



Canadian Nuclear  
Safety Commission

Commission canadienne  
de sûreté nucléaire

Canada



# CNSC Regulatory Research on Geological Disposal

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DECOVALEX-2019 Workshop

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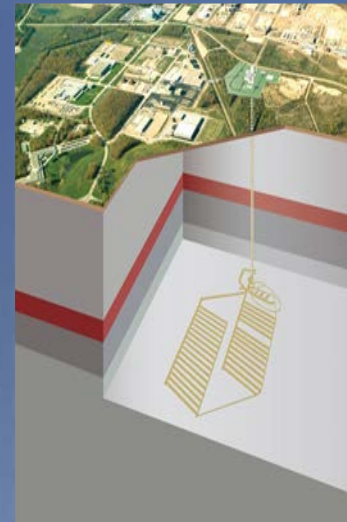
# Content

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- **Two current initiatives for geological disposal in Canada**
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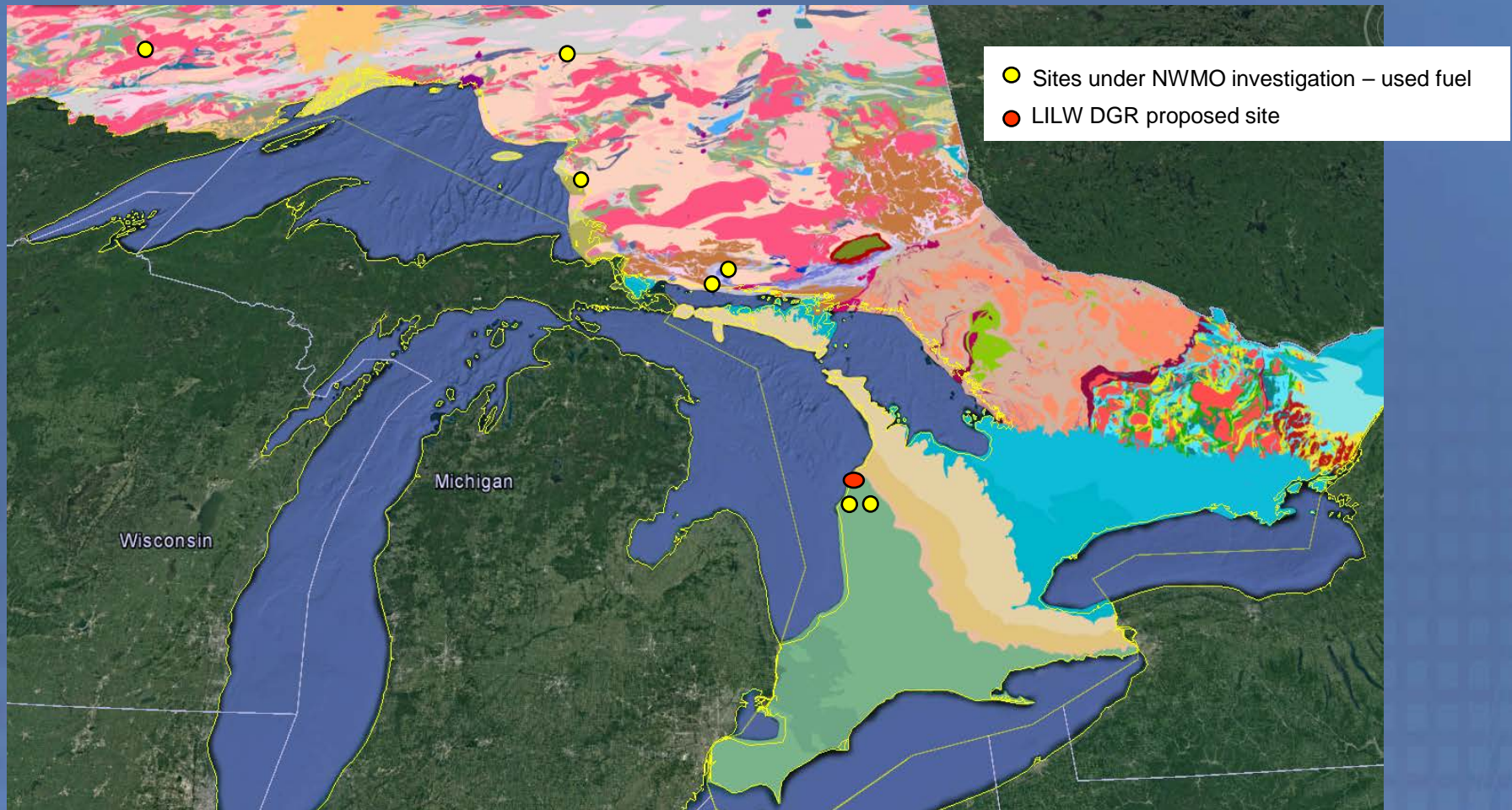


# Canadian Nuclear Safety Commission

- The Canadian Nuclear Safety Commission (CNSC):
  - regulates the use of nuclear energy and materials to protect health, safety, security and the environment
  - implements Canada's international commitments on the peaceful use of nuclear energy
  - disseminates objective scientific, technical and regulatory information to the public
- The CNSC regulates all nuclear facilities and activities in Canada throughout the nuclear fuel cycle



# Two Current Geological Disposal Initiatives



Both crystalline and sedimentary rock types are being considered



# Rationale and Overview of CNSC Research

- Geological disposal projects typically last decades from conceptualization to implementation
- Early involvement of regulator: an international best practice to keep abreast of technological, social and regulatory best practices
- Independent regulatory research: important component of this involvement
- Leveraging through national and international collaborations, while retaining in-house expertise
- Objective of regulatory research: build the CNSC's in-house knowledge in order to make well-informed licensing recommendations
- Summary of research findings is available on the [CNSC website](#)



# Chronology of CNSC Research (1)

- The chronology of CNSC research is summarized in a [chart](#) that shows:
  - the relationship between independent research from the CNSC and geological initiatives developed by the proponents
  - the way the CNSC's research results were used in the review of the proponents' submissions and in providing recommendations to the relevant authorities
- The Atomic Energy Control Board's (AECB – the CNSC's predecessor) research started in the late 1970s to prepare for the review of AECL's concept of geological disposal of used nuclear fuel in crystalline rocks

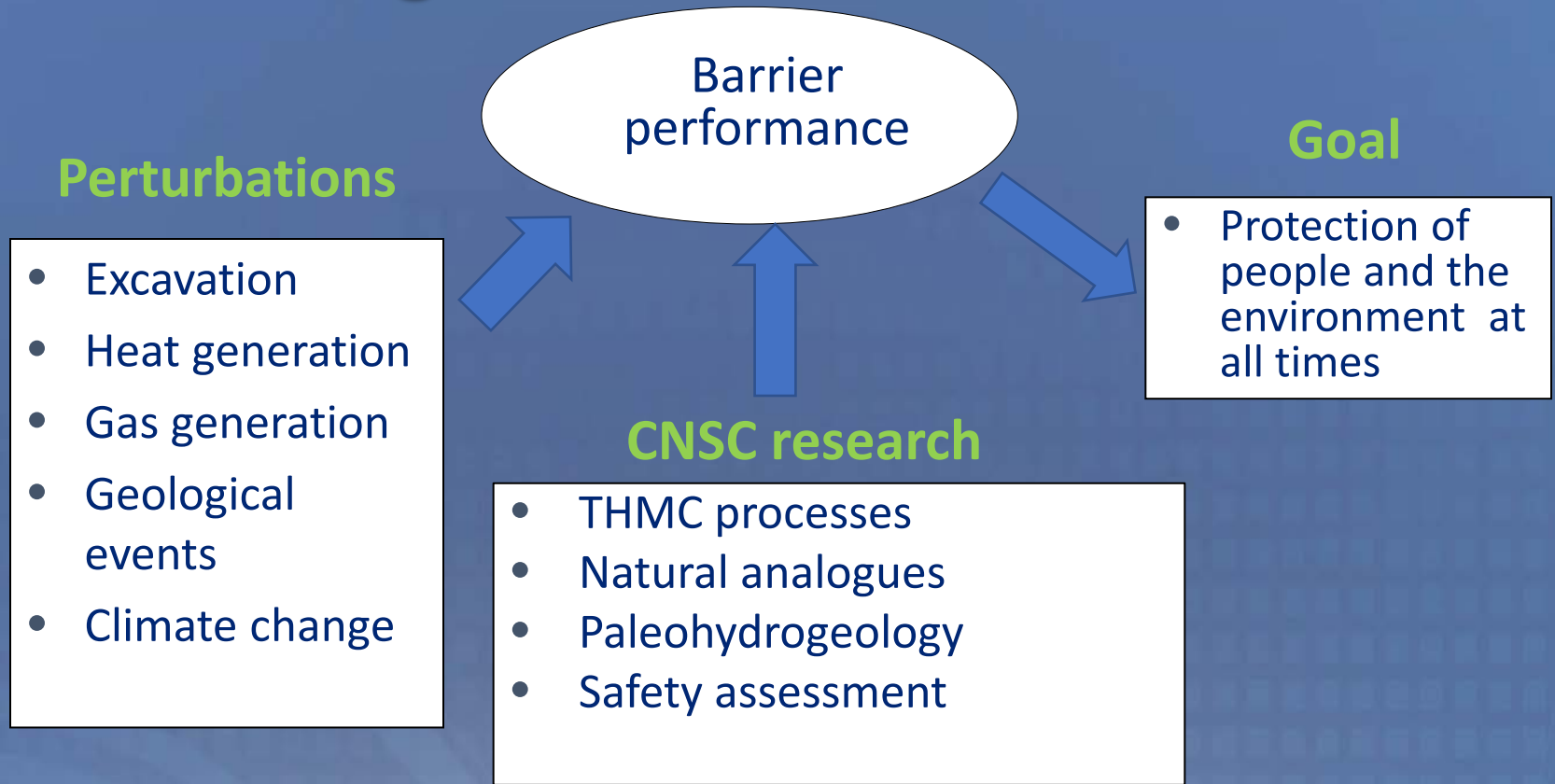


# Chronology of CNSC research (2)

- The AECB concluded in 1996 that the AECL concept is acceptable and recommended that Canada proceed to site selection
- The AECB/CNSC has conducted research from 1996 to present. The results have and will continue to enable the CNSC to provide science-based recommendations on:
  - OPG's proposal for a DGR for LILW in sedimentary rock; it was found that based on multiple lines of evidence, the proposed DGR would provide for the long-term protection of people and the environment
  - The NWMO's site selection process for Canada's used nuclear fuel and future application for a construction licence on a selected site

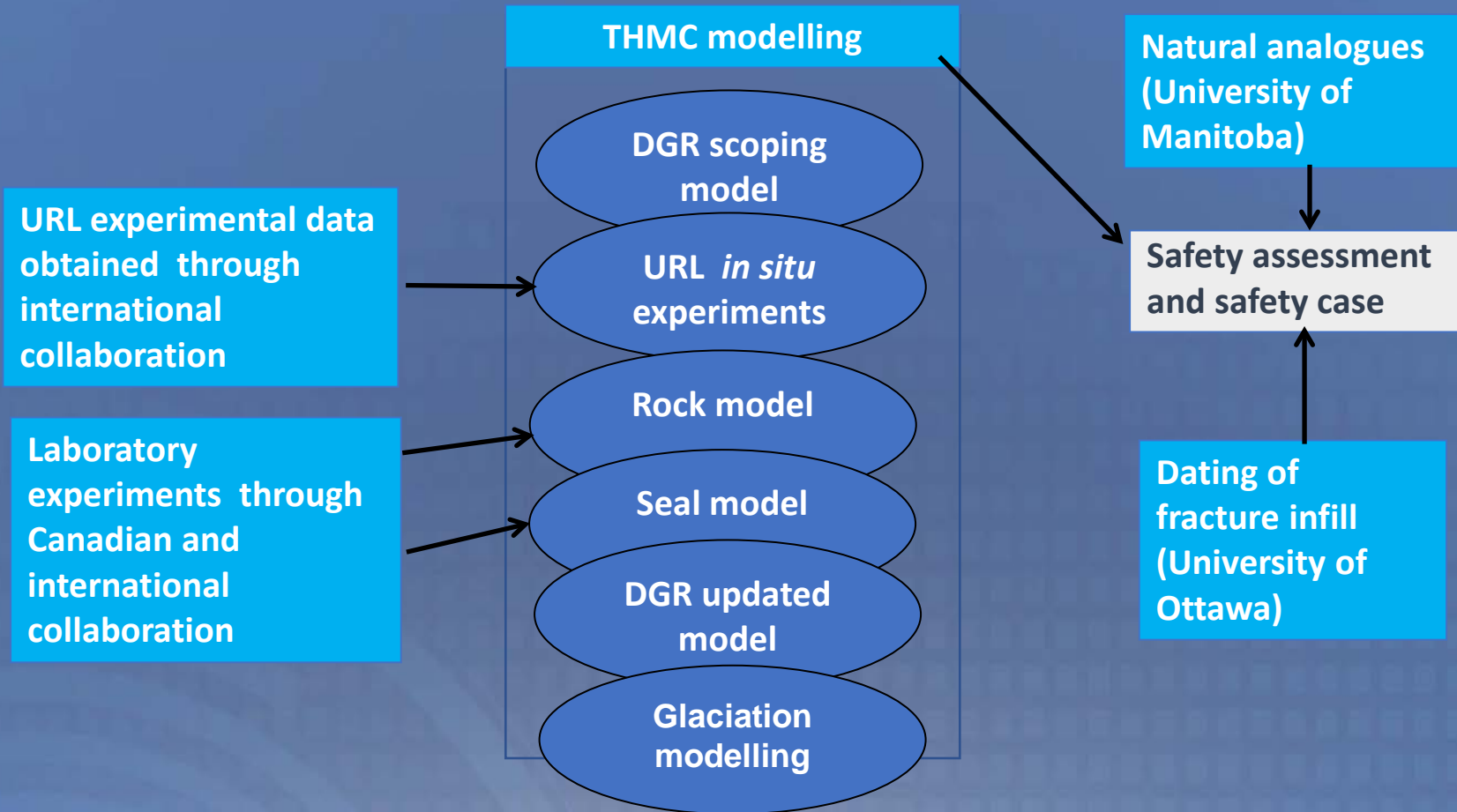


# CNSC Coordinated Assessment and Research Program





# Current Research Projects



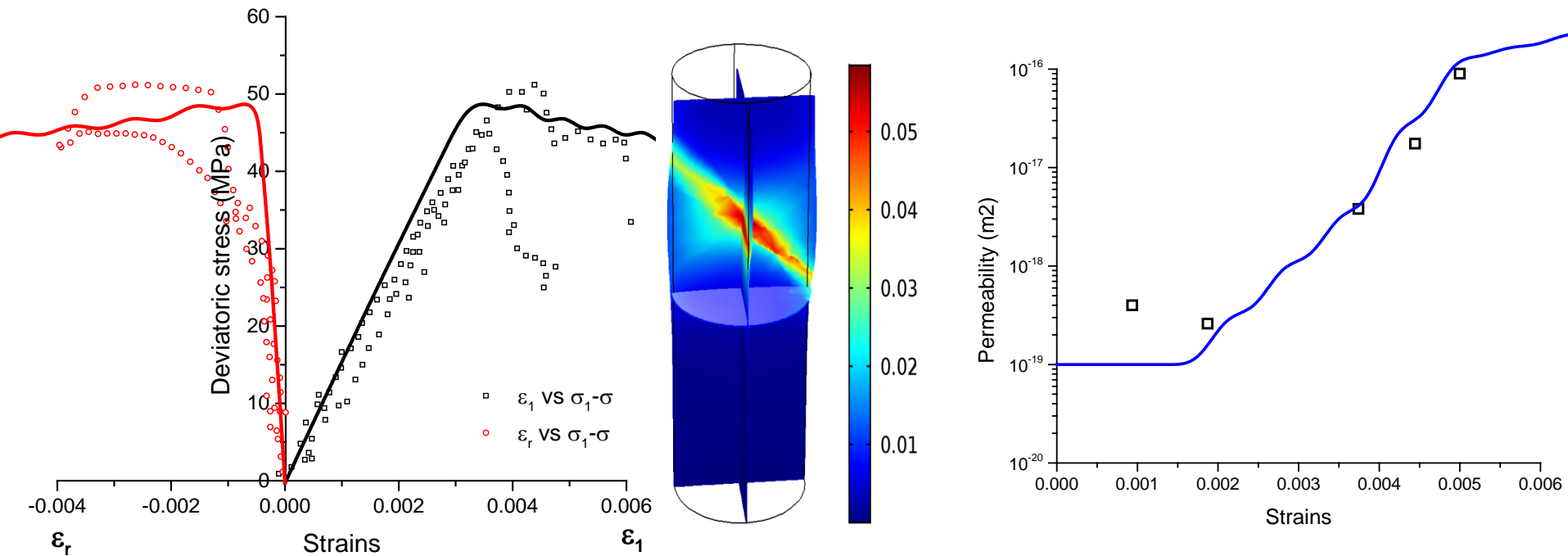
Integration of experimentation and modelling  
to verify the safety case



# Geomechanics

- Developed constitutive models for Opalinus clay, Tournemire shale and Cobourg limestone
- The models were used and validated in the simulation of laboratory and field tests consisting of excavation, water and gas injection

# Geomechanics of Cobourg Limestone – Triaxial Tests with Permeability Measurement



The hydraulic-mechanical response is well simulated by the model.  
The model is a reliable tool for assessing the excavation damage zone.

# The Behaviour of Bentonite Seals

- Simulation of heater experiment (HE), Mont-Terri URL
- Simulation of SEALEX experiment, Tournemire URL
- Experimental program on effects of brine on bentonite seals

# Swelling Pressure of Bentonite



- Very high salinity is found in porewaters of Canadian sedimentary rocks
- Swelling pressure tests at Queen's University shows a substantial reduction of the swelling potential of bentonite infiltrated with brine

**Effects of brine on the performance of bentonite seals must be taken into account in the Canadian Program**

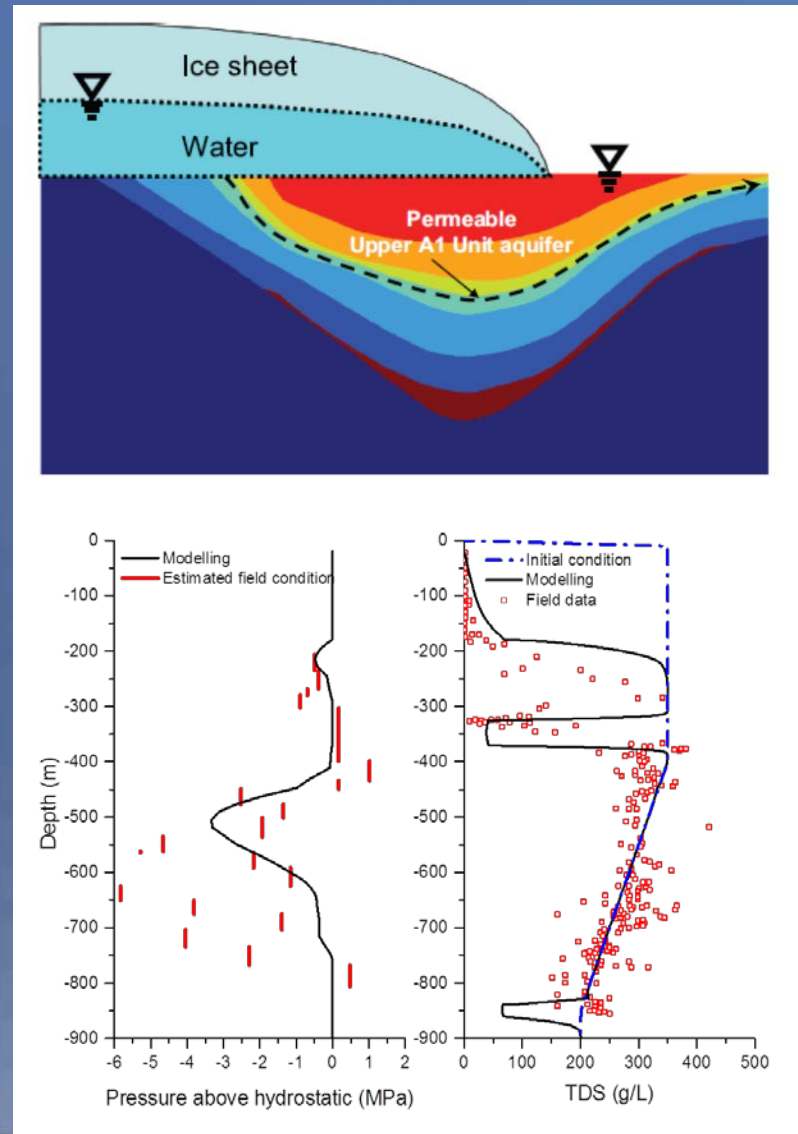
# DECOVALEX

- The CNSC has been involved since 1992 – a very fruitful collaboration with fellow researchers in THMC coupled processes
- The CNSC's current involvement in D- 2019:
  - gas flow in low-permeability materials
  - induced slip of a fault



# Glaciation Modelling

- During the last million years, Canada has been subjected to nine glacial cycles
- For each cycle, the ice sheet imposes a surface load of 30–40 MPa, leading to:
  - substantial increase in hydraulic gradients
  - redistribution of natural tracers by advection, dispersion and diffusion
- The CNSC developed and validated a mathematical model for the THMC response to the past nine glacial cycles of the sedimentary rock at a DGR for LILW proposed by OPG



# Conclusions from Glaciation Modelling

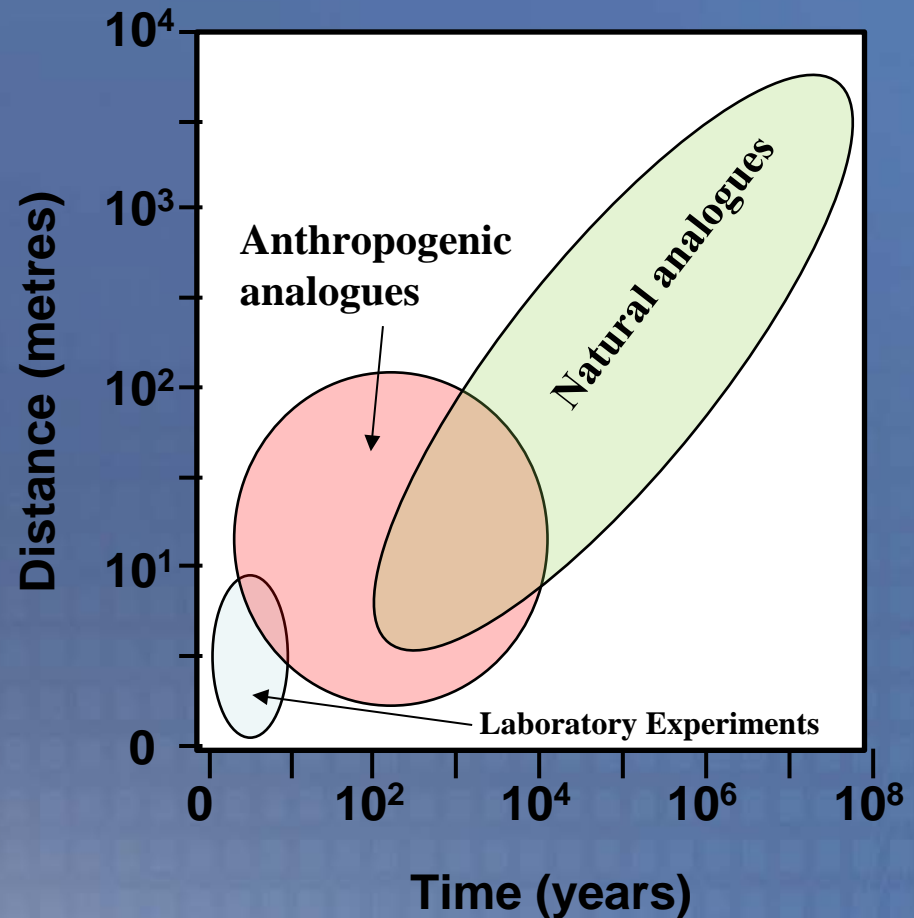
- Mathematical modelling and field data at a proposed LILW DGR site provide multiple lines of evidence that:
  - the host and cap formations at the site of the proposed DGR for LILW and their groundwater have been unaffected by nine cycles of glaciation over the last million years
  - the deep groundwater system in the host and cap rock formations at the site is hundreds of million of years old and virtually stagnant – transport of solutes is diffusion dominated
  - the Great Lakes are features resulting from Quaternary glaciation cycles – surface water bodies such as the Great Lakes have remained isolated from the deep groundwater





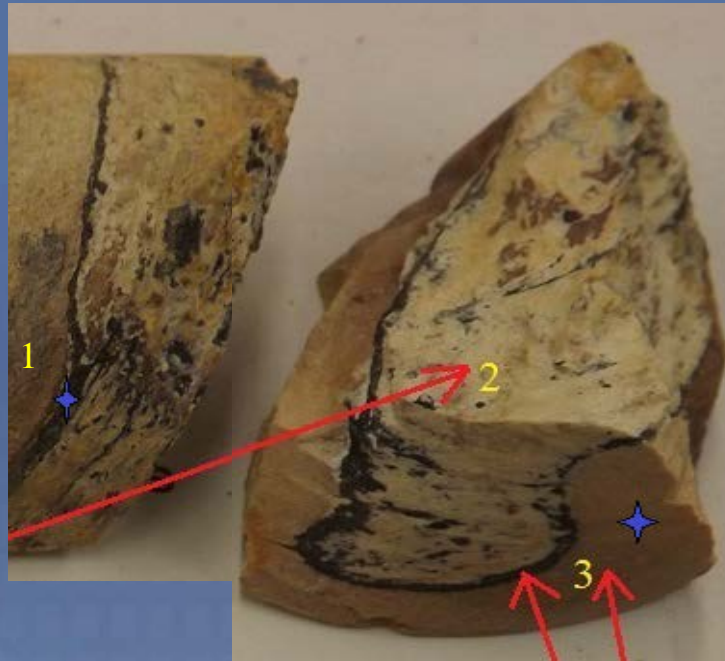
# Natural and Anthropogenic Analogues Review (1)

- Bridging the gap between laboratory experiments and modelled safety assessment time frames that are usually in excess of 10000 years
  - analogue studies increase confidence in DGR safety providing data on geological and spatial scales that can't be replicated in experiments (for example, next slide)



# Natural and Anthropogenic Analogues Review (2)

Potential Canadian source term analogue – Kiggavik, Nunavut



- Image of core samples from the End Uranium Deposit, Kiggavik, Nunavut, Canada. Area 1 shows uranium minerals along a fracture, and areas 2 and 3 show secondary uranium mineralization within a clay-rich matrix.

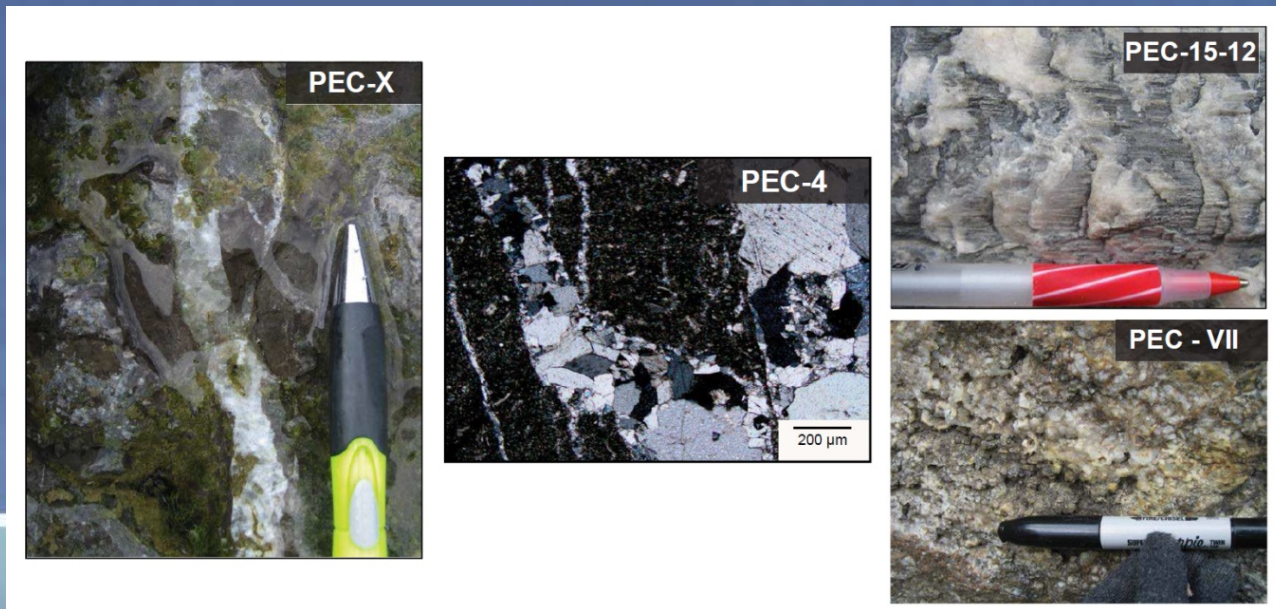
# Natural and Anthropogenic Analogues Review (3)

- Review conclusion and implications:
  - analogues provide input into the long-term safety case and increase public confidence in deep geological disposal concepts at all project stages
  - national analogues may build more public support for a DGR because of geographical and cultural familiarity
  - analogues which are site-specific are even more powerful; for example, natural tracers and past glaciation
  - integrating analogue information with other studies (e.g., hydrogeological and geomechanical studies), including laboratory experiments, can account for the range of temporal and spatial time scales



# Fracture Research in Southern Ontario

- Investigating potential for fault reactivation in southern Ontario by studying fracturing and fracture-filling minerals:
  - field-based study on the stability of the geosphere
  - absolute age dating of fracture-fill minerals
  - support seismic hazard assessment



# Fracture Infill-Analytical Approach and Conclusions

- Analytical approach:
  - field mapping and structural analysis: 35 calcite veins sampled from 15 outcrops; trace element geochemistry on 33 samples
  - stable isotope analysis of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  on 37 samples
  - radiometric dating
- Scientific conclusions:
  - Fluids are likely derived from distal sources and mobilized at  $\sim 100$  Ma, via inherited joint sets from basement-seated structures in the Grenvillian basement
  - Hypothesized plate reorganization at 100 Ma

**The fractures are millions of years old and  
have not been reactivated**



# Concluding Remarks

- CNSC research on the safety of geological disposal dates from the late 1970s
- The CNSC collaborates with national and international institutions
- Regulatory research:
  - builds independent expertise
  - adds to the CNSC's credibility
  - provides a solid scientific basis to the CNSC's licensing decisions and recommendations



# Recent Publications

- G. Su, T.S. Nguyen, E. Haghghat, S. Pietruszczak, D. Labrie, J-D. Barnichon, and H. Abdi, 2016. Characterizing the mechanical behaviour of the Tournemire argillite. Geological Society of London, Special Publications: [SP443 Radioactive Waste Confinement: Clays in Natural and Engineered Barriers](#).  
<http://sp.lyellcollection.org/cgi/reprint/SP443.20v1.pdf?ijkey=PYP8oeb2w1U2GID&keytype=finite>
- Z. Li, T.S. Nguyen, G. Su and J.D. Barnichon, 2016: Development of a visco-elastoplastic model for a bedded argillaceous rock from triaxial tests, *Canadian Geotechnical Journal*, doi: 10.1139/cgj-2016-0100
- J. Spalding, D.A. Schneider, J. Brown, 2016. Long-term stability at the edge of the Canadian Shield: insights from calcite-filled fracture inherited from basement structures, southern Ontario, Canada. GACMAC 2016 poster.
- M. Fayek and J.L. Brown, 2015. Natural and Anthropogenic Analogues for High-Level Nuclear Waste Disposal Repositories: A Review. Canadian Nuclear Safety Commission RSP-310. 59p.
- T.S. Nguyen and D.A. Le, 2014, Development of a constitutive model for a bedded argillaceous rock from triaxial and true triaxial tests, *Canadian Geotechnical Journal*, d.o.i. 10.1139/cgj-2013-0323
- T.S. Nguyen and D.A. Le, 2014, Simultaneous gas and water flow in a bedded argillaceous rock, *Canadian Geotechnical Journal*, d.o.i. 10.1139/cgj-2013-0457
- D.A. Le and T.S. Nguyen, 2014, Hydromechanical response of a bedded argillaceous rock formation to excavation and water injection, *Canadian Geotechnical Journal*, d.o.i. 10.1139/cgj-2013-0324
- T.S. Nguyen, Z. Li, J.D. Barnichon and B. Garitte, 2017. Modelling a heater experiment for radioactive waste disposal , *Environmental Geotechnics*, doi.org/10.1680/jenge.15.00060
- O. Nasir, T.S. Nguyen, J.D. Barnichon and A. Millard, 2017. Simulation of hydromechanical behaviour of bentonite seals for containment of radioactive wastes, *Canadian Geotechnical Journal*, [doi.org/10.1139/cgj-2016-0102](https://doi.org/10.1139/cgj-2016-0102)
- M.H.B. Nasser, M. Tibbo, M. Sehzadeh, S. Ye, R.P. Young, G. Su and T.S. Nguyen, 2016, “Coupled hydro-mechanical properties of Cobourg limestone with special reference to excavation damaged zones”, European Geosciences Union fall meeting, Vienna
- T.S. Nguyen, Z. Li, G. Su and M. Herod, 2017. Swelling of bentonite hydrated with brine- a double porosity model, poster presentation, GEOPROC conference 2017
- T.S. Nguyen, Z. Li and M. Herod, 2017. Effects of glaciation on the rock formations around a proposed nuclear waste repository, oral presentation, GEOPROC conference 2017.

# Acronyms

- AECL: Atomic of Energy of Canada Limited
- APM: Adaptive Phased Management
- DGR: Deep Geological Repository
- OPG: Ontario Power Generation
- NWMO: Nuclear Waste Management Organization
- THMC: Thermal-Hydrological-Mechanical-Chemical
- URL: Underground Research Laboratory
- LILW: Low- and Intermediate-Level Waste







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# Questions?

## Thank You!



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