24th ANNUAL BRITISH COLUMBIA-MEND ML/ARD WORKSHOP

Challenges and Best Practices in Metal Leaching and Acid Rock Drainage

Simon Fraser University, Vancouver, November 29 and 30, 2017

Waste Rock Inclusions to Improve the Performance of Tailings Impoundments: The Canadian Malartic Case Study

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POLYTECHNIQUE MONTRÉAL LE GÉNIE EN PREMIÈRE CLASSE

Content

- Introduction
- Use of waste rock inclusions (WRI)
  - Drainage and consolidation
  - Geotechnical stability
  - Other aspects
- CRD Project at Canadian Malartic Mine
- Discussion
- Final remarks

In collaboration with Michael James, Bruno Bussière, Thomas Pabst (RIME), Normand D'Anjou, Carl Pednault (CM), Nicolas Pépin, Marielle Limoges (Golder), and many students

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RioTinto

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Mine Wastes Management

- Many challenges related to chemical and physical (geotechnical) stability
- Various types of environmental impacts
- Waste rock and tailings usually managed separately; co-disposal offers different options

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Tailings impoundments and waste rock piles

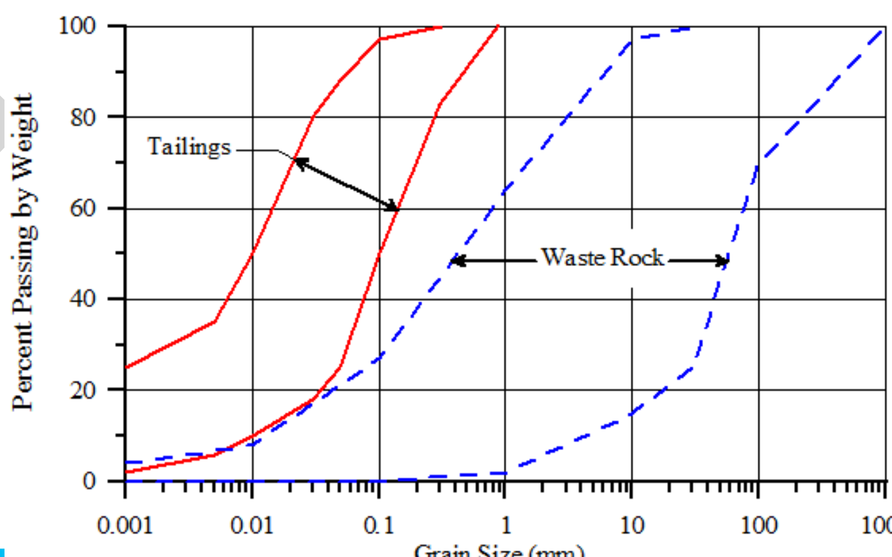
Hard rock mine tailings

Cohesionless;
Low plasticity (ML or SM-ML)
Compressible, low strength;
Low hydraulic conductivity

Waste Rock

Coarse grained;
Stiff and strong,
Pervious

(Aubertin et al. 1991, 2002, 2013; Bussière, 2007; James et al. 2011, 2013, 2017)



TSF historical failures worldwide

(Davies, 2002; Aubertin et al. 2002, 2011; Azam and Li 2010; www.wise-uranium.org, 2017)

- 5 major events/yr in ‘60,70 & 80s
- 2 major events/yr in 1990s and 2000+
- **Little improvement over last 25 years.**
- TSF still highly prone to failure; rates ~ 10 X higher
- Mainly during mine operation (> 80%).
- Upstream dikes represent more than 90% of cases.


Independent Expert Engineering Investigation and Review Panel

Report on Mount Polley Tailings Storage Facility Breach

Morgenstern, Vick, Van Zyl, 2015

Samarco; village of Bento Rodriguez (Brazil 2015)

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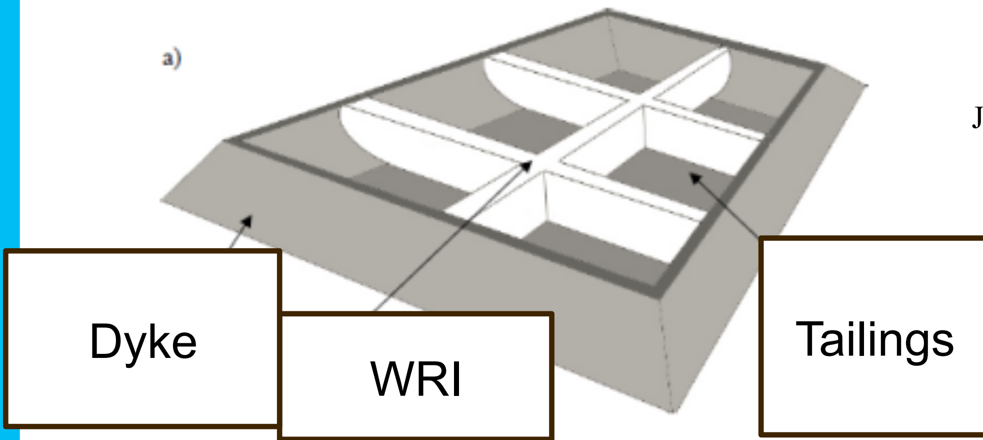
Improved disposal with waste rock inclusions (WRI) in tailings impoundment

(Aubertin et al. 2002; James et Aubertin, 2009, 2010, 2012)

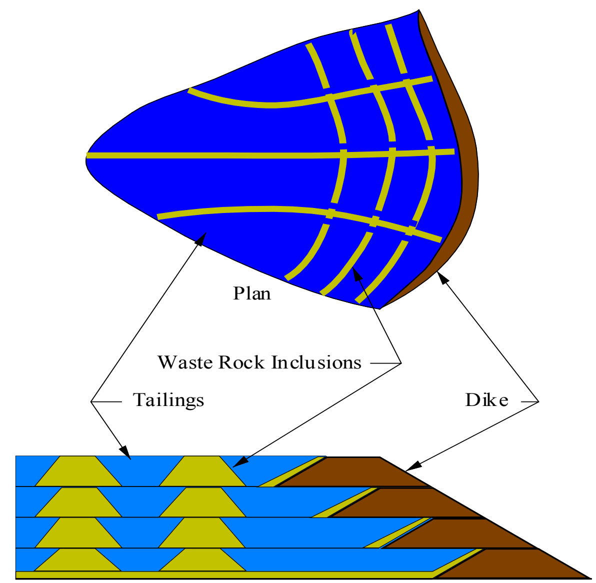
- Main considerations:
  - Properties of tailings and waste rock, and interfaces
  - Location and geometry of waste rock inclusions
  - Effect on the geotechnical behaviour (consolidation, stability)

The Concept of Waste Rock Inclusion



Jaouhar, 2011

WRI : accelerate consolidation;
Increase overall strength and stability;
Compartmentalize impoundment;
Reduces (avoid) WR Piles
Control the effects of liquefaction:
Loading on dike; Limit deformation;
Reduce potential for flow.
Facilitate closure and reclamation



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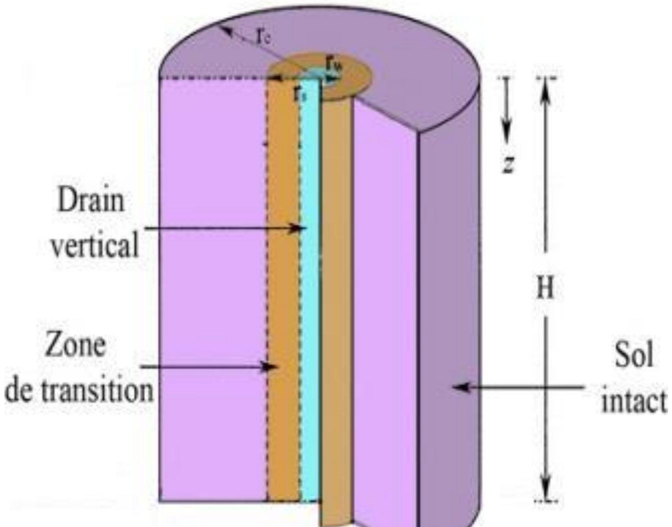
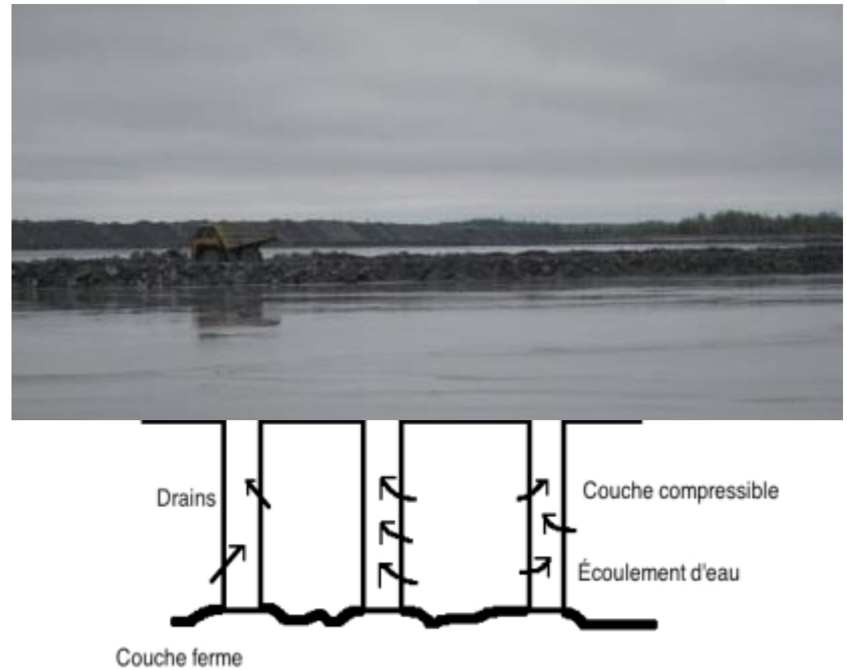
Somewhat similar to sand drains,
rock drains, wick drains (Barksdale et al. 1983)





Water flow and horizontal drainage due to vertical drains (also reinforcement)

Consolidation during filling (added layers)

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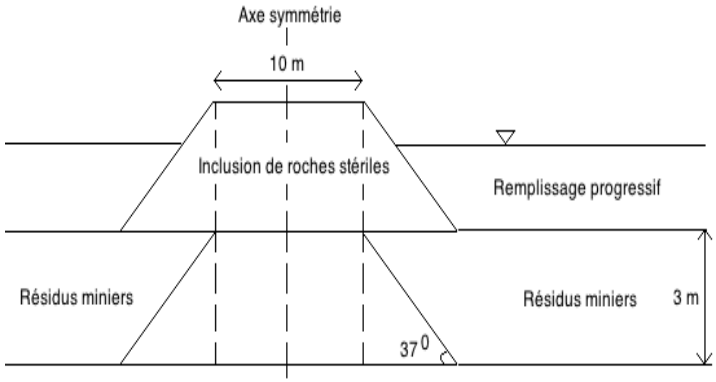
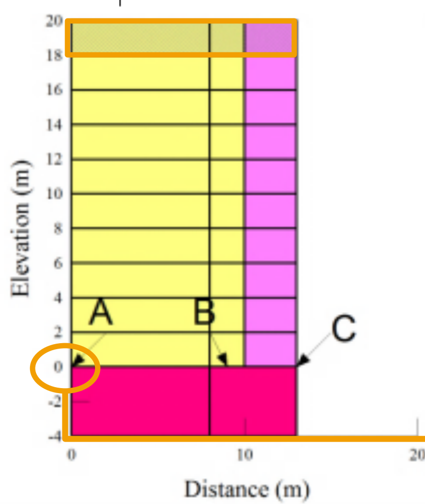
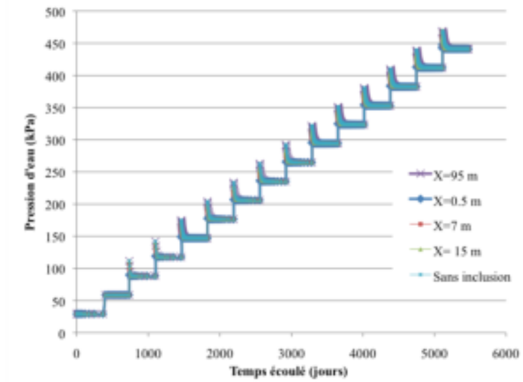
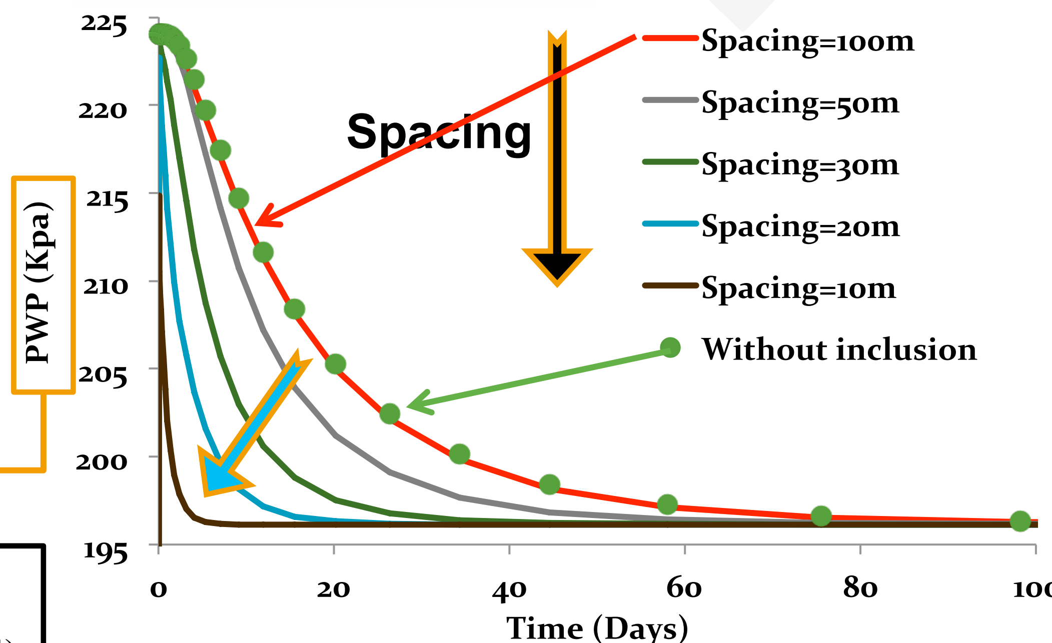






Simulations with SIGMA/W (GeoSlope)



WRI accelerates consolidation

(Jaouhar et al. 2011; L. Bolduc et Aubertin, 2913 2914)

Effect depends on spacing

(and many other factors).

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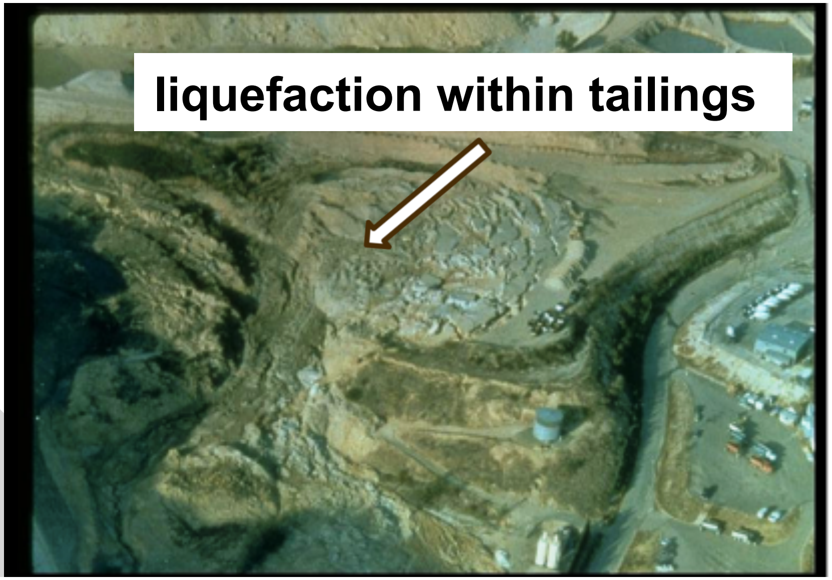
Seismic behavior (stability) of tailings impoundments

Liquefaction due to generation of excess porewater pressure within saturated, contractive, cohesionless media (soils, tailings) under static or dynamic loading, sufficient to reduce the strength (effective stress) near zero (e.g. Kramer, 1996)



Tapo Canyon tailings impoundment USA, Northridge 1994 (adapted NISEE 2003)

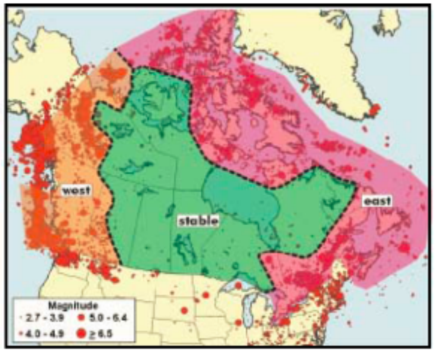
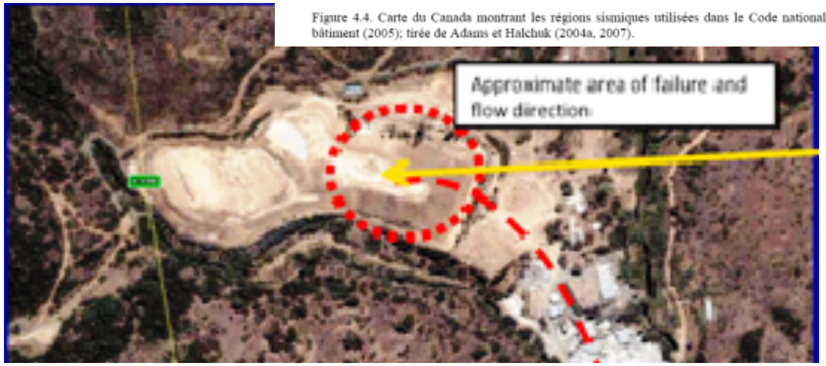


Figure 4.4. Carte du Canada montrant les régions sismiques utilisées dans le Code national du bâtiment (2005); tirée de Adams et Halchuk (2004a, 2007).



Las Palmas Tailing dam failure, 2010 , Chile (adapted from Bray 2010)

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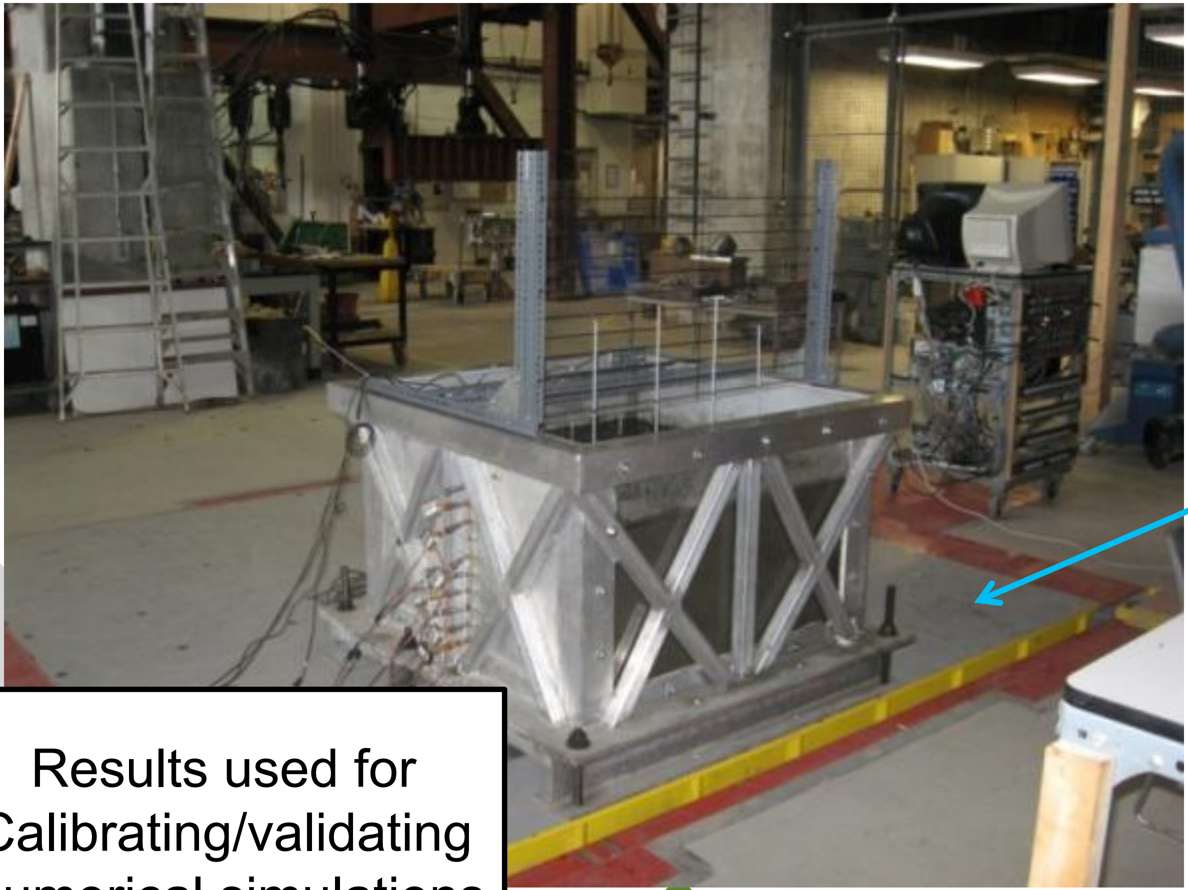
Cyclic DSS testing (James 2009) and physical modeling
(Shaking Table Tests; Pépin et al. 2012)



- Signal sinusoïdal 1 hz
- 0,12g max
- tests on sand and tailings

Results used for Calibrating/validating Numerical simulations With FLAC and UBC-Sand model

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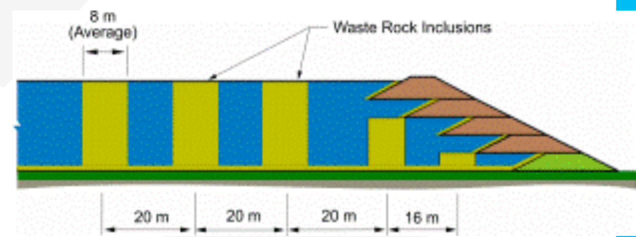
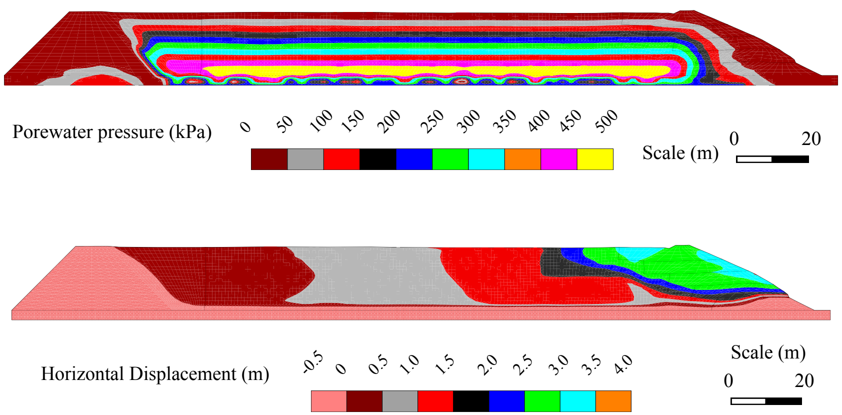
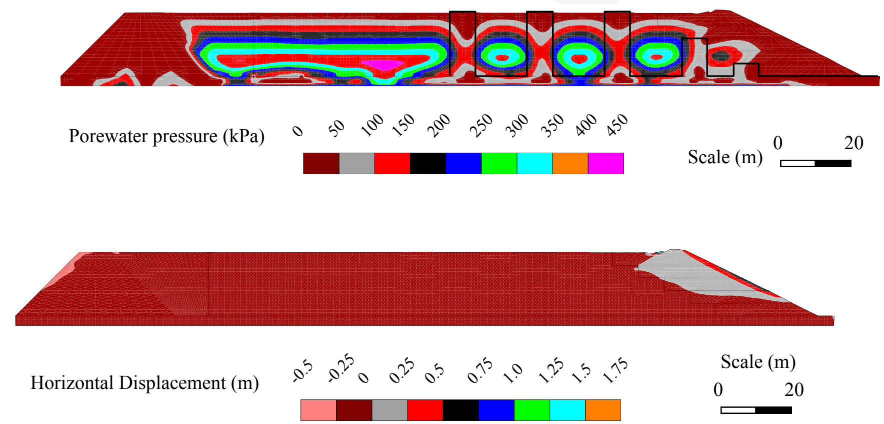
James, 2009; Ferdosi et al., 2014, 2015; FLAC & UBCSand model

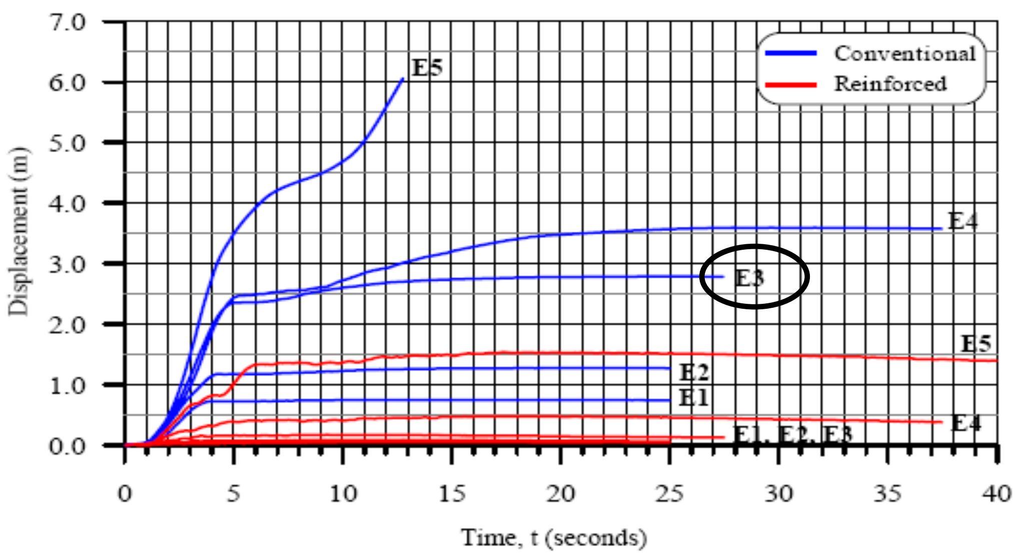


No Inclusion



With Inclusions





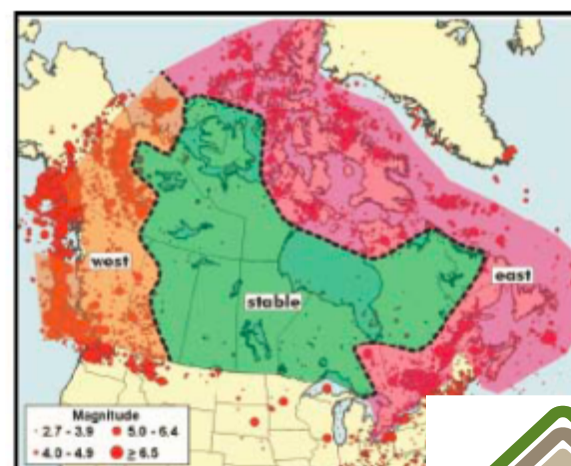


Figure 4.4. Carte du Canada montrant les régions sismiques uti bâtiment (2005); tirée de Adams et Halchuk (2004a, 2007).

CRD Projet on Waste Rock inclusions 2015-2019 +

In situ measurements with extensive characterization and modelling; Optimisation of WRI

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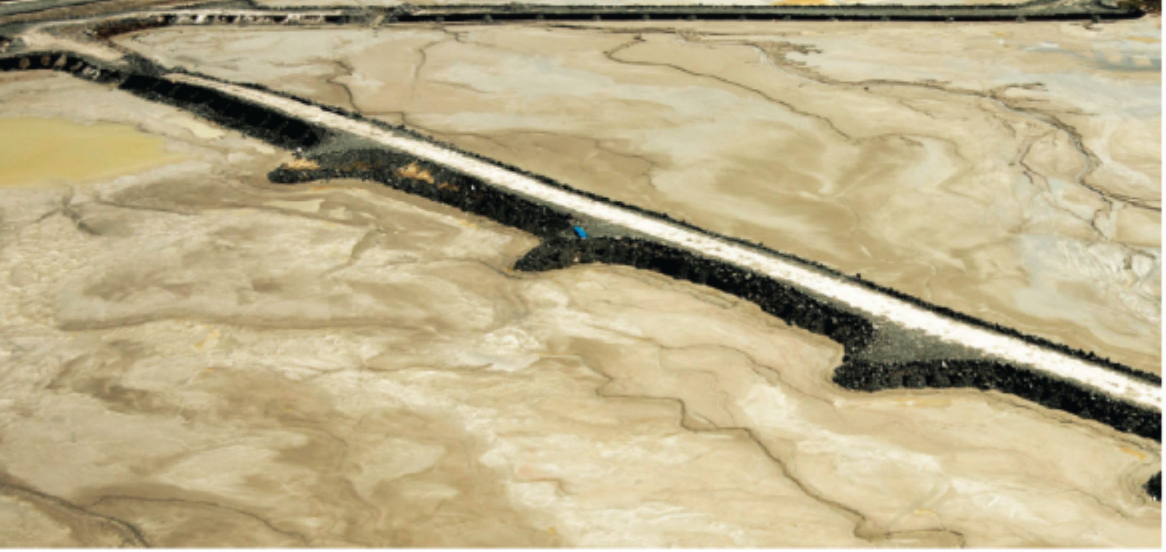
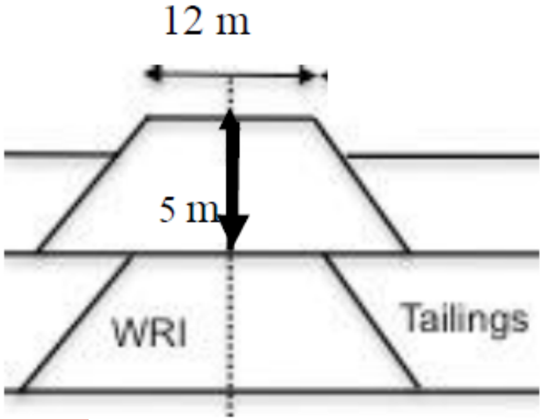


Waste rock inclusion constructed in the tailings impoundment at the Canadian Malartic mine. Such inclusions act as drainage and reinforcement elements to improve the hydro-geotechnical behaviour of the impoundment (photo provided by Osisko).



b)

Figure 3 – a) Photo of the southern part of the Canadian Malartic tailings impoundment with the approximate location of the two new waste rock inclusions (arrows) that will be built for this project; b) Schematic view of the waste rock inclusions in the impoundment

CRD PROJECT

INTEGRATED PROGRAM OF:

- Conventional and specialized lab tests
- Physical modelling in the laboratory
- Site observation and monitoring
- Numerical simulation

COMPONENTS AND TASKS

Material characterization

Interaction between the tailings and waste

Monitoring and data analysis

Numerical simulations (laboratory & field scale)

Optimization strategy and guidelines

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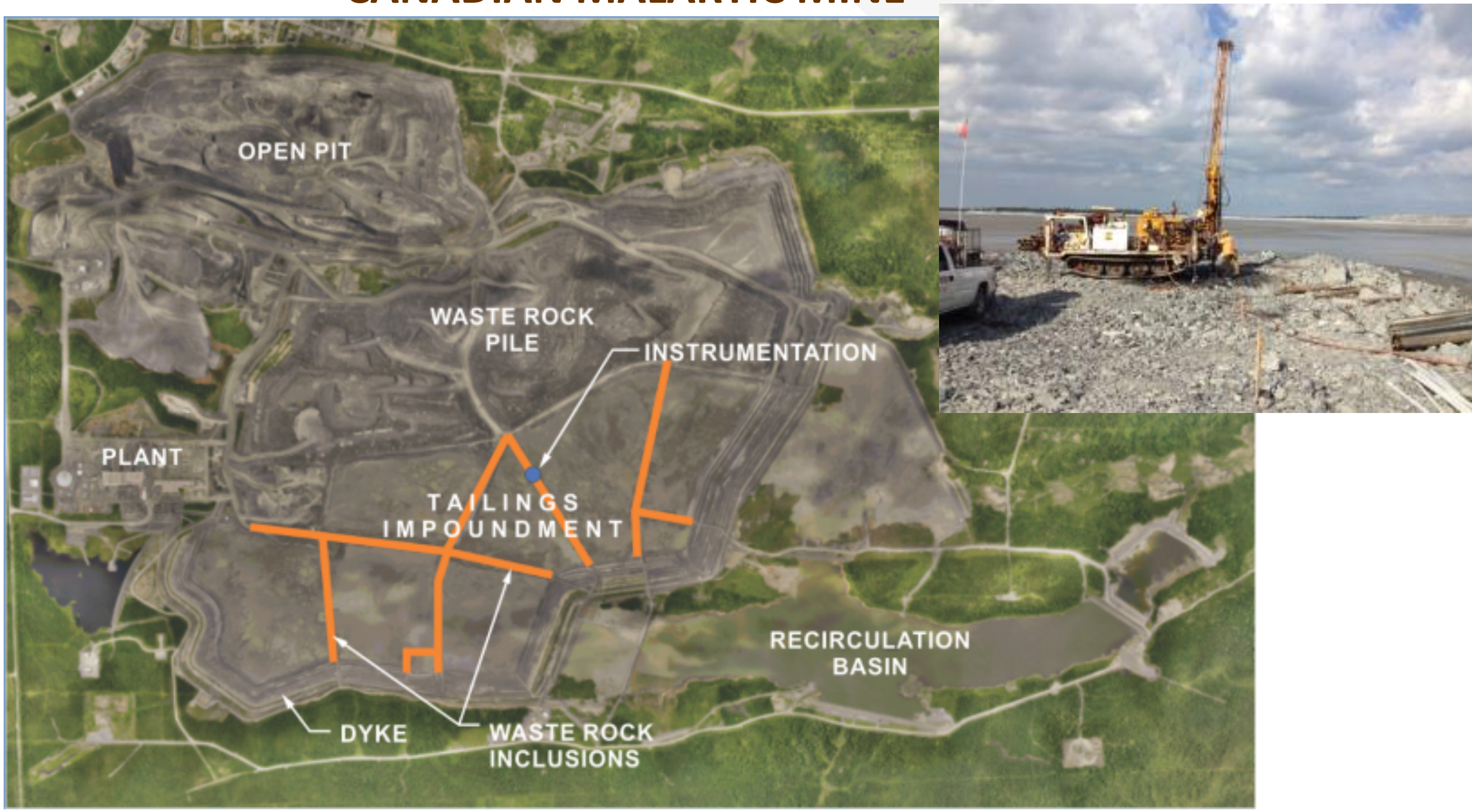
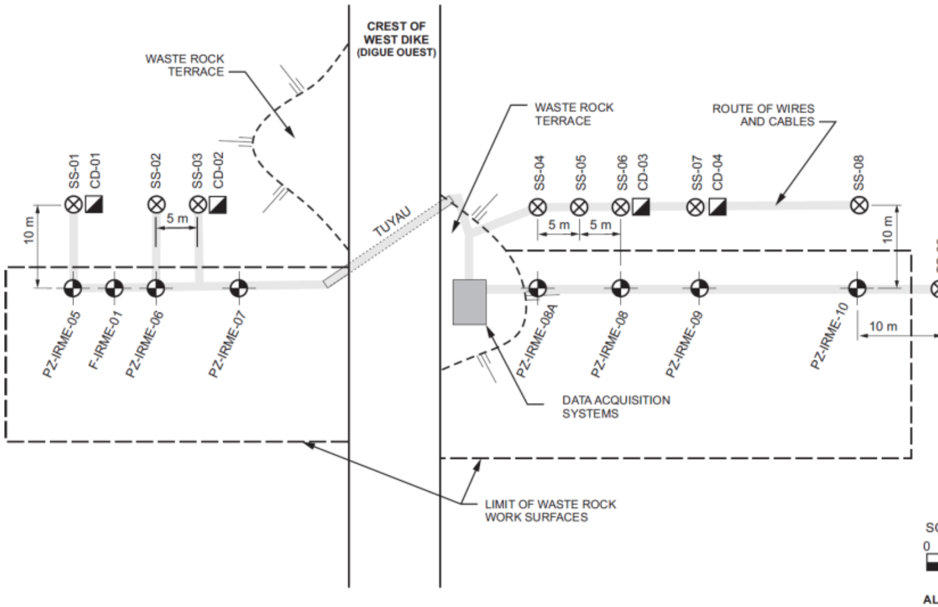
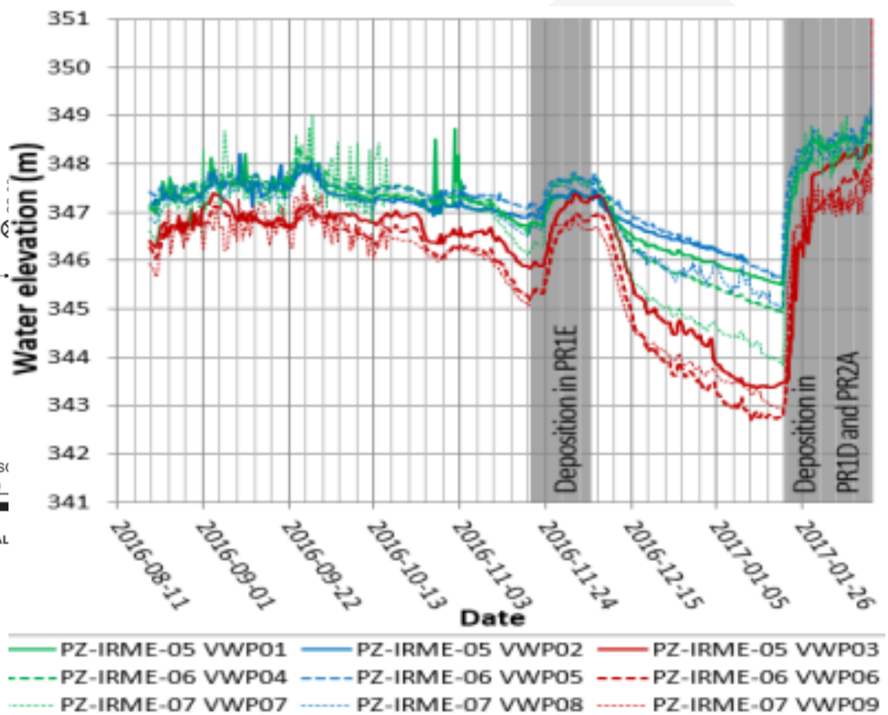
CANADIAN MALARTIC MINE

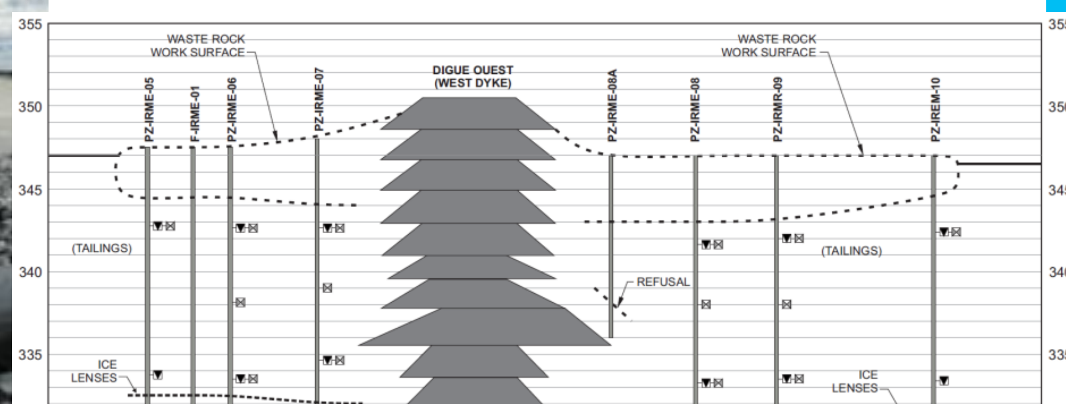


- Annual production : 580 000 oz of gold
- Daily production of 55 000 tons ore and 180 000 tons waste rock
- Impoundment of 470 hectares (+); P > 65%
- Expected dike height ~ 40 m
- 6.7 km of perimeter dykes

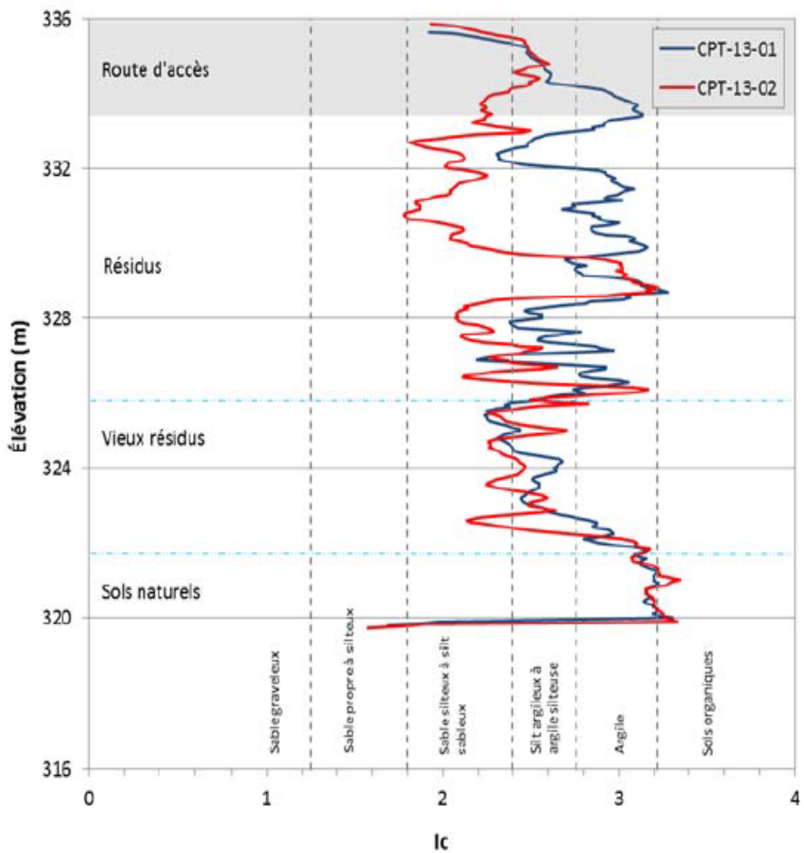
MONITORING AND OBSERVATION: PWP, VWC, SETTLEMENTS, V_S

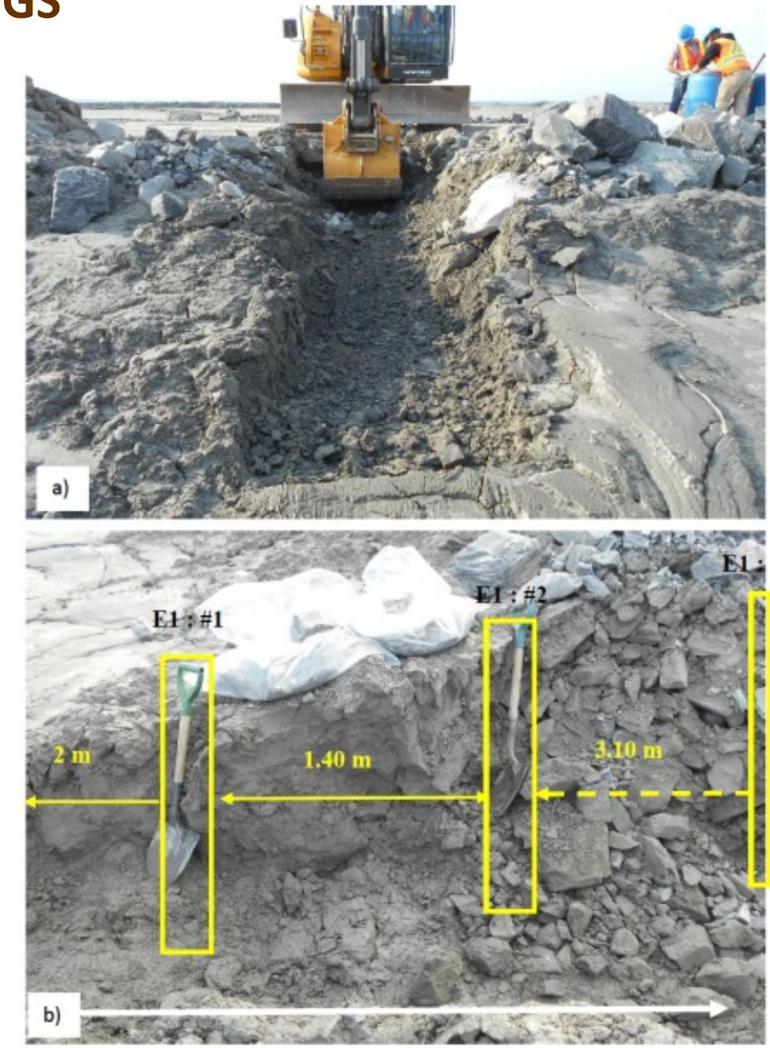






FIELD TESTS AND SITE INVESTIGATION; INTERACTION OF WASTE ROCK AND TAILINGS





Increased Strength (CPT) close to WRI (Golder, 2013, 2017)

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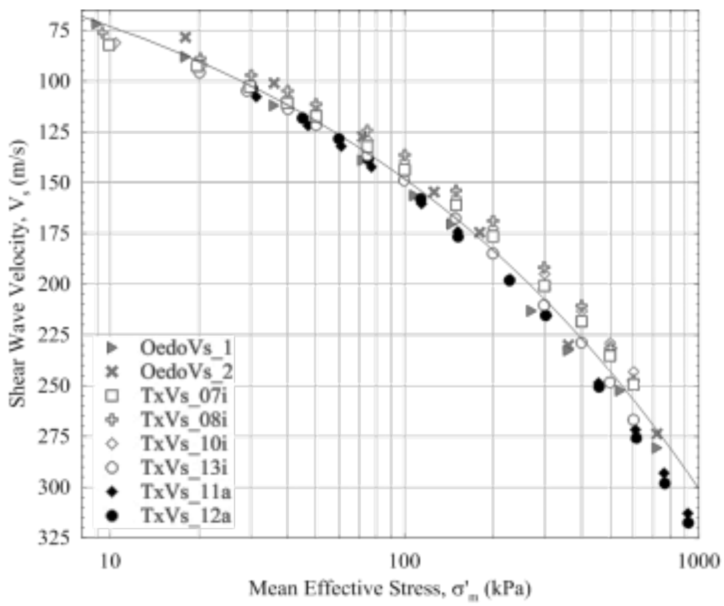
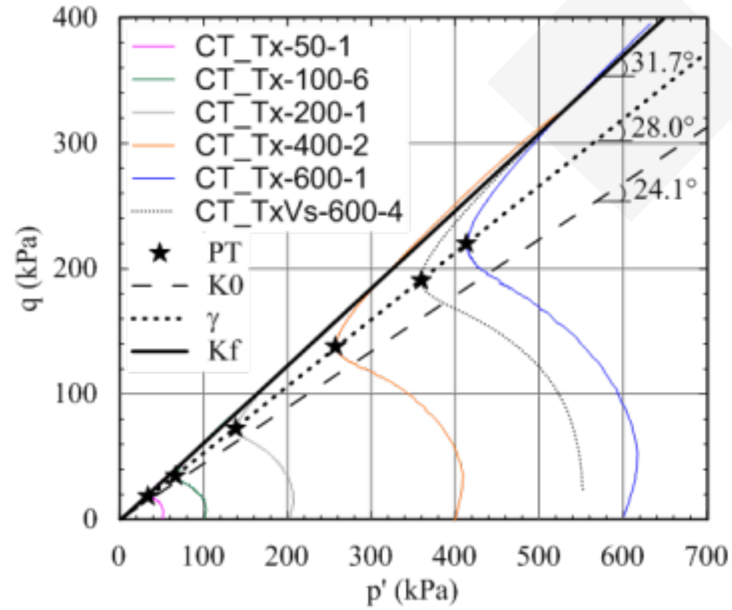
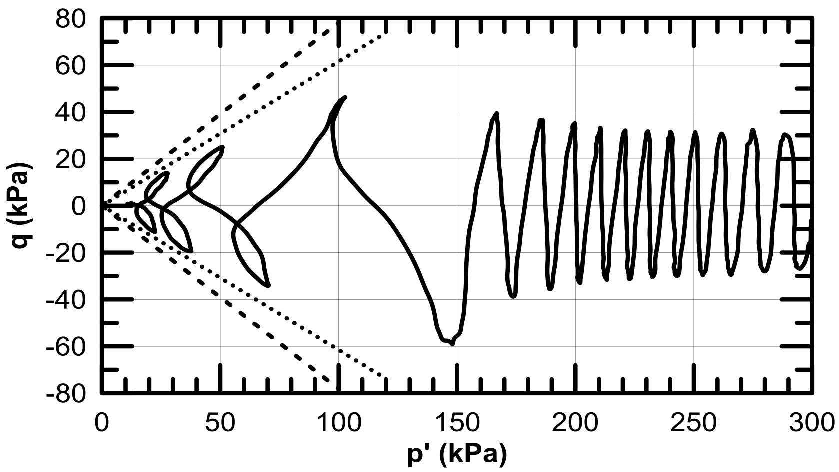
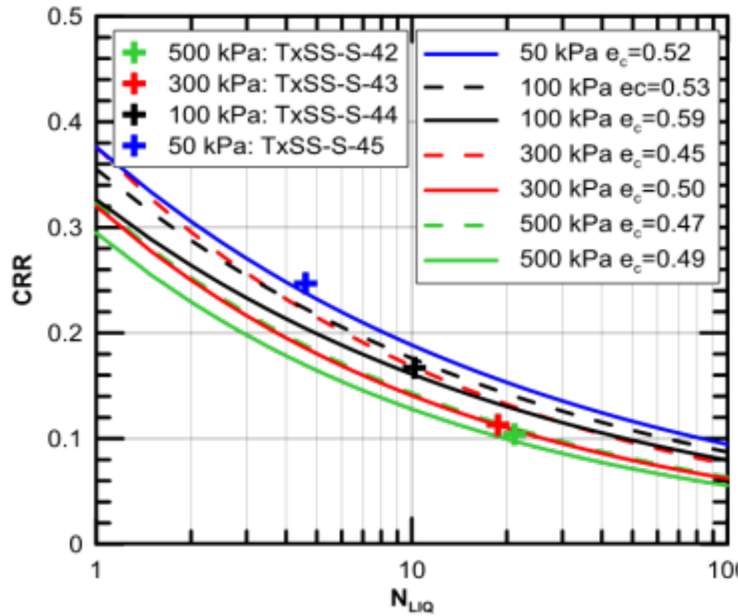
MATERIAL CHARACTERIZATION – STATIC & CYCLIC LIQUEFACTION

Geotechnical testing with undrained loading(Grimard; Archambault-A. 2017)









INTERACTION OF WASTE ROCK AND TAILINGS

Physical modelling (Saleh Mbemba, 2015; Essayad, 2017)

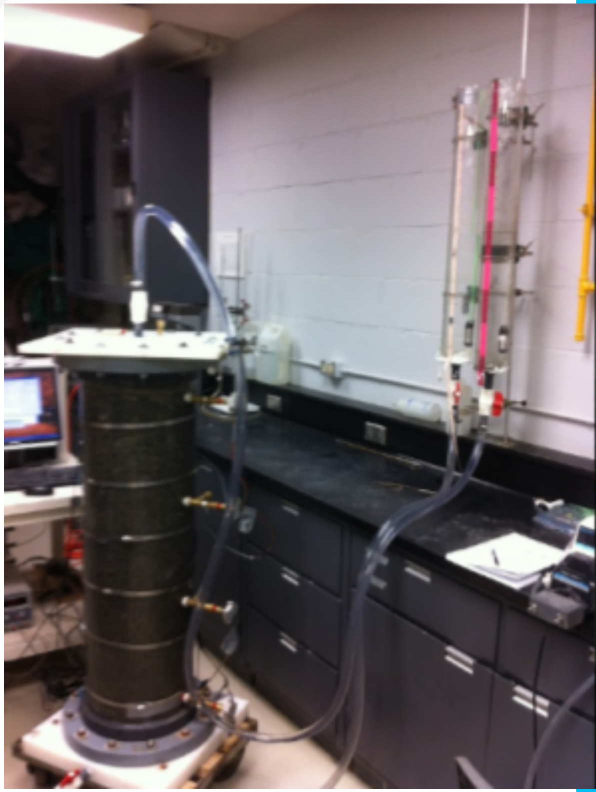
Tailings infiltration

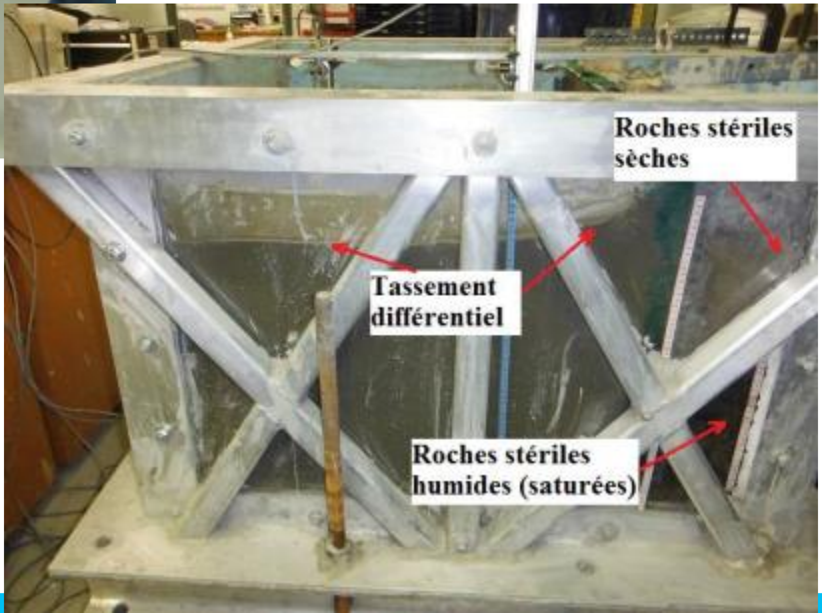
Tailings flow characterization

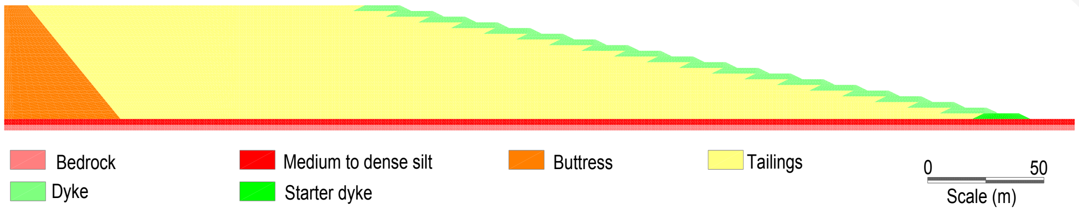
Drainage capacity

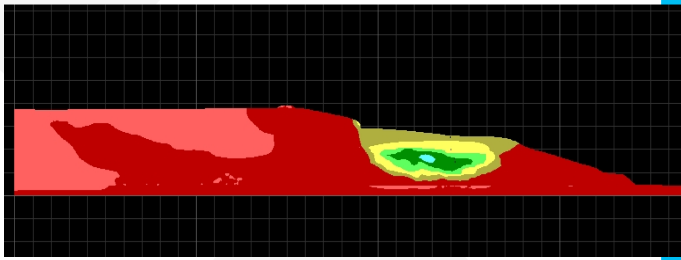
Potential for internal erosion

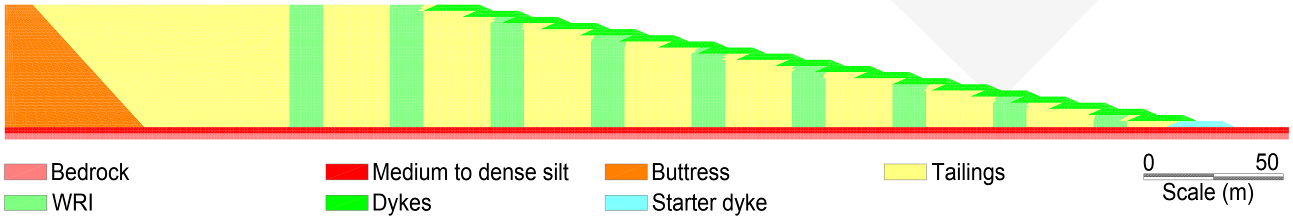
Effects of macro-porosity



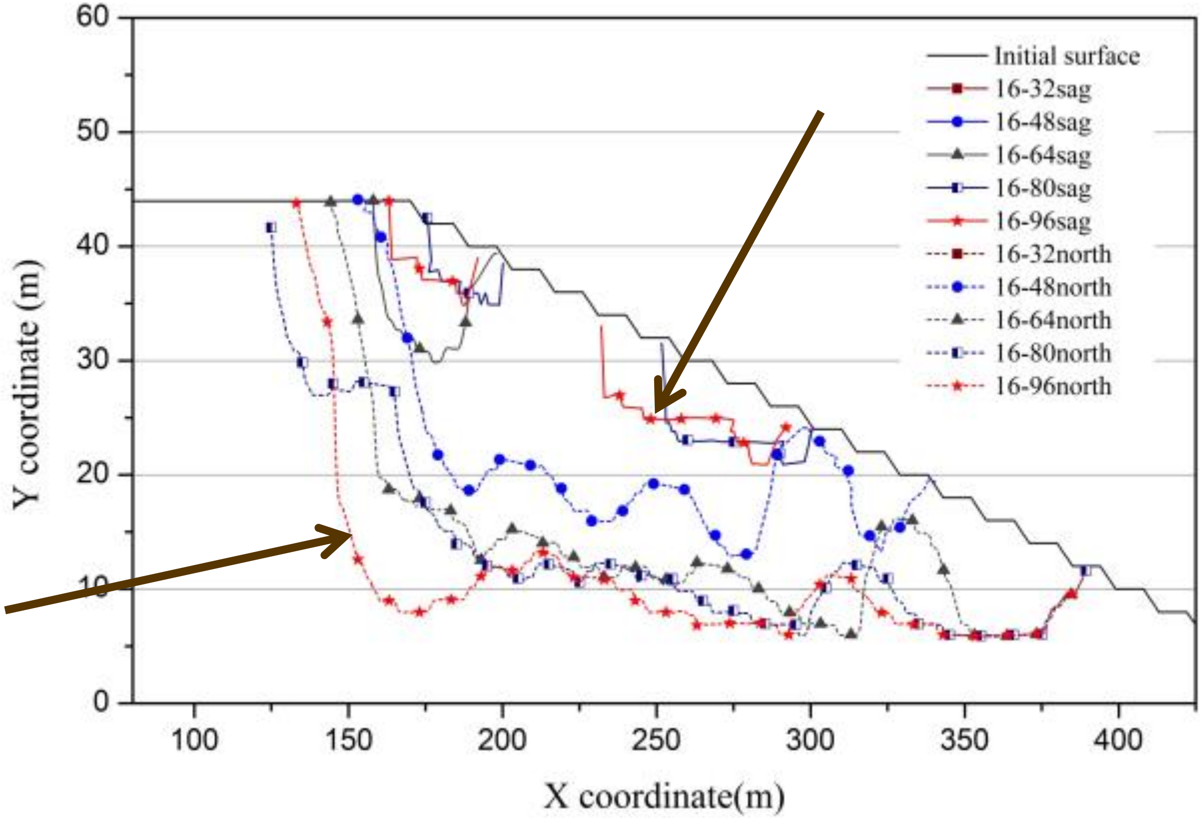






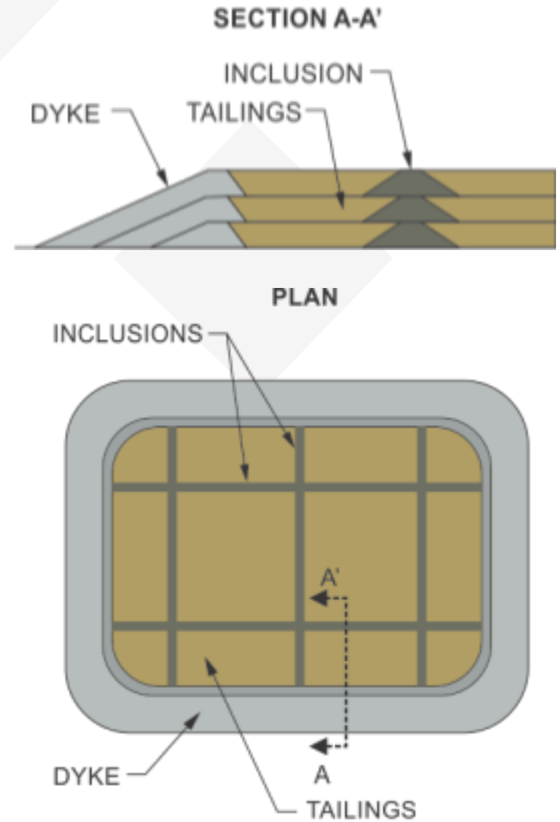


Seismic Numerical Analyses (Ferdosi et al. 2015, 16); Various WRI Configuraitons & Mw

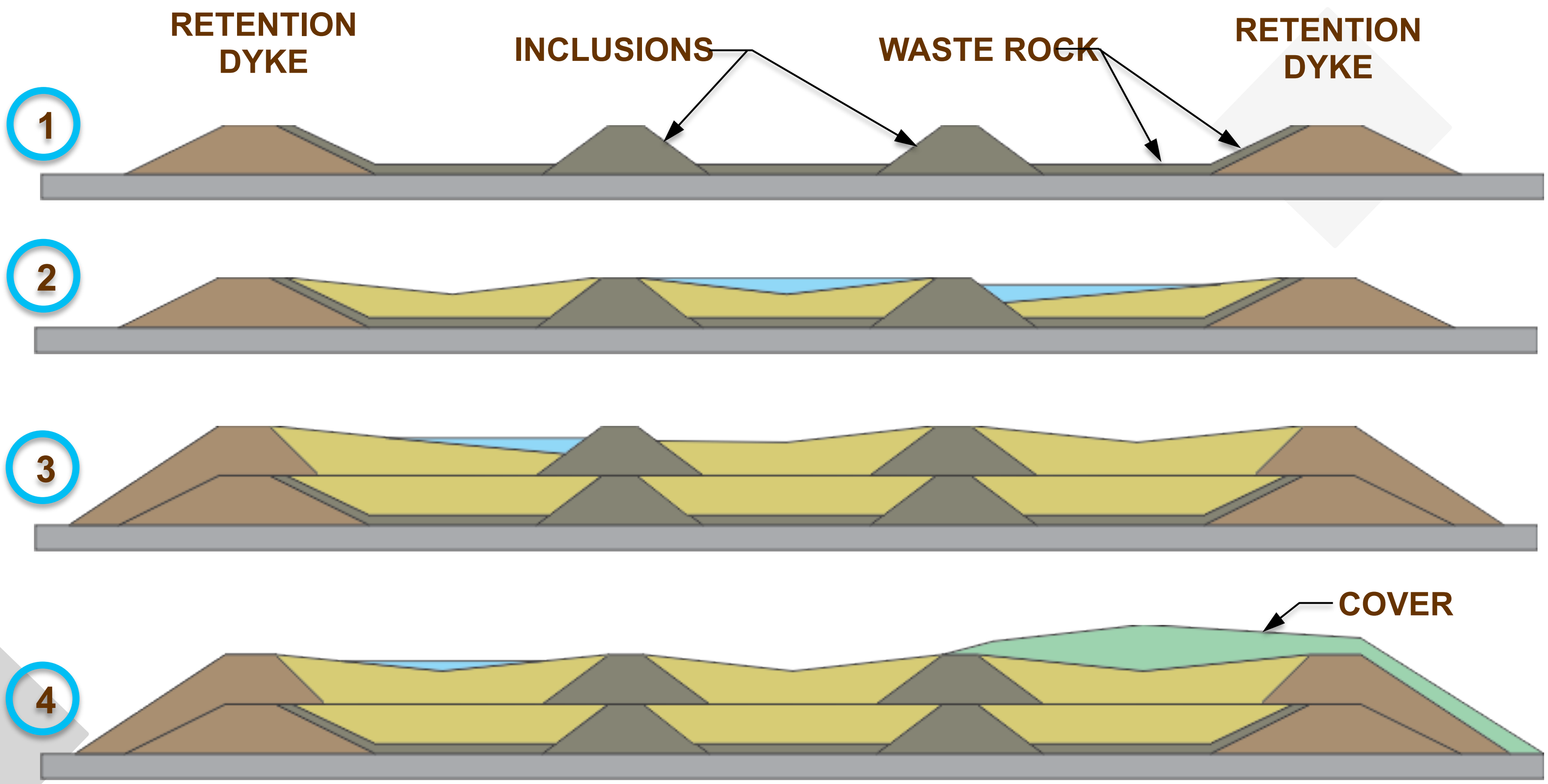


MAIN ADVANTAGES OF WRI (James et al. 2013)

- ✓ Accelerated drainage and consolidation
- ✓ Denser tailings; more rapid strength gain
- ✓ Reduced susceptibility to liquefaction and erosion
- ✓ Controlled dissipation of post-seismic EPWP
- ✓ Improved static and seismic stability
- ✓ Less material released in the event of a rupture
- ✓ More management options (compartmentalization)
- ✓ Progressive closure of the tailings impoundment
- ✓ Working surface for the placement of a cover
- ✓ Less material in the waste rock pile;
- ✓ Submerged reactive minerals; reduced risk of AMD or CND from the waste rock pile



LIFE CYCLE OF A TAILINGS IMPOUNDMENT WITH WRI (James et al. 2017)



Step 1 – Construction of dykes and inclusions
Step 2 – Tailings deposition
Step 3 – Management towards (for) closure
Step 4 – Start closure before end of operations
Step 5 – Ultimate condition (landform)

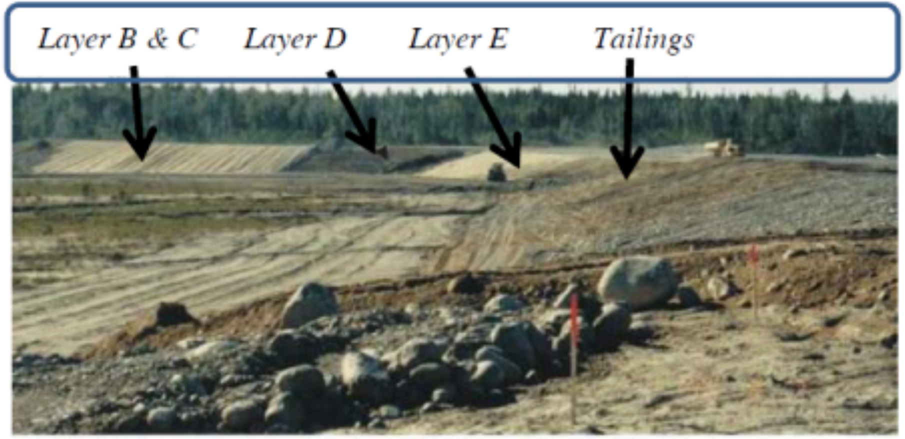
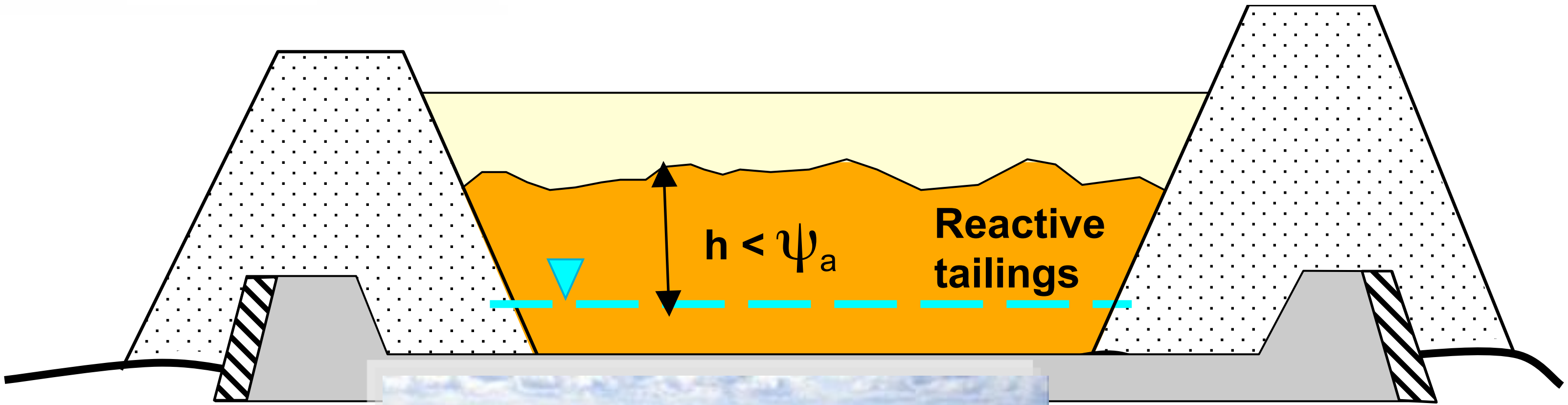


FIG. 5. The LTA tailings disposal site during the construction of a CCBE made of three layers (adapted from Aubertin et al., 2002)



(Aubertin et al., 1999; Dagenais, Ouangrawa, Cosset, Pabst, Broda, Éthier)

Prevention and Control of AMD or CND; Closure and reclamation

Final remarks

- Exist various ways of improving disposal practices to help prevent geotechnical and hydro-geochemical problems
- Ongoing R&D on WRI with industrial partners aims at developing another option to manage tailings and waste rock.
- Various publications on WRI since 2002 (including a few at CGS GeoOttawa 2017)
- Other results to come.

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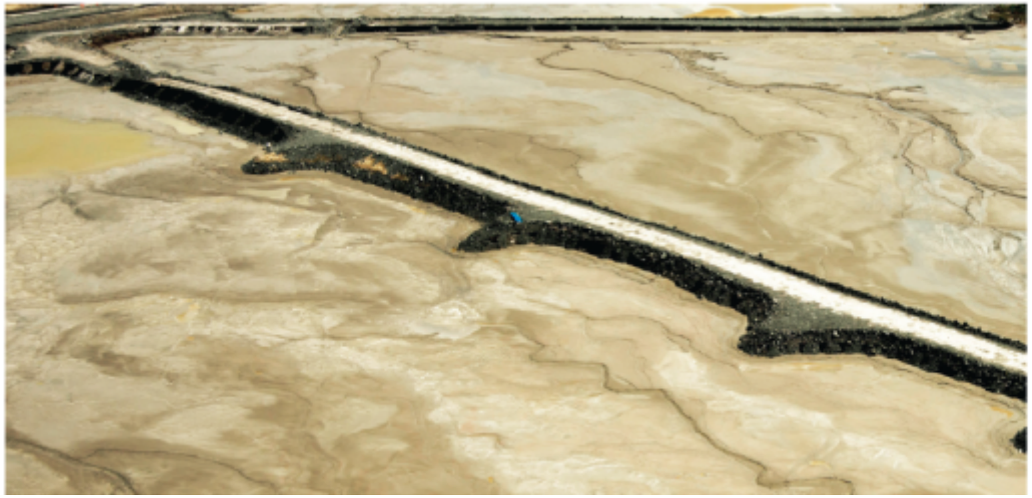

Agnico Eagle

Mine Canadian Malartic — Agnico Eagle, Yamana Gold

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