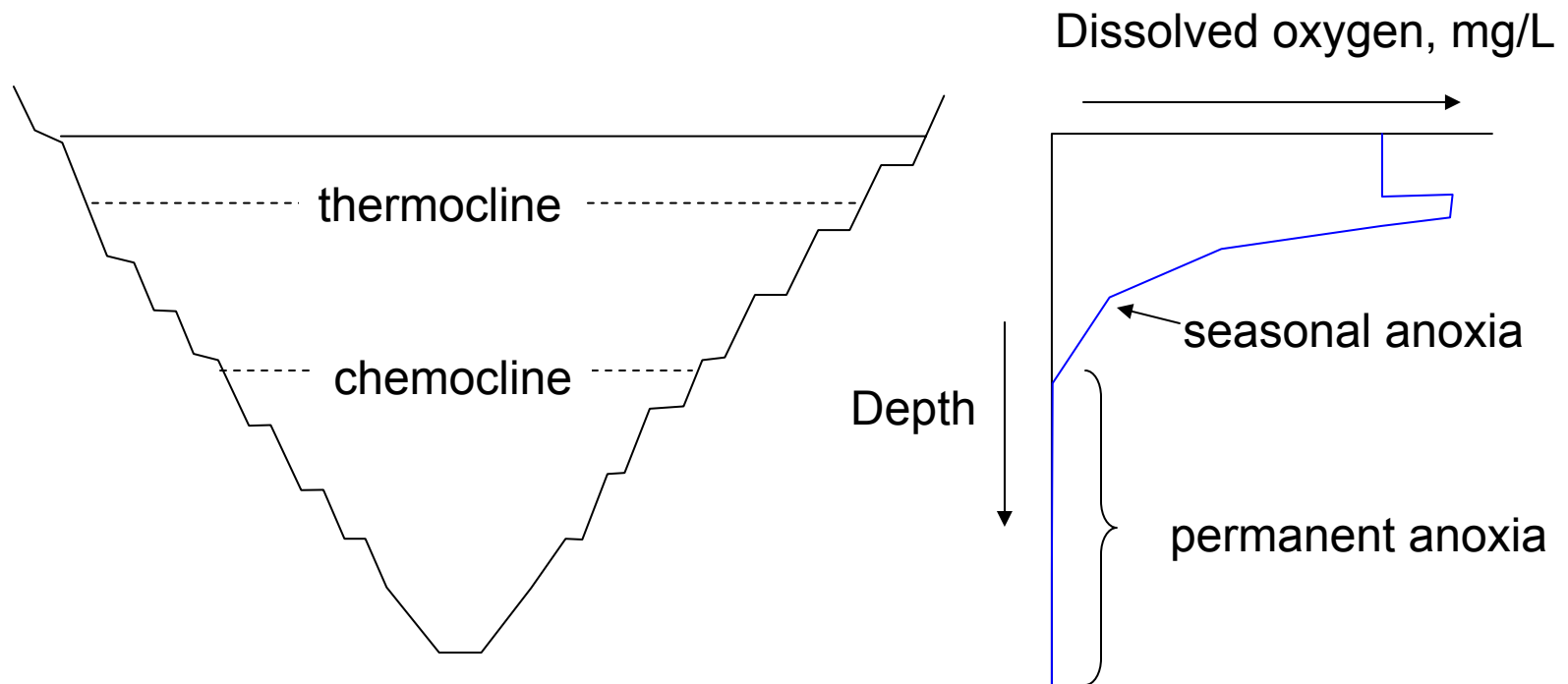


Example: Calvert pit lake



Dissolved oxygen profiles (cont.)

2. meromictic lake



Biology of pit lakes: general considerations

- Nutrient budget
 - Oligotrophic (nutrient-poor) conditions are common
 - Large lake volume/surface area ratio
 - Sequestration of phosphate by Fe-oxides
 - Eutrophic (nutrient-rich) is possible
 - E.g., Colomac pit lake
High nitrate from breakdown of cyanide
 - Nutrient amendments (e.g., Gilt Edge, S. Dakota)
- Turbidity
 - Common problem in mining lakes
 - Decreases secchi depth and may impact fish

Biology of pit lakes (cont.)

■ Water chemistry

- pH, redox, trace metals and metalloids
 - Fish have lower and upper limits of tolerance on pH, D.O.
 - Salmonids are extremely sensitive to certain trace metals (e.g., Cd, Cu, Zn)

■ Morphometry

- Most pit lakes are deep and steep-sided
 - Lack of littoral habitat may be a serious problem

■ Connection with other water bodies

- Pit lakes are often “isolated” ecosystems
 - Delayed species recruitment
 - Opportunities for introduction of specific (native) species
 - Long time to biological “equilibrium”

Engineering pit-lakes for beneficial end-use

- Permanent disposal of mine waste
- Tourism

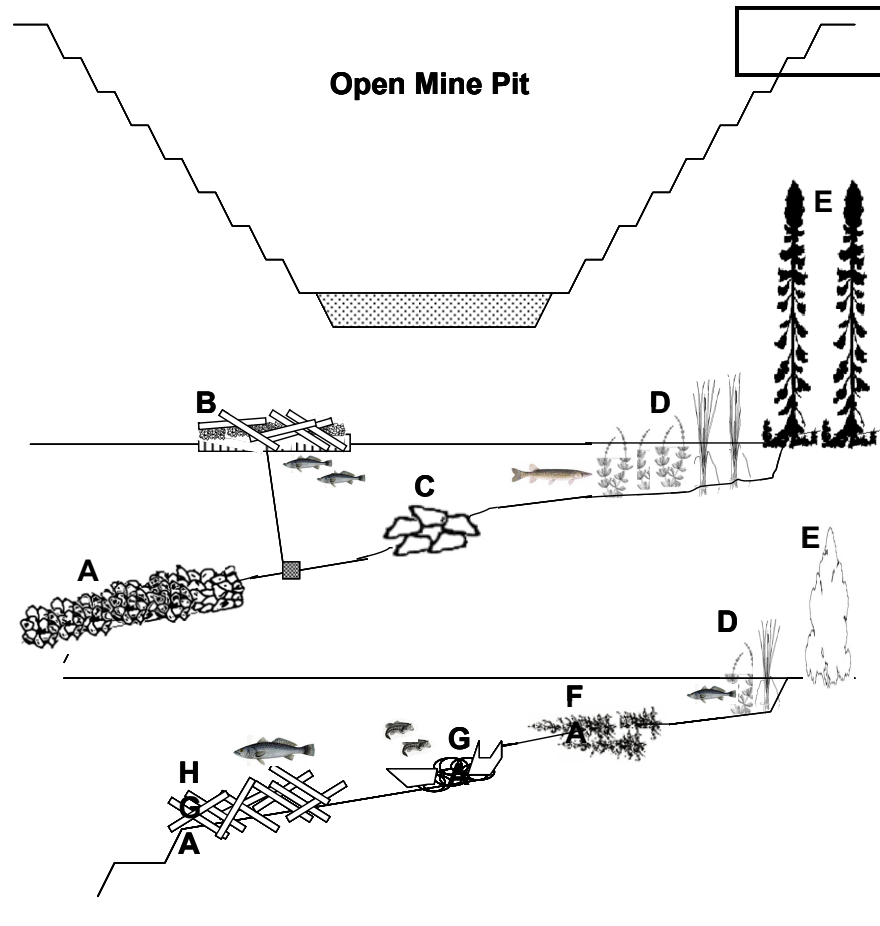
Good lakes

- Water supply
 - Irrigation
 - Drinking water
 - Ice roads
- Fisheries
- Recreation
- Real estate

Bad lakes

- Metal extraction
(e.g., Berkeley Pit, Butte)
- Study of life in
extreme environments
(e.g., Germany)

Habitat enhancement for fisheries



Slide courtesy of Les Harris, UBC

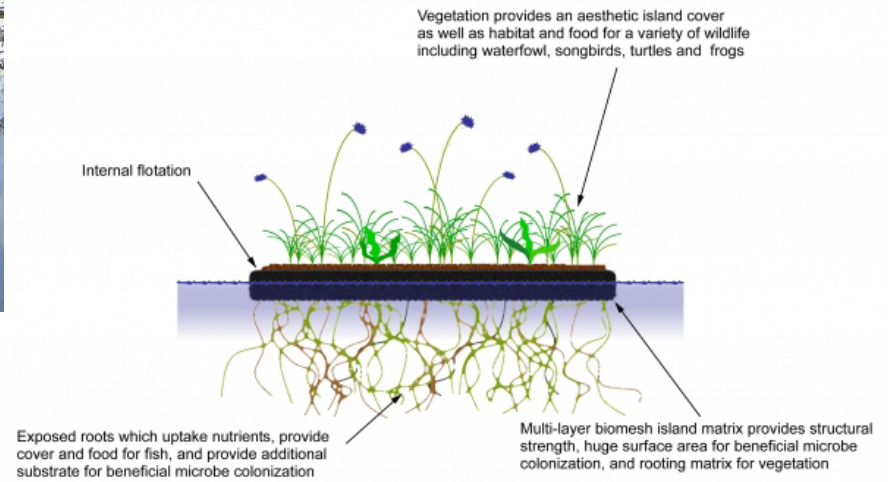
- Shallow benches for littoral zone
 - Macrophytes
 - Spawning habitat
- Add structures for shelter, aquatic life
 - Woody debris
 - Rip-rap
 - Rafts, floating islands
- Establish riparian vegetation
 - Stabilize shoreline
 - Source of carbon, terrestrial insects

Floating Islands



“Biohaven” website

“FloatingIslandsInternational” website



Methods for improving water quality

- Re-landscaping pit-walls for final “end use”
 - Prevent erosion
 - Provide littoral habitat
 - Cover acid-generating rocks
- Nutrient amendments
 - Stimulate growth of algae, bacteria
- pH adjustment
 - Addition of NaOH, lime or limestone
 - Difficult to mix entire water column

Can bad lakes be turned into good lakes?

Example: Gilt Edge (Anchor Hill) mine, S. Dakota

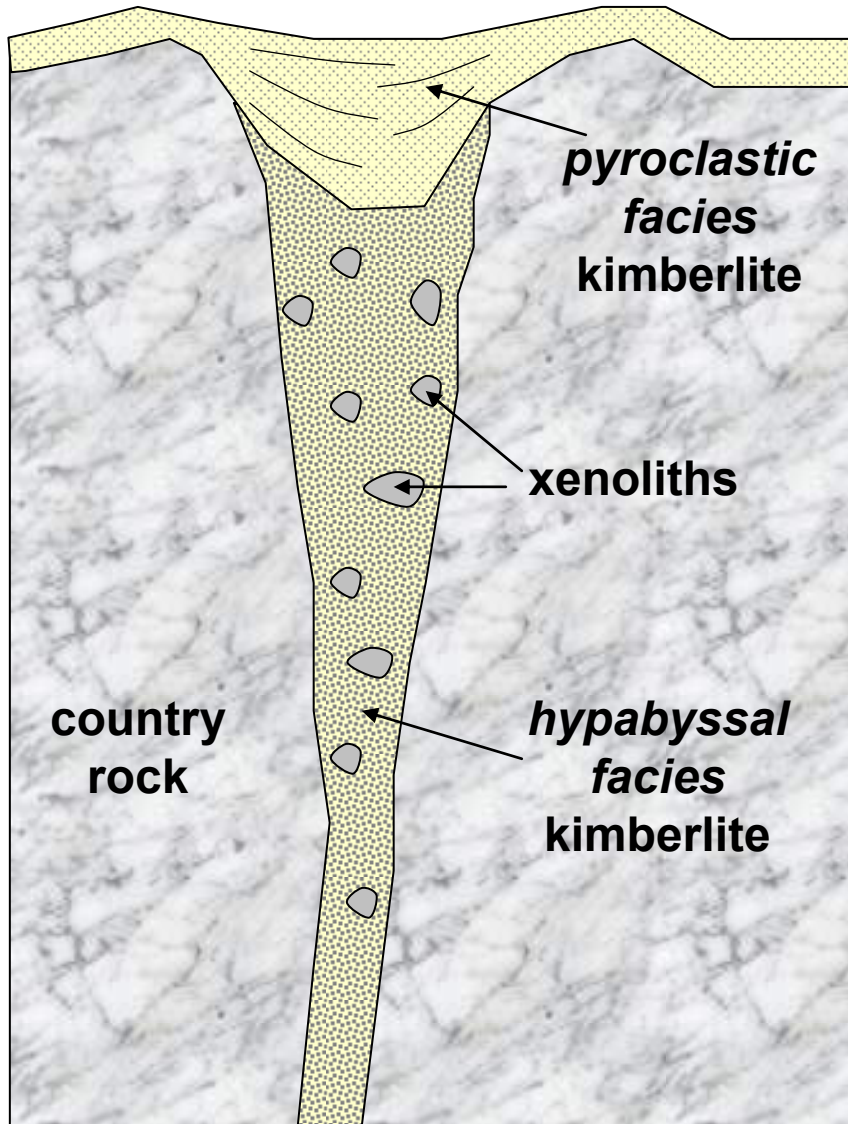


(Photo by Brian Park, May, 2001)

too much H_2S !
Expensive!

- Addition of methanol, molasses
- Stimulate bacterial sulfate reduction
- Raise pH, knock down dissolved metals

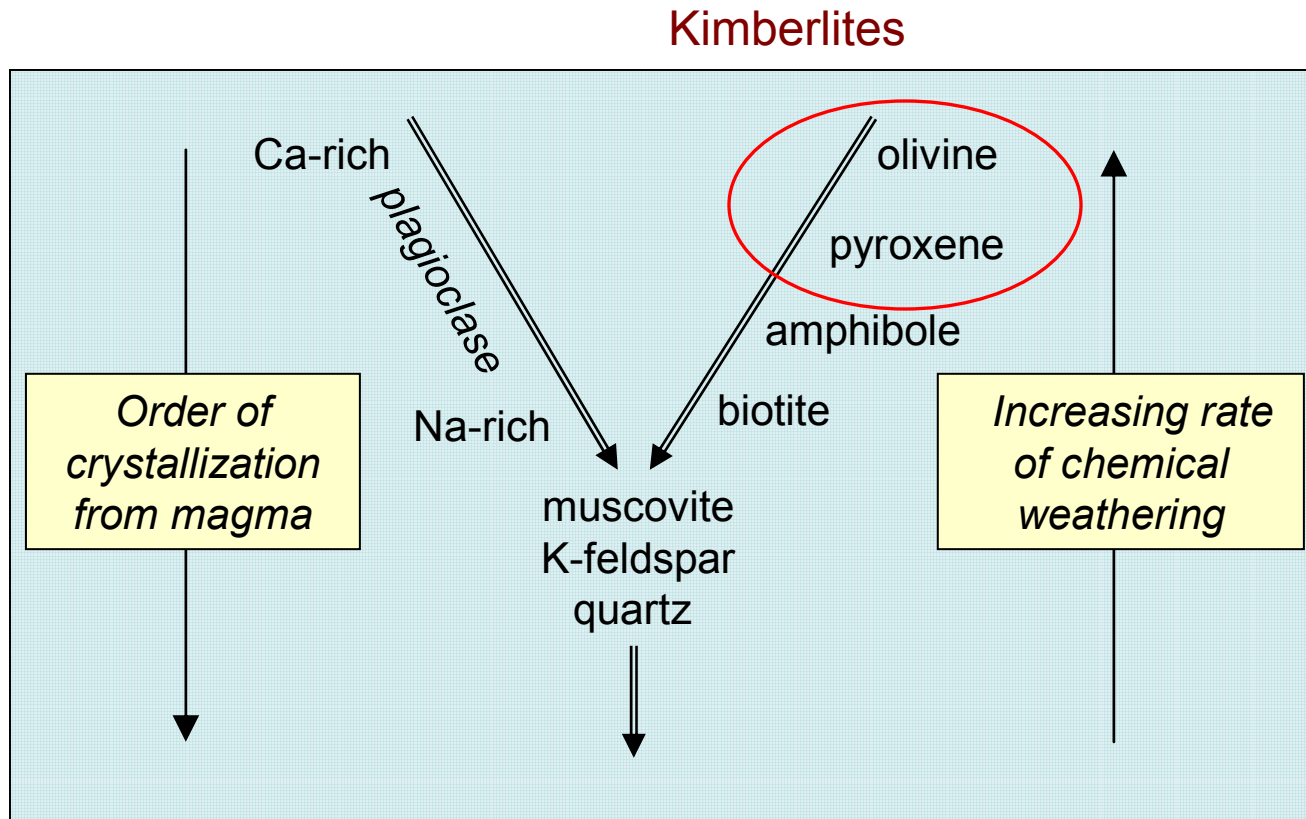
Diamond mines and pit lakes



The "Big Hole" pit lake at Kimberley, South Africa.

(Source: Wikipedia.org; photo by R. Botha, 2005).

Wall-rock buffering of mine water pH

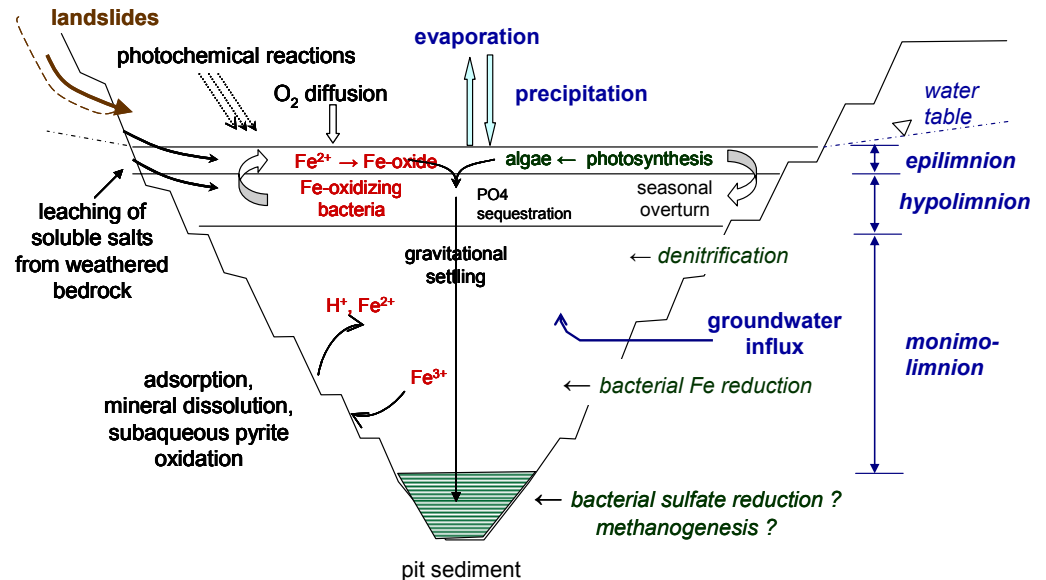


Bowen's Reaction Series

NWT diamond mines

- Kimberlite rock is net acid-neutralizing: should not generate AMD
- Unusually *high* pH has been reported for groundwater in contact with kimberlite in other parts of the world (e.g., Ontario)
- Country rock into which the kimberlite intrudes may contain pyrite and may be a source of heavy metals (e.g., Fe, Ni)
- Influx of deep, saline groundwater below permafrost may lead to pit-lake stratification.

Questions?



■ Principal reference:

Gammons C.H., Harris L.N., Castro J.M., Cott P.A., and Hanna B.W. (2009) Creating lakes from open pit mines: processes and considerations, with emphasis on northern environments. Canadian Technical Report of Fisheries and Aquatic Sciences 2826, 106pp.