Creating Lakes from Open-Pit Mines: Processes and Considerations, with Emphasis on Northern Environments

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Post-Mining Uses of Pit Lakes

- Aquatic habitat (fish, birds, and other aquatic wildlife)
- Source of public water supply for domestic use
- Source of water for agriculture, industry
- Recreational use
- Groundwater recharge
- Etc.

Northern Climates

The climate and other environmental conditions present special problems in reclamation of a mine and formation of a pit lake.

Canadian Fisheries Act

Lost fish habitat must be compensated for through the creation of new fish habitat or enhancement of existing habitat.

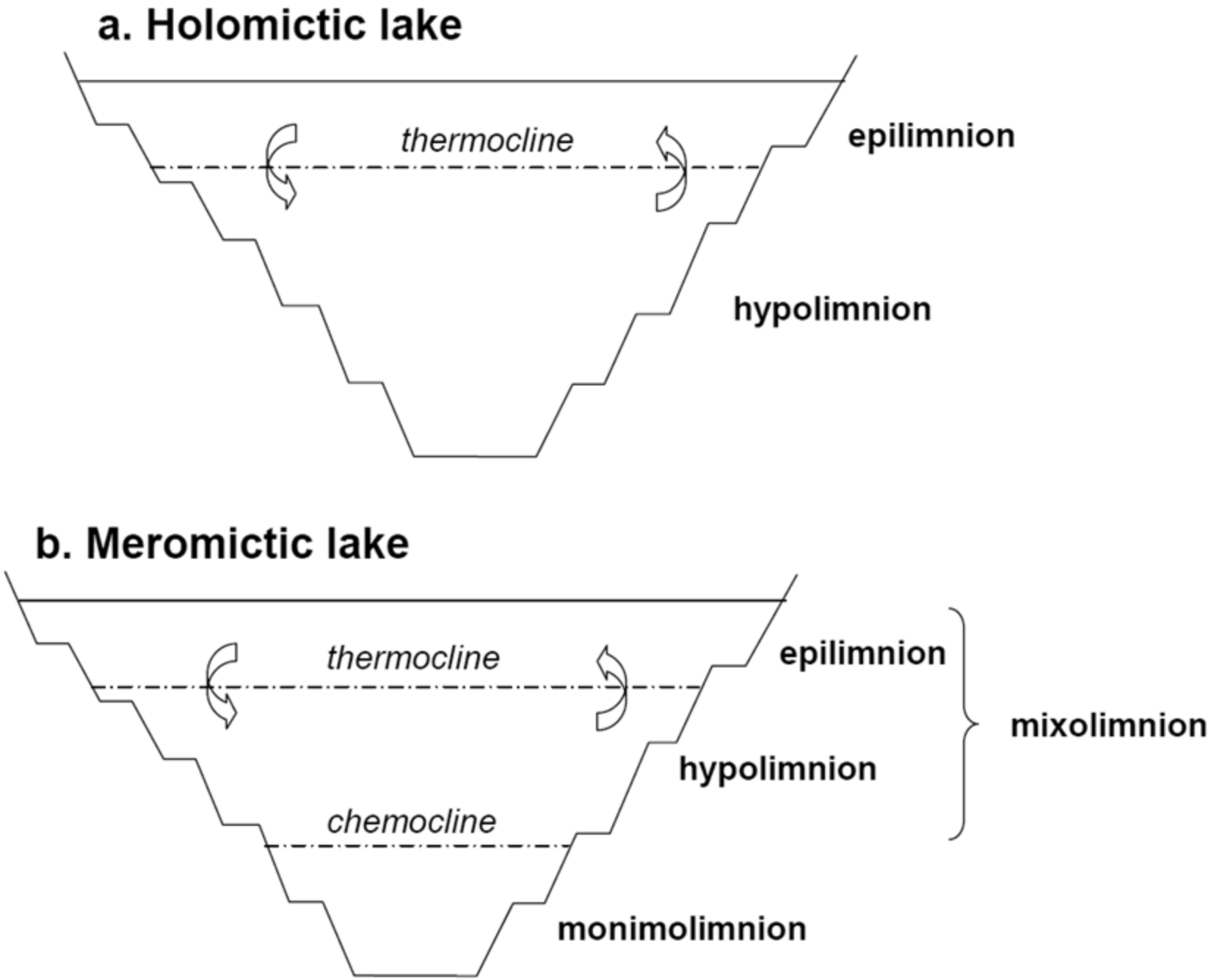
Outline

- Limnology
- Chemistry
- Biology
- Unique aspects of northern lakes
- Enhancing beneficial uses of pit lakes

Limnology

The physical structure of a lake is a key factor in determining its properties.

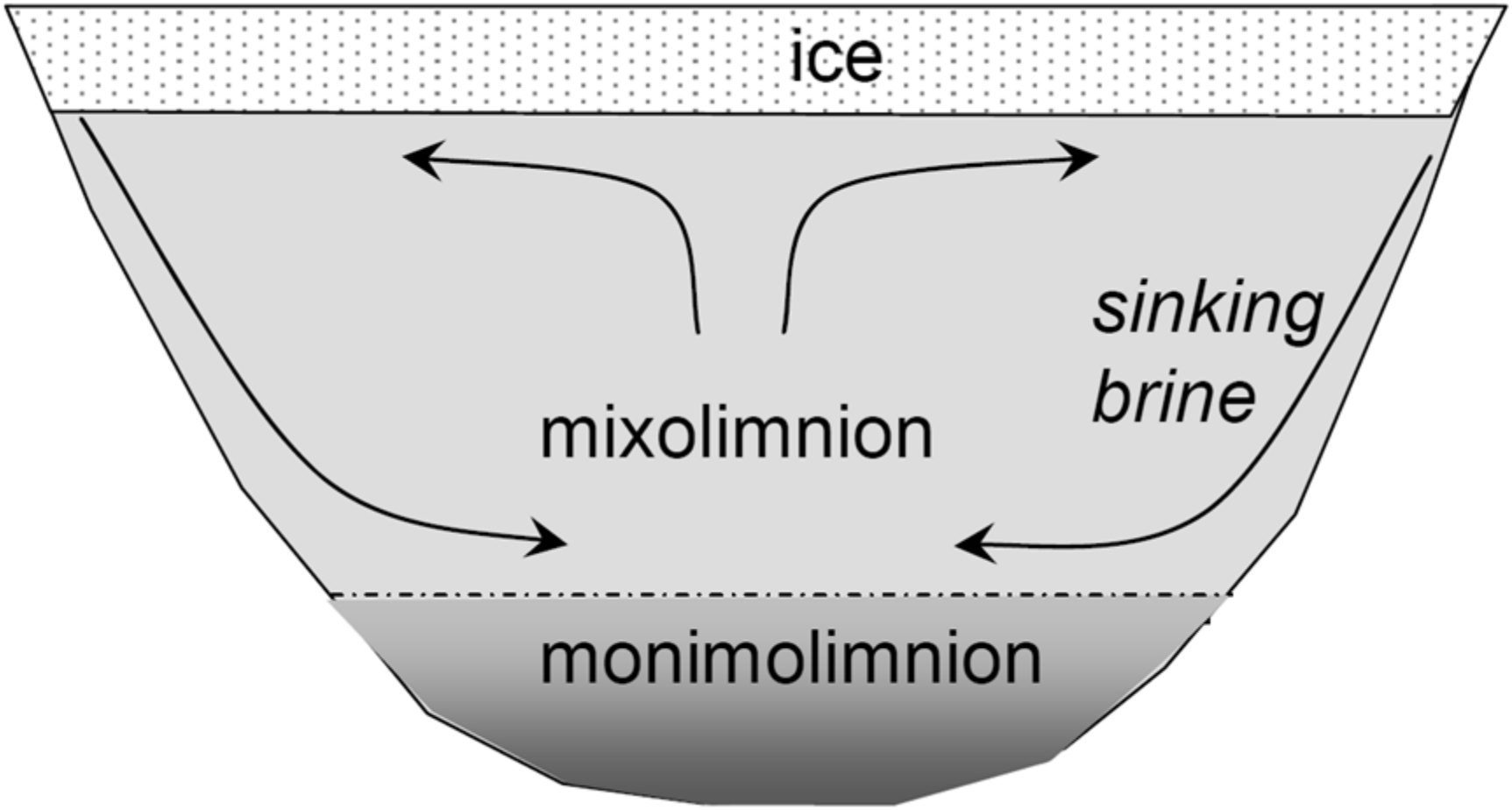
1. The deeper a lake is compared to its horizontal dimensions, the more likely it is to stratify permanently.
2. The larger the volume is compared to its catchment area, the poorer in nutrients it is likely to be.


a. Holomictic lake
thermocline
epilimnion
hypolimnion
b. Meromictic lake
thermocline
epilimnion
mixolimnion
hypolimnion
chemocline
monimolimnion

Common Causes of Meromixis

- *Biogenic*: Biological processes concentrate salts at bottom of lake.
- *Cryogenic*: Salt exclusion during freeze-up forms brine that sinks to bottom (thermohaline convection).

Thermohaline Convection



Less Common Causes of Meromixis

- *Ectogenic*: Human activity brings saline water into a lake. E.g., Island Copper Mine, BC.
- *Crenogenic*: Saline groundwater from lake-bottom springs. E.g., Lac Pavin, France (volcanic crater lake); Brenda Pit, BC.

A Slight Complication

A rock slide can overturn an otherwise stable meromictic lake.

Advantages of Pit Lake Stratification

- The anoxic bottom layer isolates metal sulfides.
- A monimolimnion can be a good place to dispose of acid rock drainage.

Drawbacks of Pit Lake Stratification

- Anoxic bottom waters exclude benthic life from lake ecology.

- Under some conditions, *limnic eruptions* become possible, e.g., Lake Nyos, Cameroon, 1986. (However, this is unlikely in a mine pit lake.)

Chemistry

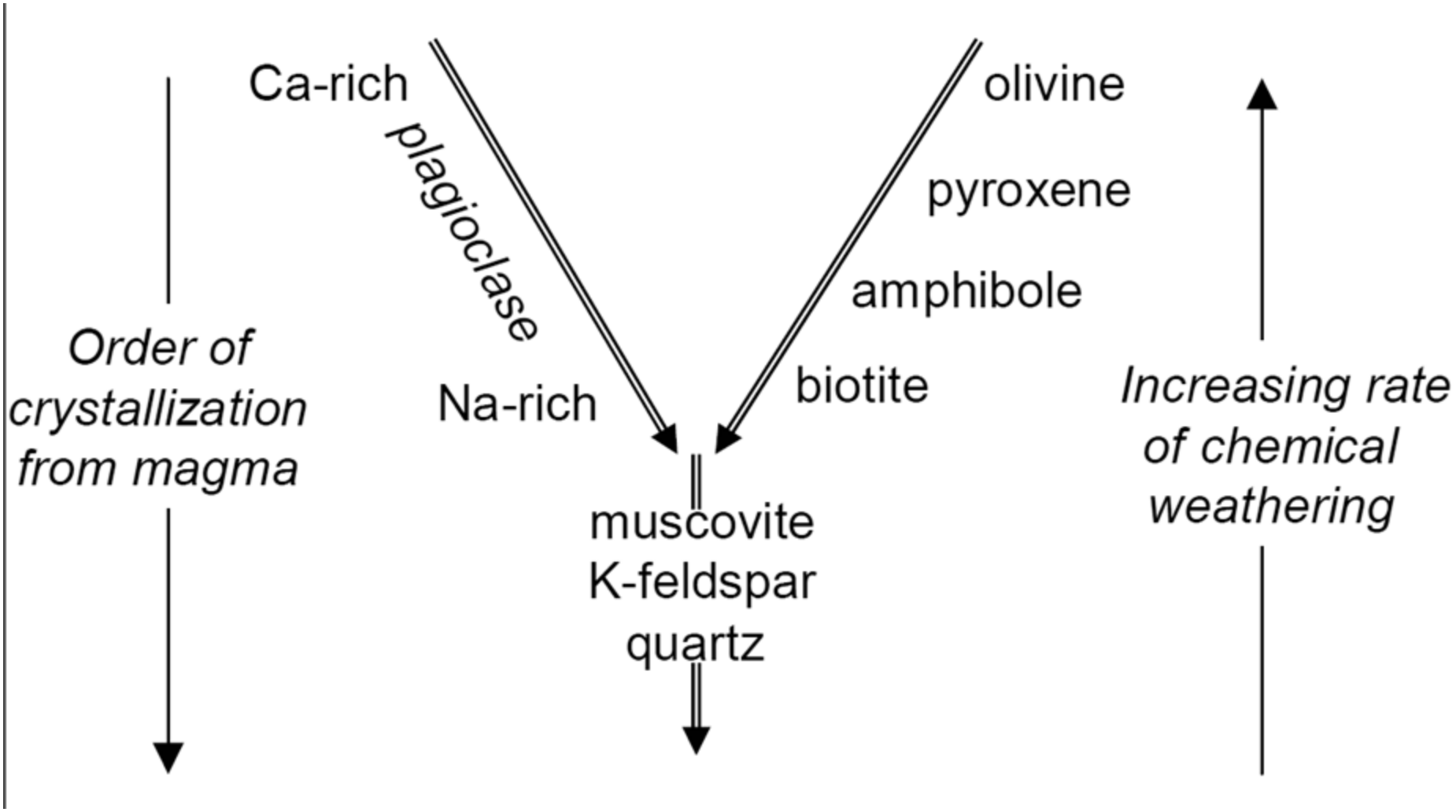
Key Chemical Parameters

- pH
- Total dissolved solids
- Turbidity (limits photosynthesis)
- Dissolved oxygen
- Nutrients
- Acid neutralization
- Dissolved Fe

Acid Neutralization

- Static tests like the Sobek test methods assume that carbonates are the only acid-neutralizing species.

- Silicates can have considerable acid-neutralizing potential but are generally slow-acting.


Order of crystallization from magma
Ca-rich
plagioclase
Na-rich
olivine
pyroxene
amphibole
biotite
muscovite
K-feldspar
quartz
Increasing rate of chemical weathering

Kimberlite

Kimberlite is made up of megacrysts dispersed in a groundmass.

- Groundmass contains calcite, serpentine, and clay minerals and may also contain olivine, phlogopite, perovskite, spinel, and/or diopside.
- Megacrysts may contain diamond, olivine, serpentine, phlogopite, ilmenite, garnet, chromium diopside, apatite, spinel, perovskite, enstatite, and/or monticellite.
- Altered xenoliths may also be present.

Neutralization Reactions in Kimberlite

- Calcite reaction:

$$2\,H^+ + CaCO_3 \rightarrow H_2O + CO_2 + Ca^{2+}$$

- Serpentine reactions:

$$2\,Mg_3Si_2O_5(OH)_4 + 6\,H^+ \rightarrow Mg_3Si_4O_{10}(OH)_2 + 3\,Mg^{2+} + 6\,H_2O$$

$$Mg_3Si_2O_5(OH)_4 + 3\,CO_2 \rightarrow 3\,MgCO_3 + 2\,SiO_2 + 2\,H_2O$$

$$2\,H^+ + MgCO_3 \rightarrow H_2O + CO_2 + Mg^{2+}$$

Kimberlite Chemistry

- Kimberlites generally have very large net acid neutralization potentials.
- Example: Ekati Mine ore
  - AP = 13 kg $CaCO_3$/tonne
  - NP = 240 kg $CaCO_3$/tonne
  - NP:AP = 18

Kimberlite Chemistry: Basic Rock Drainage

Some kimberlites have unusually alkaline groundwater (pH > 10), probably due to weathering reactions of ultramafic minerals and serpentine.

Biology

We will concentrate on lakes with moderate pH and low levels of toxic substances.

Plant and Animal Life in Pit Lakes

- There will be a series of pioneer and successional species.
- The biological community of a pit lake will be influenced by the local species mix.

Ecological Differences between Pit Lakes and Natural Lakes

- Pit lakes tend to have much smaller littoral zones than natural lakes. Effects include
  - fewer plants (trees, grasses, aquatic plants, etc.)
  - Less shade along the shore
  - less spawning ground for fish
  - less cover for small fry and other prey
  - in general, less habitat diversity

Ecological Differences between Pit Lakes and Natural Lakes

- Permanent stratification leads to an anoxic monimolimnion.
- Pit lake plant ecology dominated by plankton.
- In most cases, for the first 100 to 200 years, little biological diversity in a pit lake.

Lakes in Northern Environments

Environmental Factors Affecting Arctic and Subarctic Lakes

Deep-water temperatures are not very different from those in temperate lakes
(~ 4° C ?).

Effects of Climate

- Very large annual variations in solar input
- Low average air temperatures
- Long winters

Results

- Extreme seasonal variation in primary productivity and in other photochemical reactions (such as Fe photoreduction)
- Increased risk of oxygen depletion during winter and resulting winterkill
- More ice means more thermohaline convection and increased likelihood of meromixis

Example: Ekati Diamond Mine

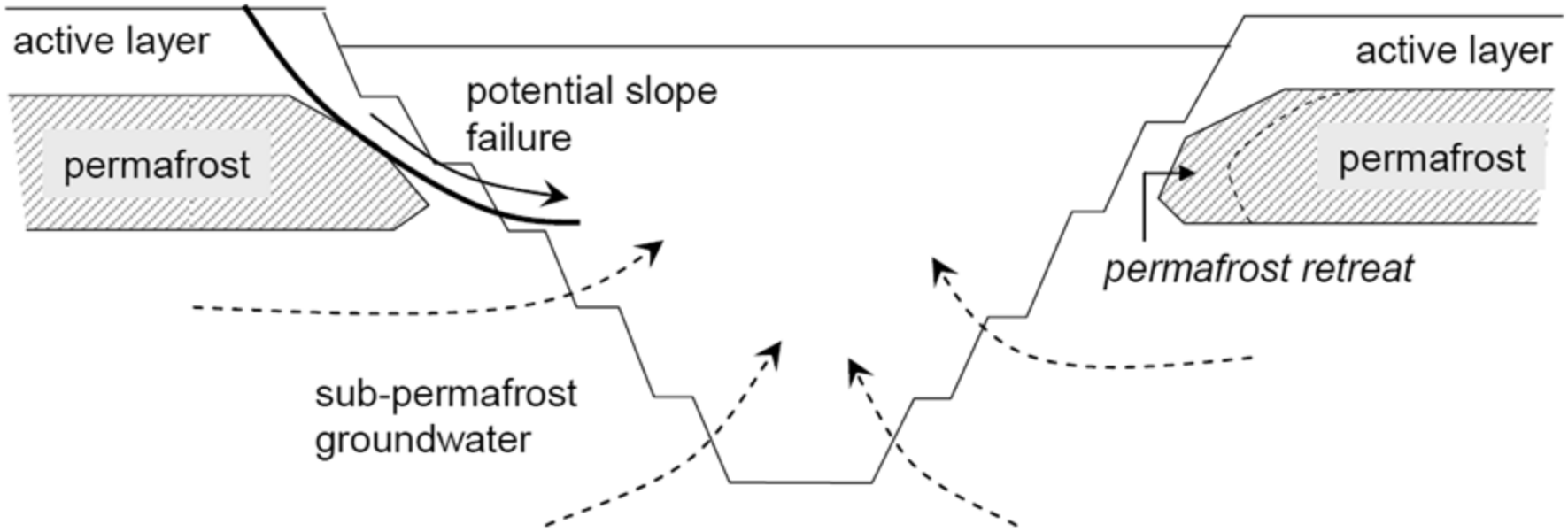
- Temperatures range from -40° to +25° C.
- Only 4 months of the year with average temperatures above freezing.
- Ice cover can be > 2 m, and lakes are frozen for more than half of the year.
- 22 h sunlight at mid-summer, 2 h sunlight in mid-winter.

Effect of Low Biological Diversity

Limited Biological Diversity in Northern Environments

	NT + Nunavut 3,119,198 km^2	Minnesota 203,819 km^2
Freshwater Fish Species	46	160
Native Plant Species	1113	~ 2400

Effects of Permafrost



Enhancing Beneficial Uses of Pit Lakes

Enhancing Beneficial Uses

- Landscaping and backfilling

East Pit Lake, Wabamun, AB

- Former coal mine (replacement for Whitewood Lake)
- Extensively recontoured after close of mining
- Average depth 3.3 m
- Maximum depth 10 m
- 800 m long by 100 m wide

East Pit Lake

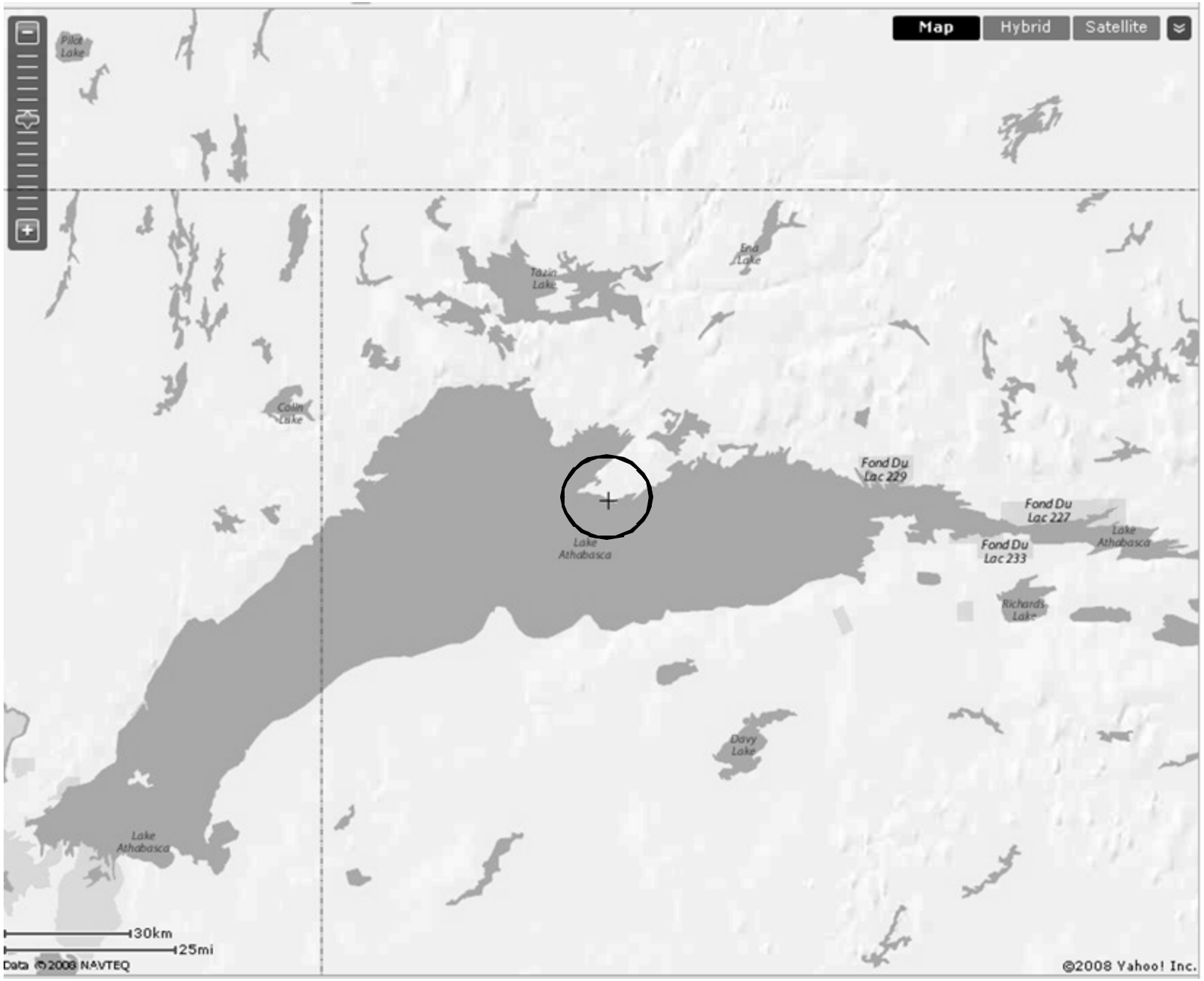
(Transalta Utilities photo)

East Pit Lake

(Sun Media Photo)

Enhancing Beneficial Uses

- Landscaping and backfilling
- Rapid Flooding


Map
Hybrid
Satellite
Pilot Lake
Tazin Lake
Ena Lake
Coin Lake
Fond Du Lac 229
Fond Du Lac 227
Fond Du Lac 233
Lake Athabasca
Lake Athabasca
Richards Lake
Davy Lake
Lake Athabasca
30km
25mi
Data ©2008 NAVTEQ
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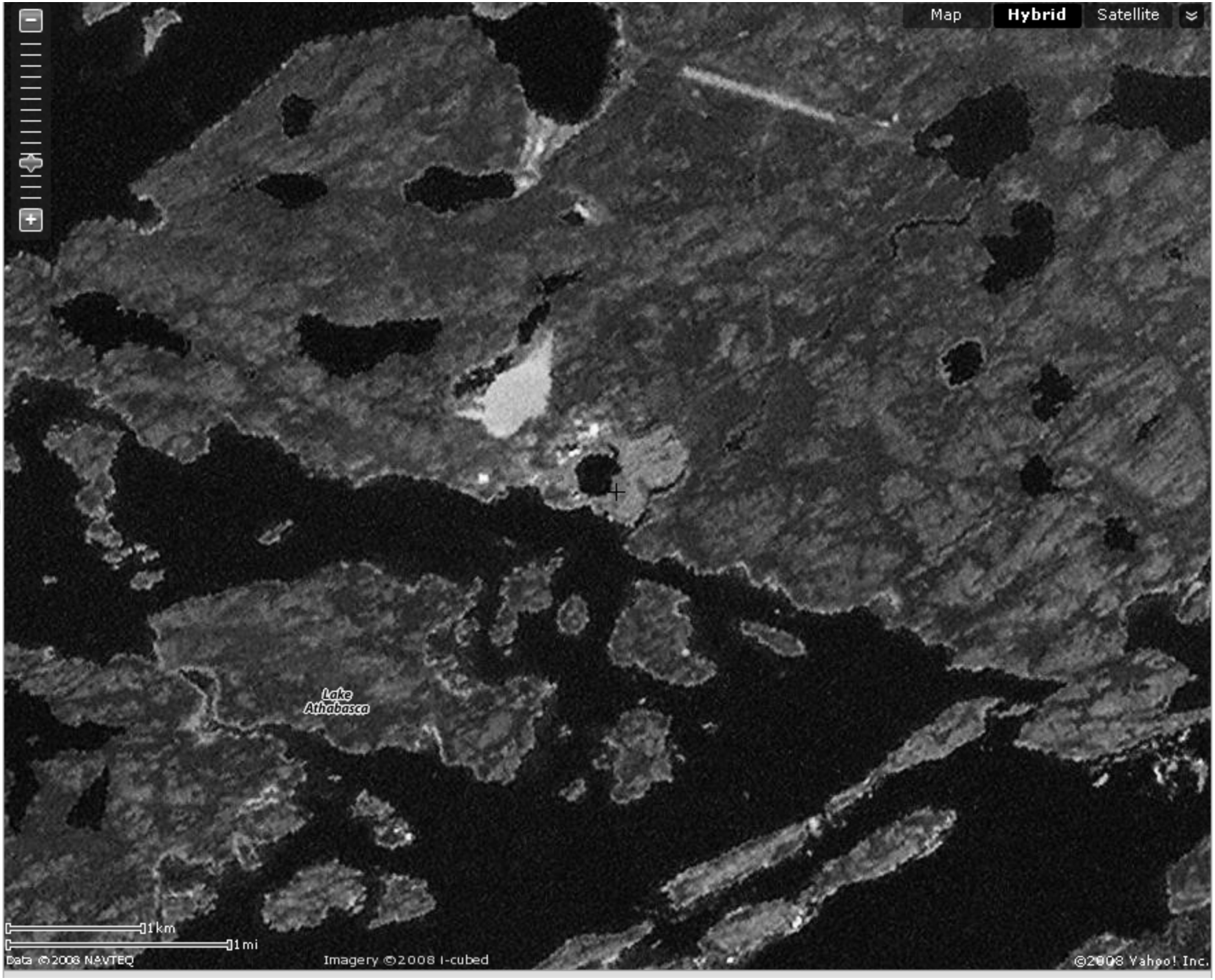
Map
Hybrid
Satellite
Lake
Athabasca
1 km
1 mi
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Enhancing Beneficial Uses

- Landscaping and backfilling
- Rapid flooding
- Biological (“passive”) treatment and chemical treatment

Enhancing Beneficial Uses

- Landscaping and backfilling
- Rapid Flooding
- Biological (“passive”) treatment and chemical treatment
- Establishment of Fisheries

Report Available as PDF File

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Questions?