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A UNIQUE RESEARCH PROGRAM

Development and application of mine site reclamation methods to control acid generation in Canada

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Introduction

Two main types of wastes: waste rock and tailings

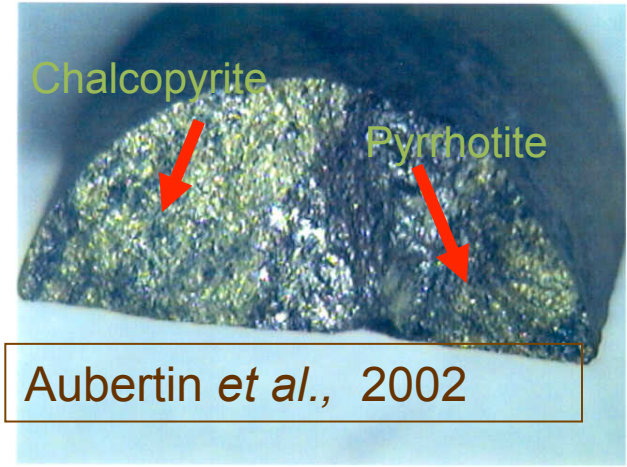
Aubertin *et al.*, 2002

Tailings –pumped to tailings impoundment

Specific impoundments created using natural topography and dykes

Introduction

- Main potential environmental impacts:
  - Physical stability problem (not discussed here)
  - Chemical stability problem: acid mine drainage (AMD)
- What is AMD?
  - Water flowing through mine wastes – affected by natural bio-geochemical phenomena
  - Two main reactions:
    - oxidation by sulphide minerals (ex. pyrite, pyrrhotite, arsenopyrite)
    - neutralization by carbonates (calcite, dolomite) and some silicate minerals



Aubertin *et al.*, 2002

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Introduction

- How can we control the AMD problem?
- By reducing the availability of one (or more) of the three ingredients (sulphide, water, and oxygen), or by controlling tailings temperature
- Different methods have been developed:
  - Oxygen barriers
  - Water infiltration barriers
  - Desulphurization
  - Thermal barriers

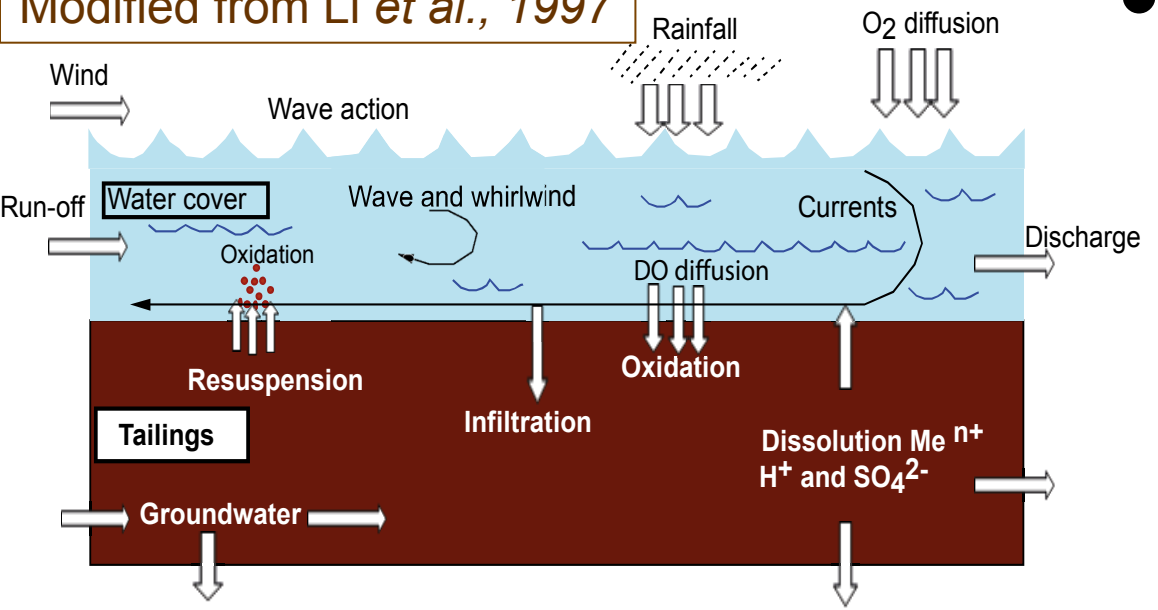
Oxygen barriers

- Water covers
- Elevated water table (EWT) with monolayer cover
- Covers with Capillary Barrier Effects (CCBE)

Oxygen barriers – water covers

- Use of water covers

Modified from Li *et al., 1997*



- Objective : to limit O_2 migration - water is an excellent barrier (diffusion coefficient is 10^4 less in water than in air)

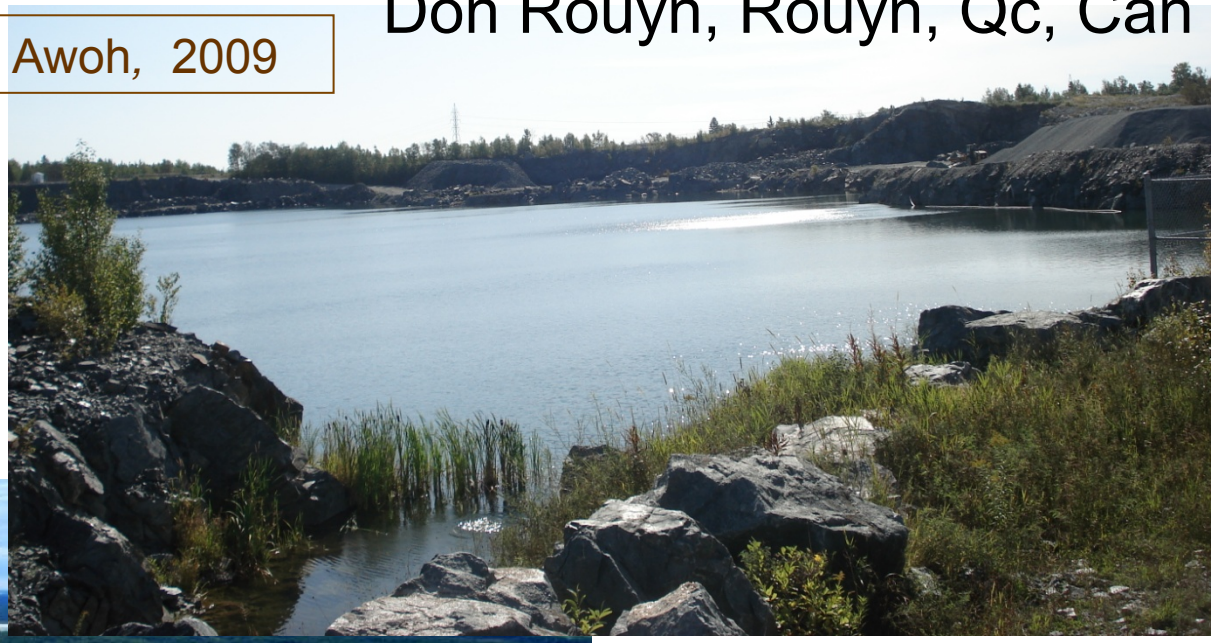
- Challenge: long term stability of the dykes, old tailings

Applied with success at many sites (ex. Louvicourt, Solbec, etc.)

Oxygen barriers – water covers

Awoh, 2009

Don Rouyn, Rouyn, Qc, Can



Subaqueous disposal
= good performance
to control AMD

Louvicourt, Val-d'Or, Qc, Can

MEND MANUAL
VOLUME 1 – SUMMARY
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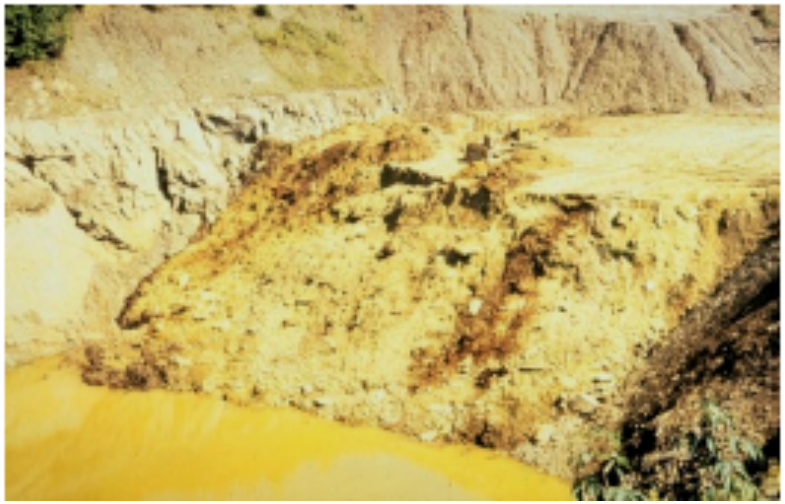
Oxygen barriers – water covers

Solbec (Québec)

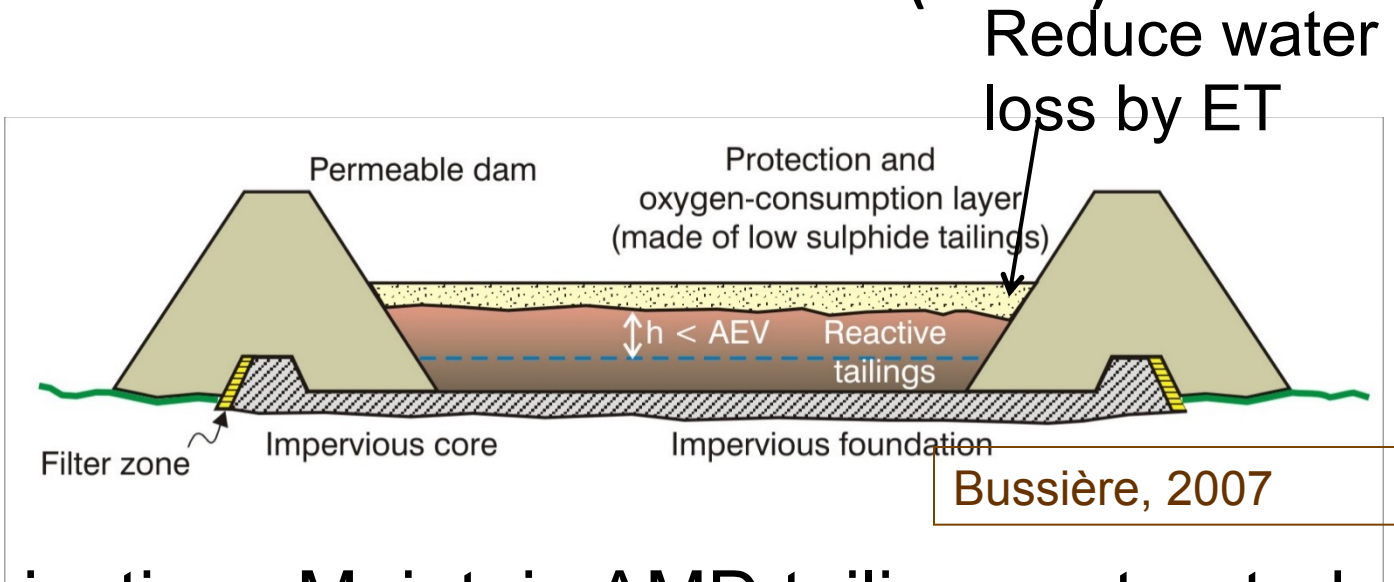


Flooding after tailings oxidation (ex. Quirke; Solbec)

- Interactions between the contaminated pore water and the water cover.
- Progressive improvement of water quality.
- A diffusion barrier can reduce the influence of prior water contamination

Oxygen barriers – EWT and monolayer cover

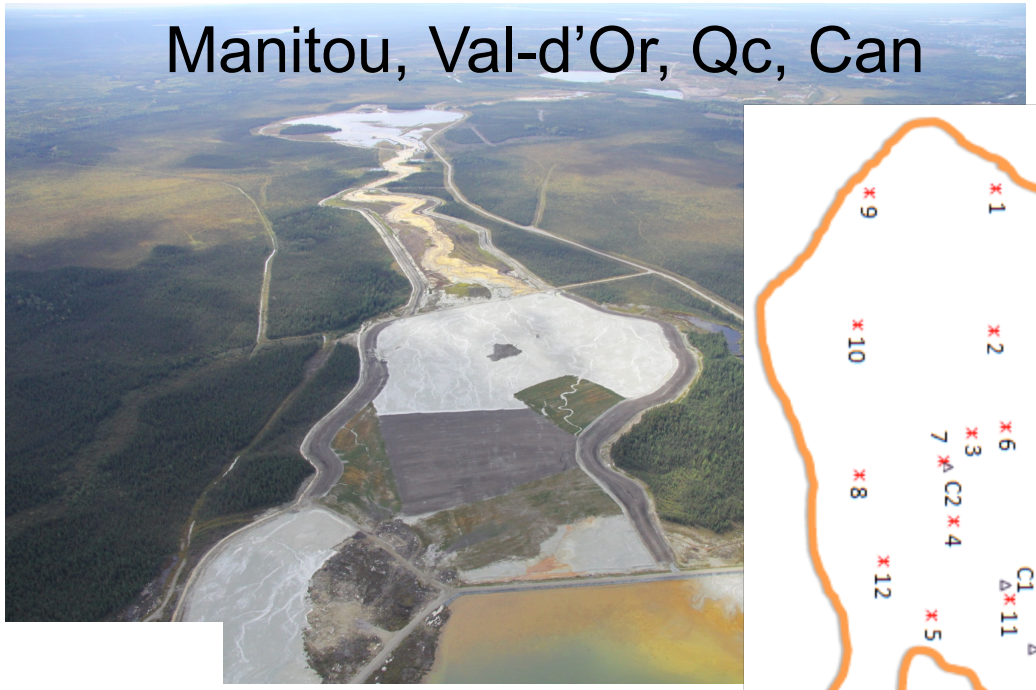
- Use of a monolayer cover combined with an elevated water table (EWT)

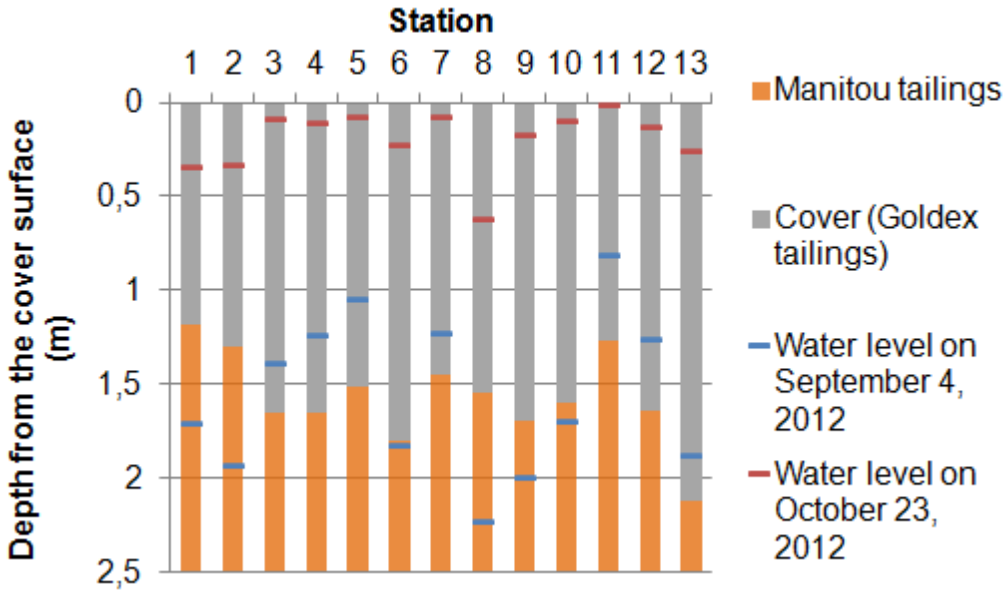


- Objective : Maintain AMD tailings saturated at all times (low O_2 concentration)

Oxygen barriers – EWT and monolayer cover

Flux of O_2 that reach the Manitou tailings < 2 moles/m²/yr





Ethier et al., 2013

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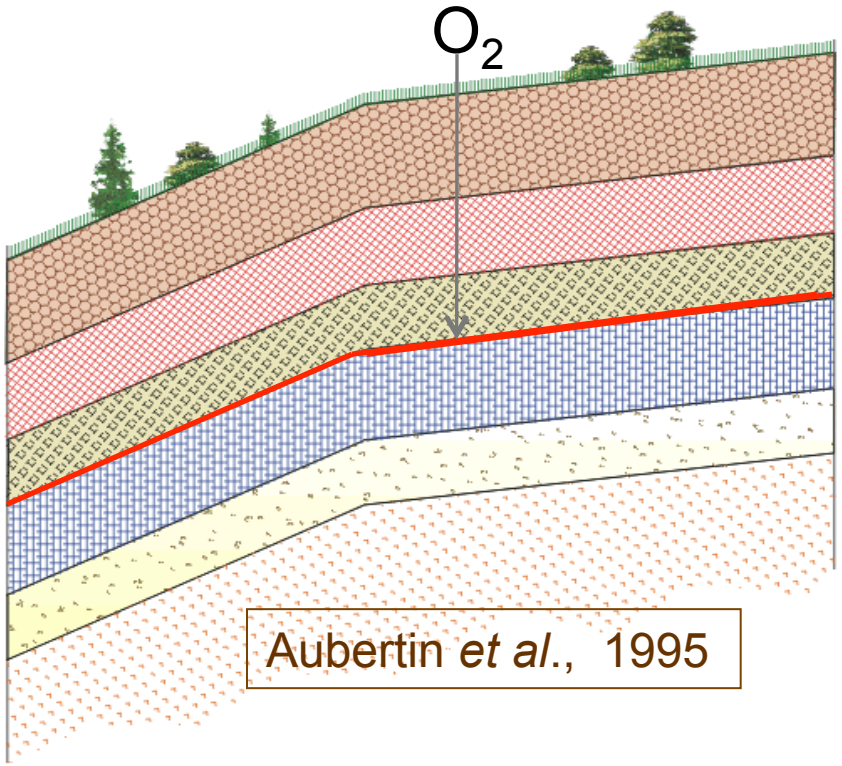
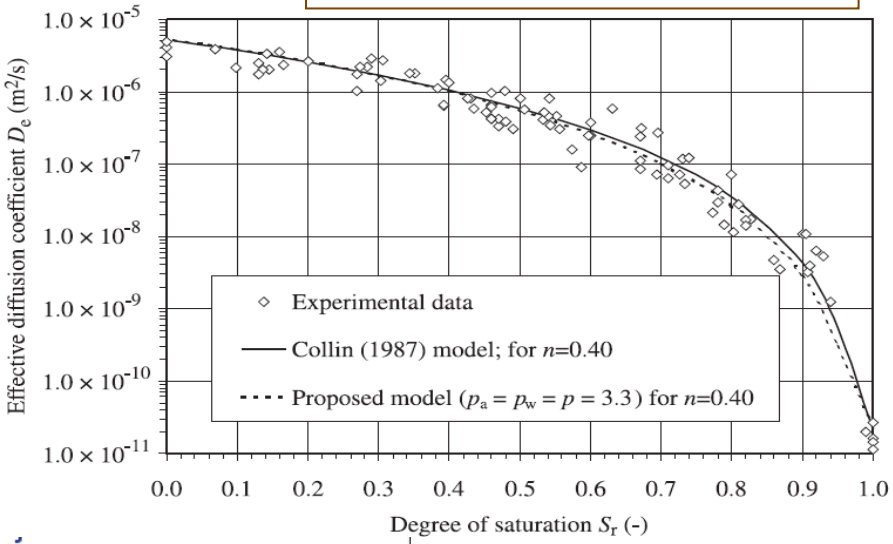
Oxygen barriers – Cover with Capillary Barrier Effects (CCBE)



Aubertin *et al.*, 1995

Mbonimpa *et al.*, 2002



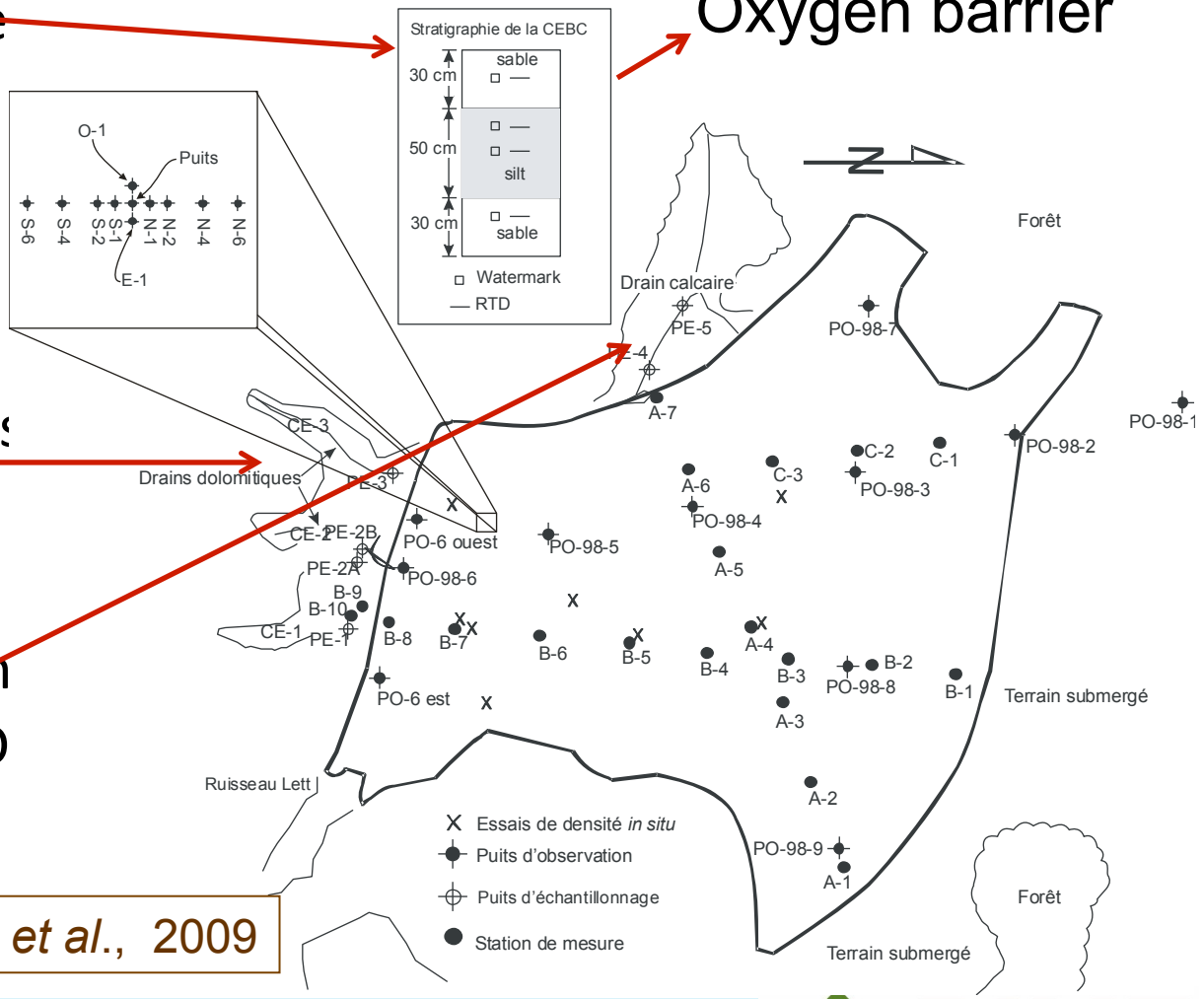
$$F_o^D(z,t) = -D_e \frac{\partial C(z,t)}{\partial z}$$

Applied with success at 3 sites : LTA (1995-96), Lorraine (1999), Bouchard-Hébert (2002-2003)

Oxygen barriers – CCBE at Lorraine site

- CCBE built on the tailings
- Instrumentation installed in the cover layers
- 3 dolomitic drains (Dol-1, Dol-2 and Dol-3)
- 1 limestone drain (Cal-1) – No AMD at this drain

Oxygen barrier



Bussière *et al.*, 2009

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Oxygen barriers – CCBE at Lorraine site

Before

After

Instrumentation

NSERC Industrial Chair on Environment and Mine Waste Management

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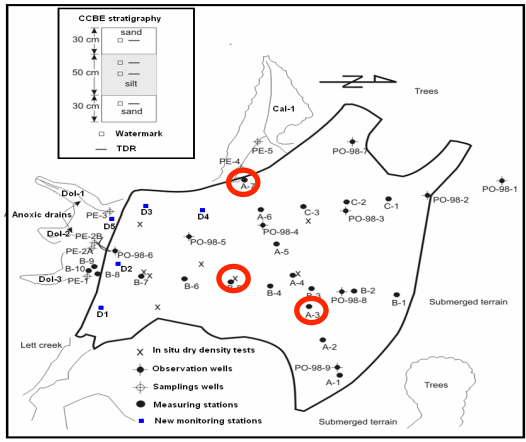
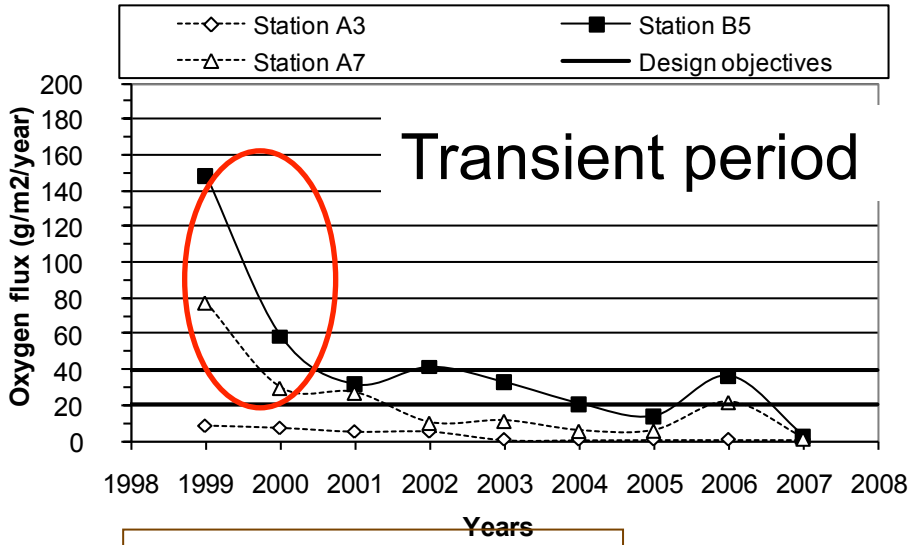
Oxygen barriers – CCBE at Lorraine site

– Steady-state oxygen flux were calculated using Fick's first law and D_e estimated from volumetric water content measurements





Bussière *et al.*, 2009

The CCBE is effective as oxygen barrier

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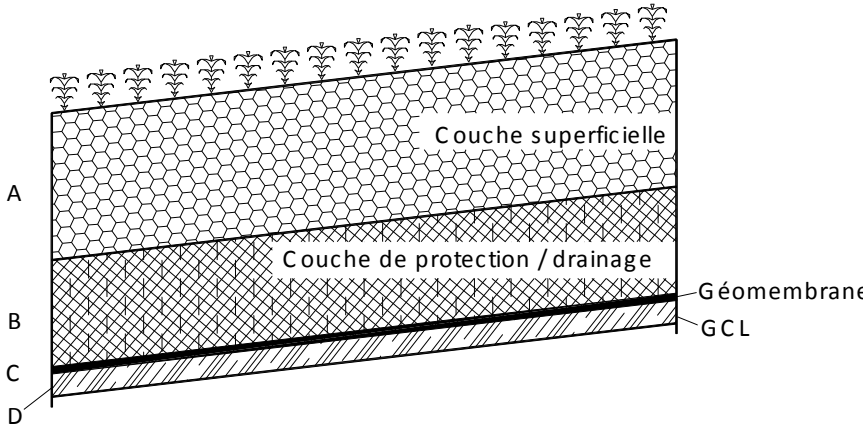
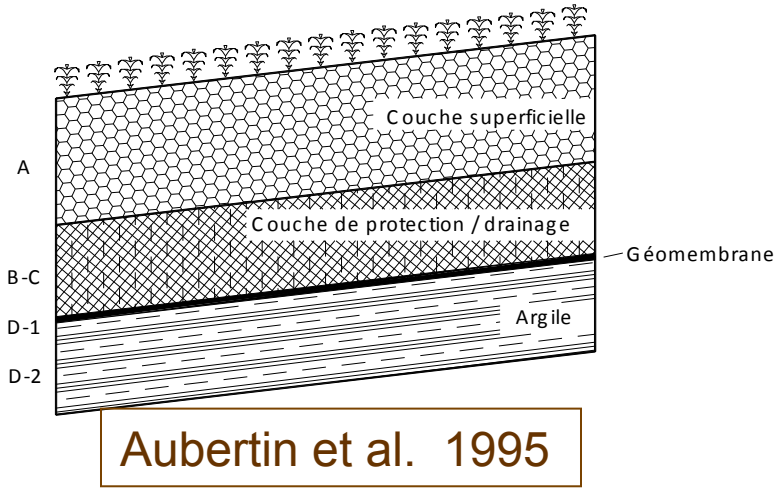
Water infiltration barriers

- Low saturated hydraulic conductivity covers
- Store-and-release cover (not discussed)

Covers made of low k_{sat} materials

- Low k_{sat} materials (double liner is usually recommend): natural and/or geosynthetics





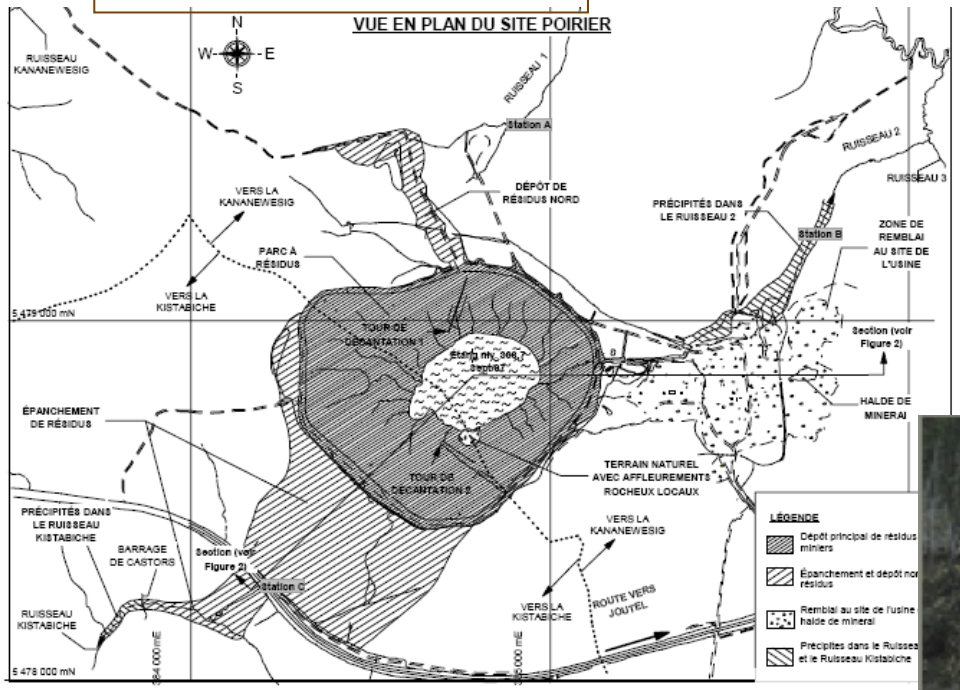
Aubertin et al. 1995

- Challenge: stop water infiltration in the long term (not easy in humid climates)

Applied at abandoned sites in Quebec: Poirier, Aldermac, Barvue, Normétal

Covers made of low k_{sat} materials

Maurice *et al.*, 2002



Poirier site, Joutel, Qc, Canada

- Geomembrane (HDPE) on a geotextile directly on tailings
- Protected by a 1m till layer (sand and gravel)

- No long term monitoring data available
- Drop of water table, but still contaminated effluent

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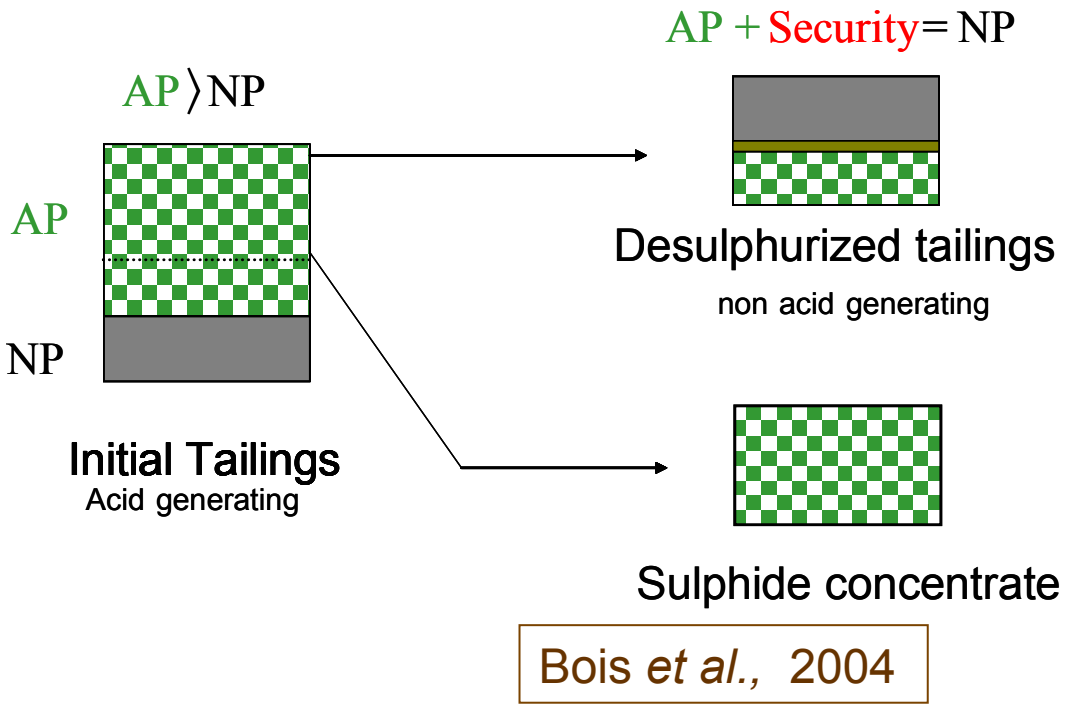
Desulphurization

Desulphurization

- Concentrate:
  - To paste backfill plant
  - To a specific portion of the tailings impoundment
- Desulphurized tailings:
  - Can be used as construction material

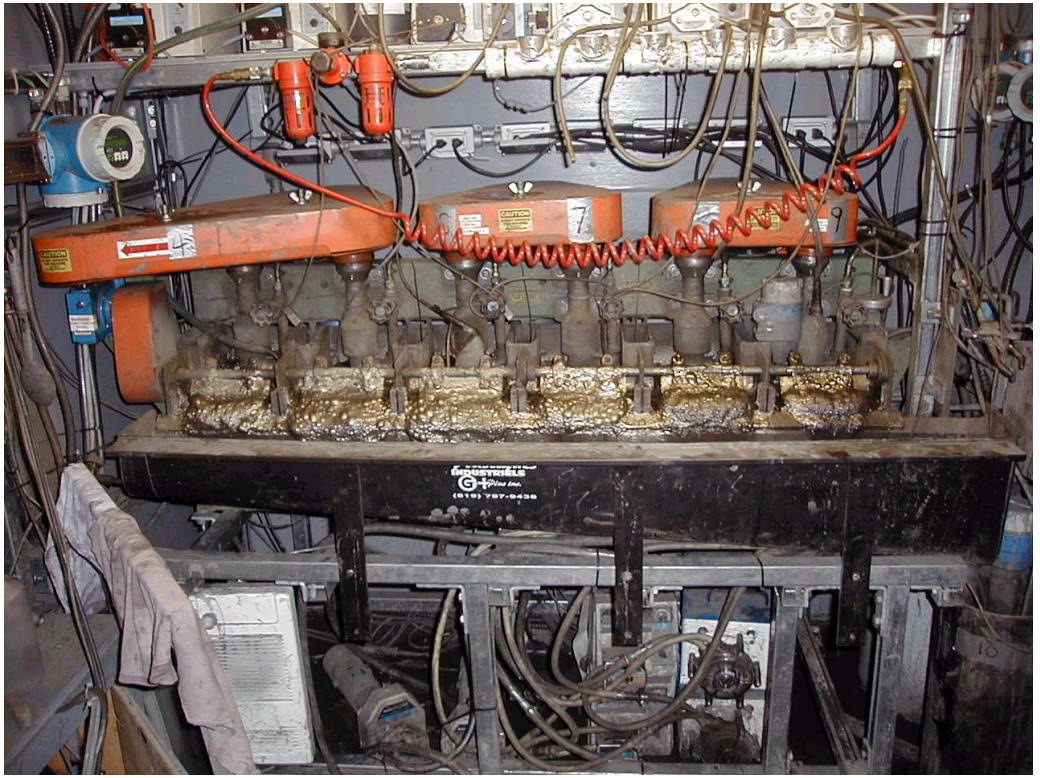
Concept: reduce the mass of problematic tailings at the mill and to re-use the non problematic portion



Bois *et al.*, 2004

Desulphurization

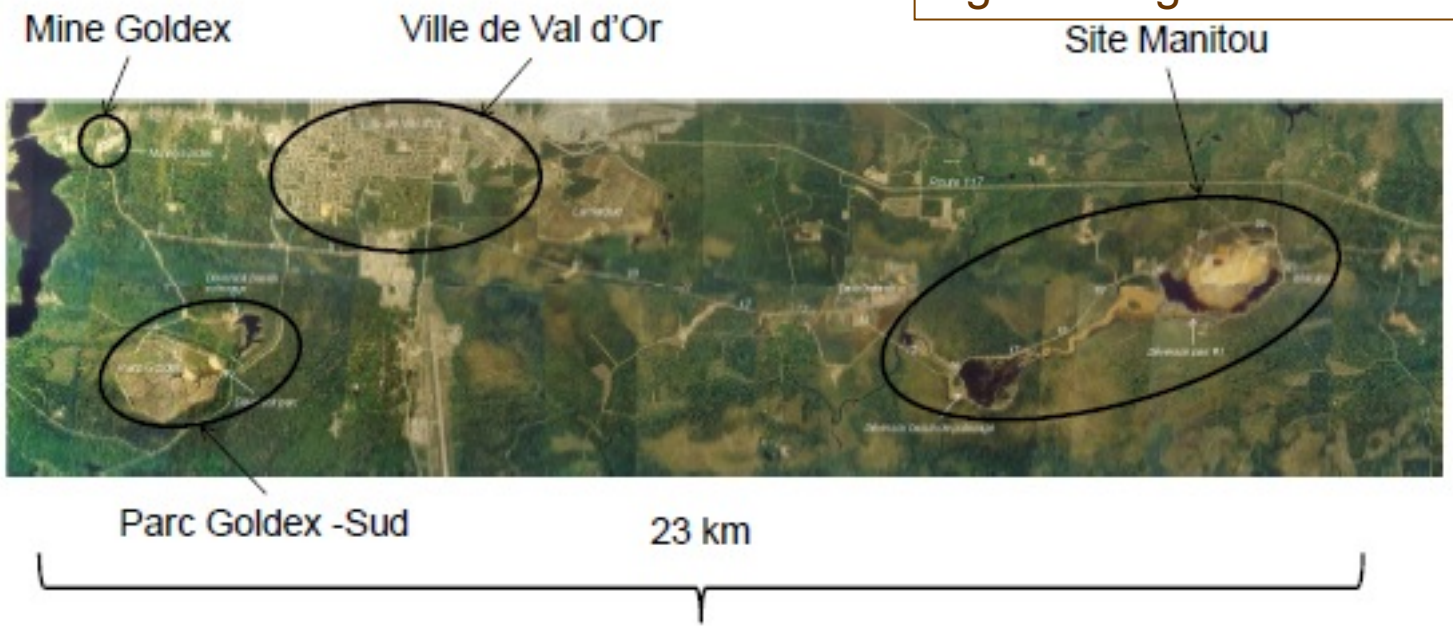
- Main uncertainties:
  - New way of managing tailings
  - Desulphurization cost (0.15 to 0.75$/t)
  - The level of desulphurization needed

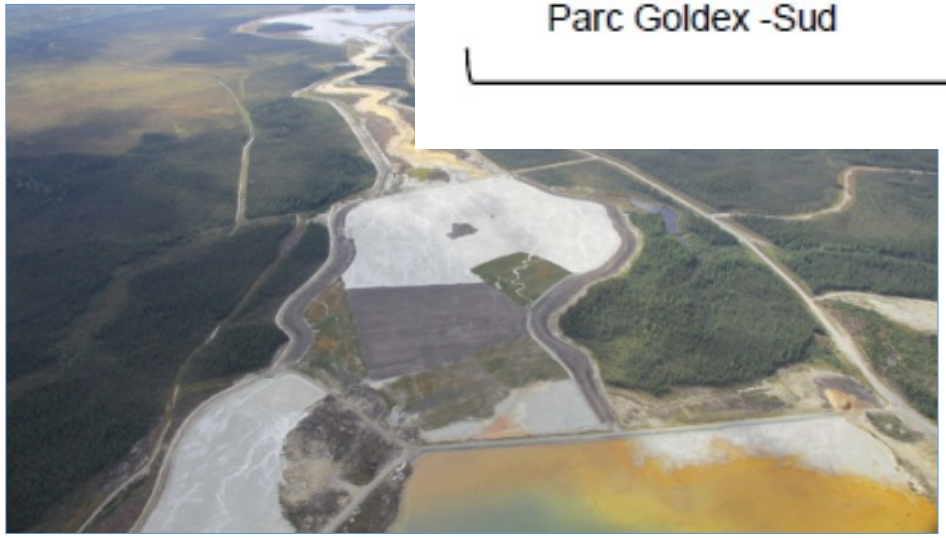


Bois *et al.*, 2004

Desulphurization

Agnico-Eagle Mines Ltd





Manitou site

- Use of the desulphurized Goldex tailings as cover material
- Combined with an EWT

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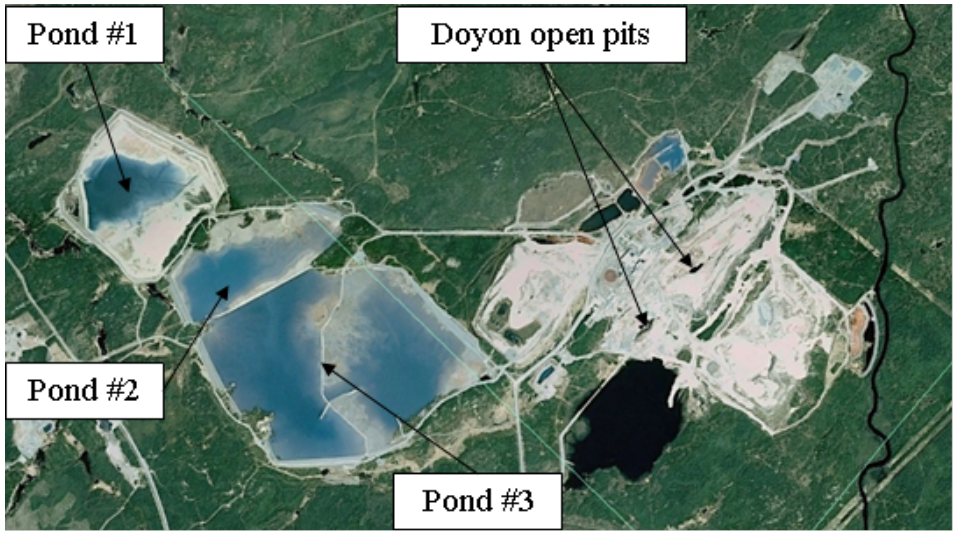
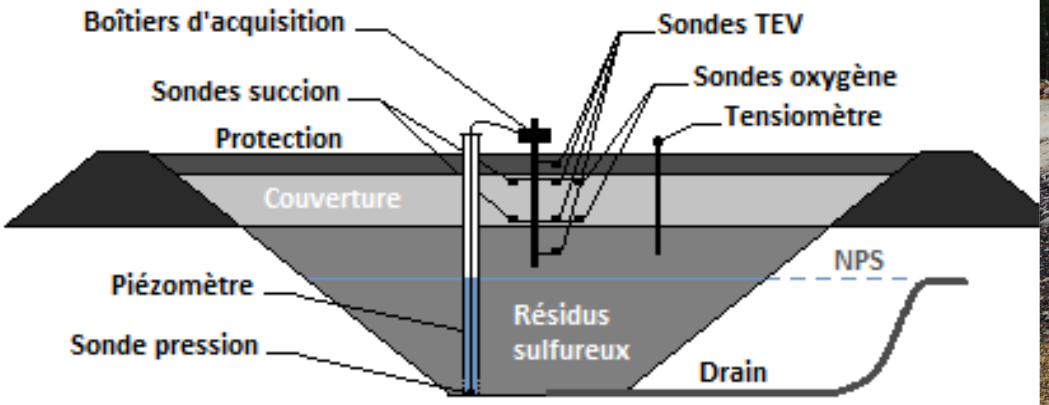
Desulphurization

Doyon mine

- Option: Desulphurized Westwood tailings to produce cover material
- Combined with an EWT
- Evaluated at intermediate scale in the field





Rey *et al.*, 2016

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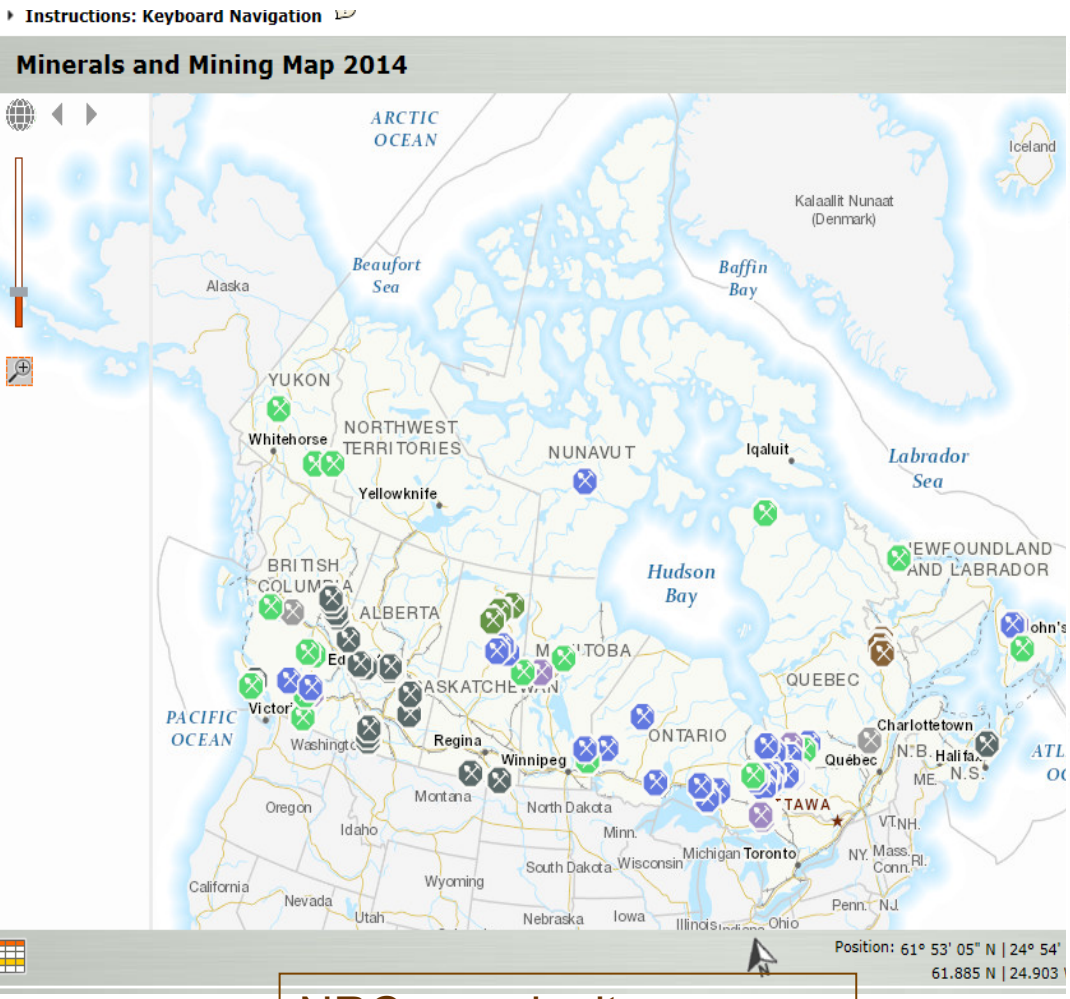
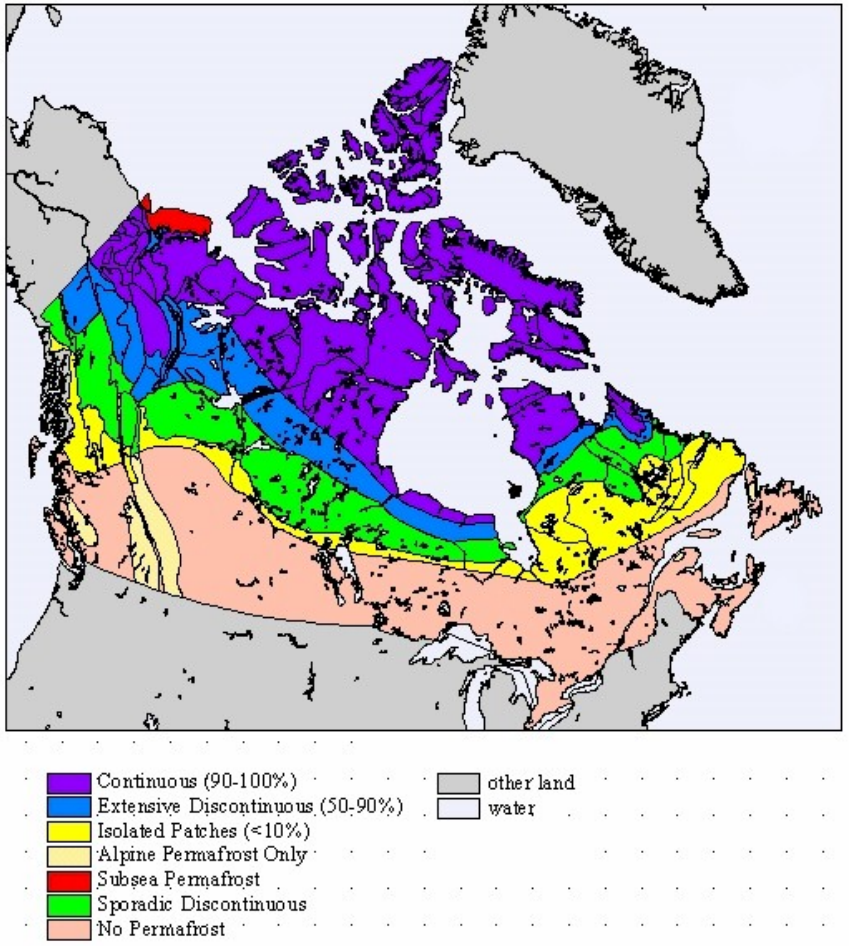
Thermal barriers

Thermal barriers

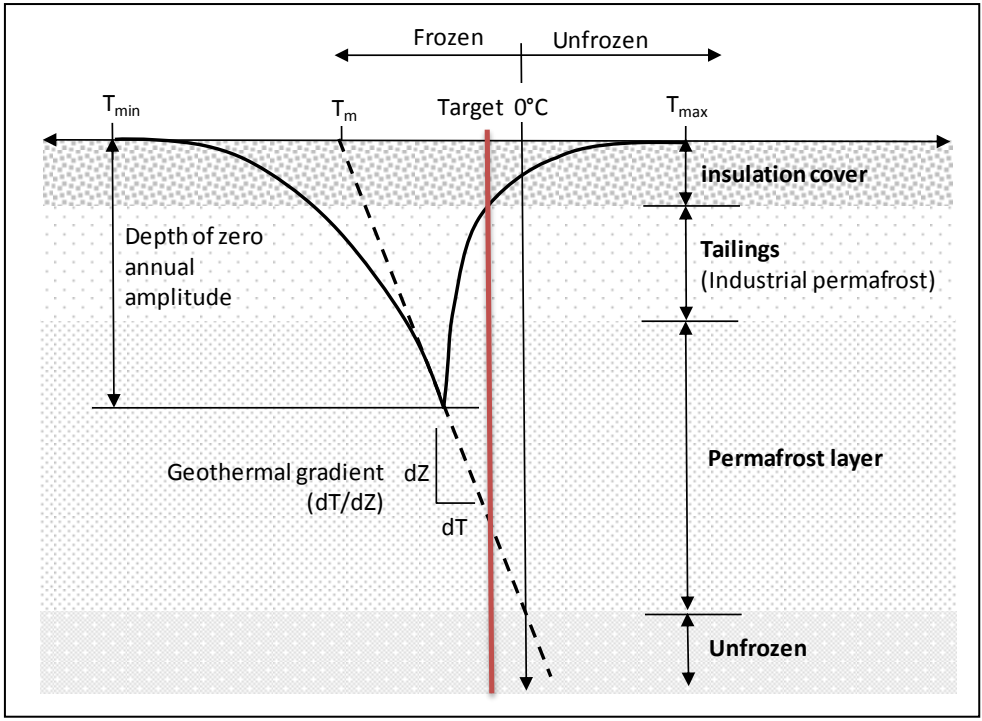




NRCan web site

Thermal barriers

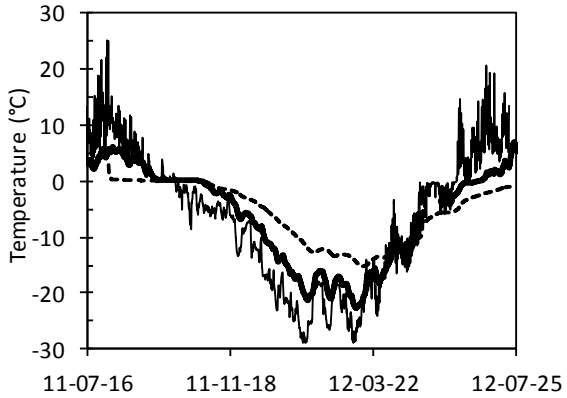
- Integrate tailings within the permafrost by adding a cover of inert material
- Low temperature in the reactive tailings will :
  - slow down both chemical and biological oxidation reactions
  - reduce the generation and migration of pollutants (Holubec, 1993)
- Target tailings temperature
  - tailings can still oxidize at temperature below 0°C (-2°C ; Meldrum et al., 2001; -4°C ; Elberling, 2001)



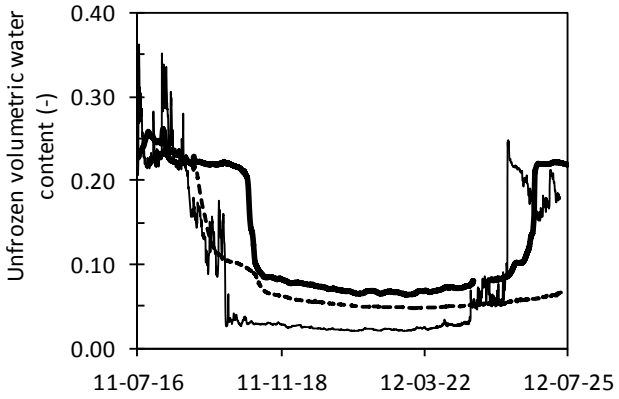
Soil temperature profile in continuous permafrost zone (modified from Andersland and Ladanyi, 2004)

Thermal barriers

T° and θ at the tailings interface

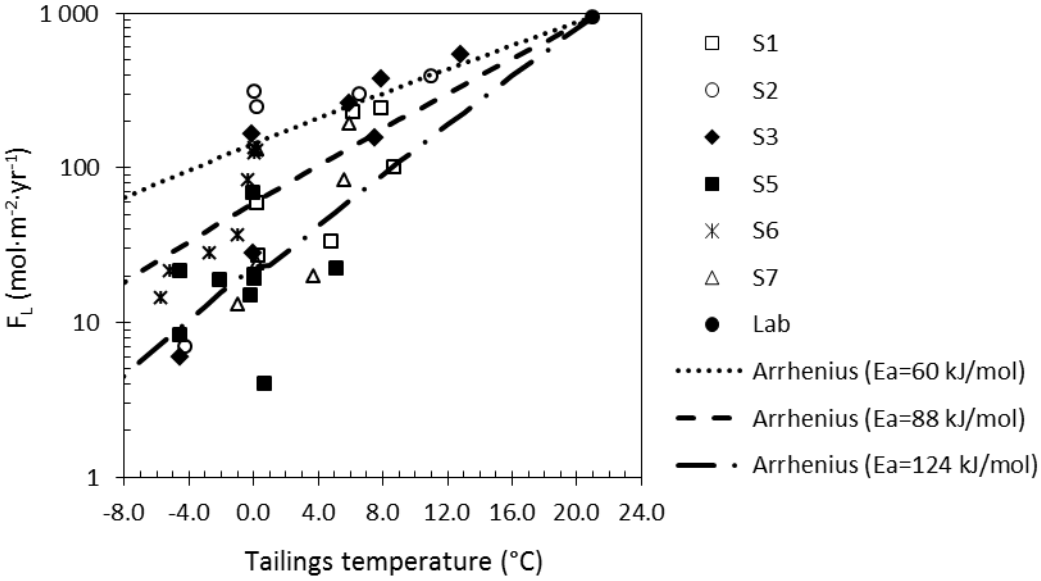


a)



b)

Coulombe, 2012



Conclusion

- Reclamation = control the AMD formation
- Different options – site specific (no panacea)
- Each technique has his own challenges
  - Water cover – dyke stability and prior contamination
  - CCBE, EWT and thermal covers – Climate change
  - Geomembrane covers – durability, physical stability
  - Desulphurization – production of a non-problematic desulphurized tailings
- R&D is essential to improve existing reclamation approach

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