NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

How will a Deep Geological Repository Contain and Isolate Used Nuclear Fuel from People and the Environment

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Presentation Topics

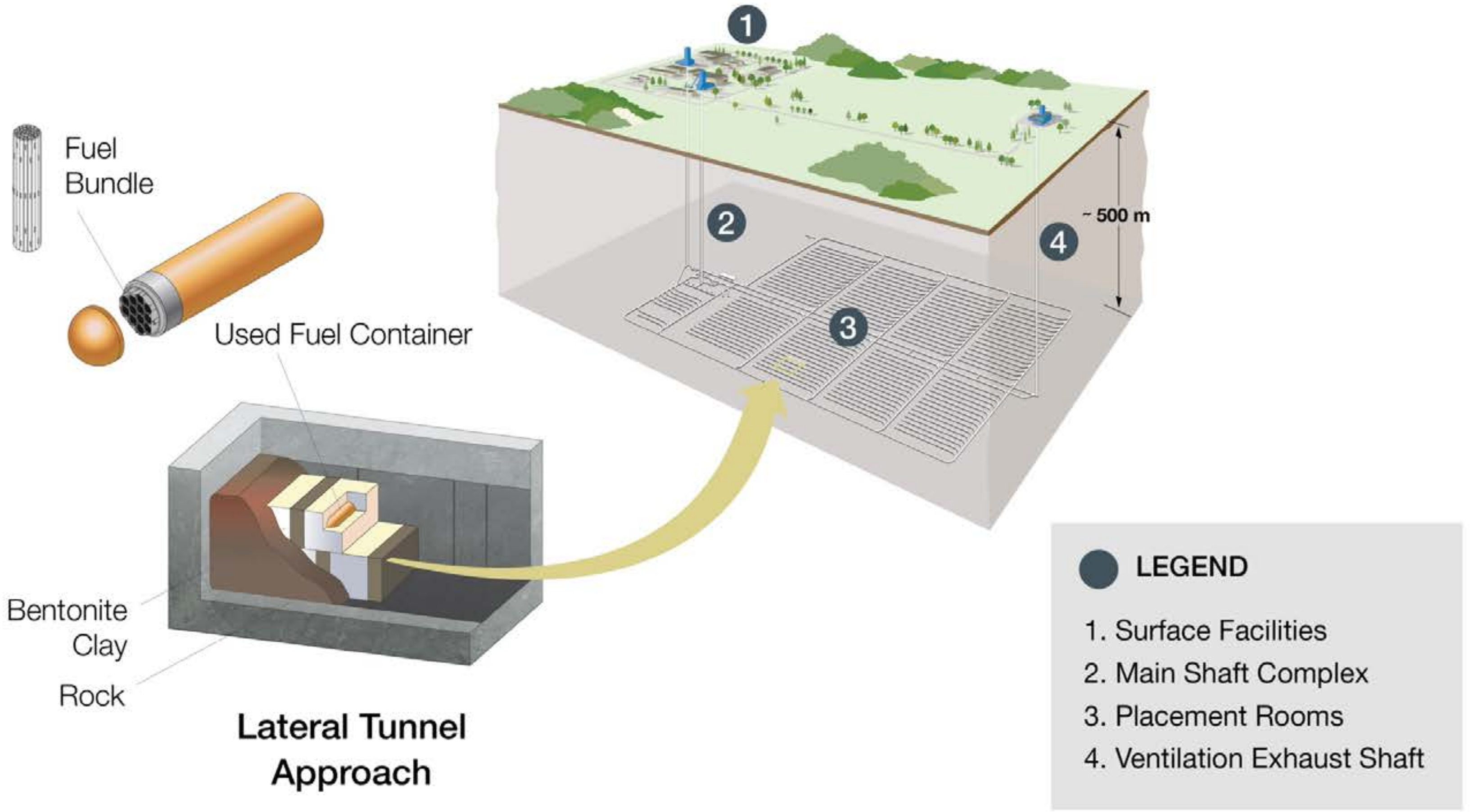
- Multiple Barriers – Engineered and Natural
- Sub-surface Geology

A Multiple-Barrier System

- A series of engineered and natural barriers work together to safely contain and isolate the radioactive atoms in used nuclear fuel from people and the environment
- Each barrier provides a unique and stand-alone level of protection.

What are the barriers?

Design is Based on Combination of Engineered and Natural Barriers



The Fuel Pellet

Why is a fuel pellet a good barrier?

- It is manufactured as a hard, high-density ceramic
- Ceramics are extremely durable and do not readily dissolve even if exposed to water
- Radioactive elements are contained within the ceramic pellet and therefore their ability to move is extremely limited

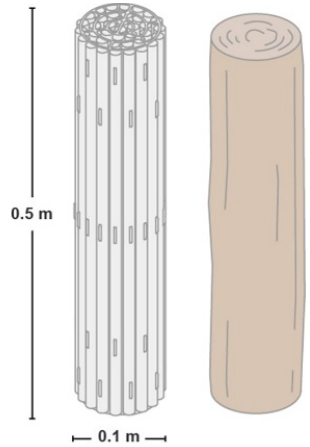
UO_2 ceramic pellet

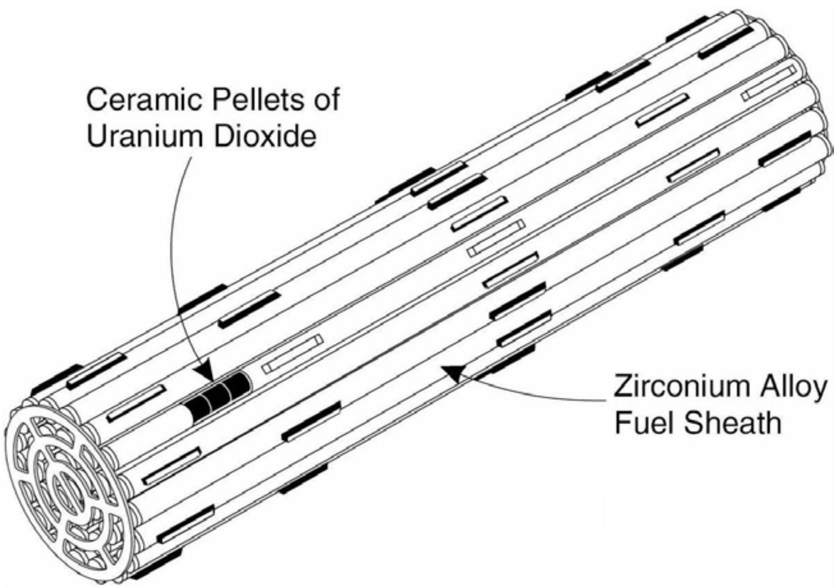
900 y old ceramic

>2500 y old ceramic

Engineered Barrier: Zircaloy Fuel Element

- Used fuel pellets are held in sealed tubes made of Zircaloy (a zirconium alloy).
- Zircaloy is a strong, corrosion-resistant, **passive metal**.





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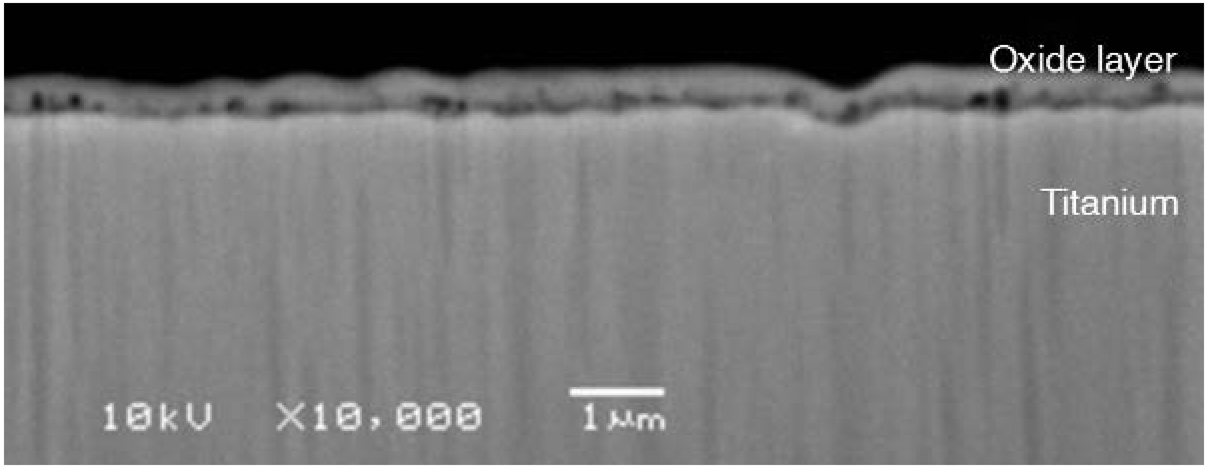
Passive Metals – How do they work?

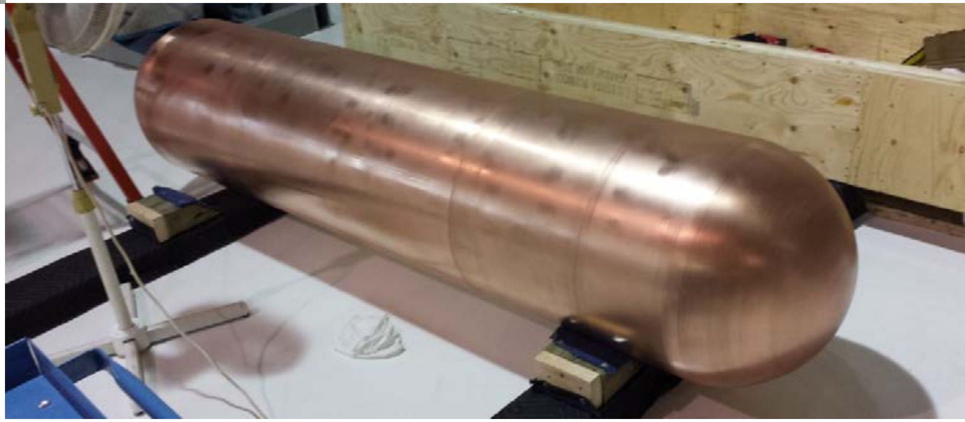
- Many metals are corrosion resistant due to forming a protective compact oxide layer on surface
  - E.g. stainless steel, aluminum, titanium, zirconium
- These metals are called "passive metals"
- However, passive metals are not perfect due to localized corrosion



Engineered Barrier: Copper Coated Used Fuel Container

- Carbon steel “core”
- Length= 2.5 m
- Diameter = 0.6 m

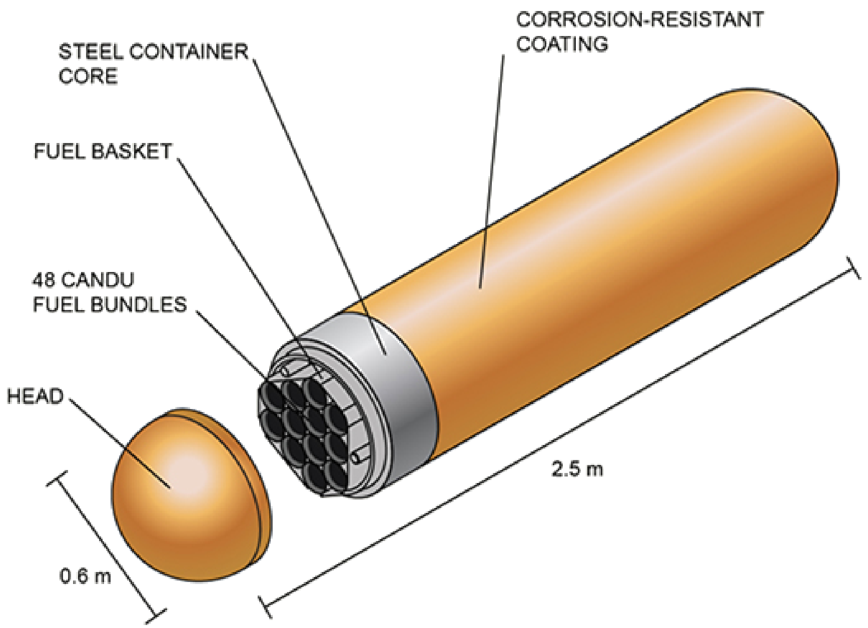
- Holds 48 CANDU bundles
- **3 mm copper coating**



Engineered Barrier: Copper-Coated Used Fuel Container

Robust and long-lived

- Steel inner shell provides strength to resist the local pressure underground, the bentonite swelling pressure and the pressure from future glaciations
- Copper coating provides corrosion protection of the inner shell
- Water cannot contact the fuel if the container remains intact
- Copper can be very stable in the conditions that exist deep underground



Why Copper for a Used Fuel Container?

- Copper is durable under typical deep geologic conditions (wet oxygen-free)
- *Man-made Artefacts*
  - 300-year old Swedish bronze cannon
  - 1600-year old bronze London tableware
- *Native Copper Deposits*
  - 1 ton, million-year old native copper ore from Michigan
  - t copper

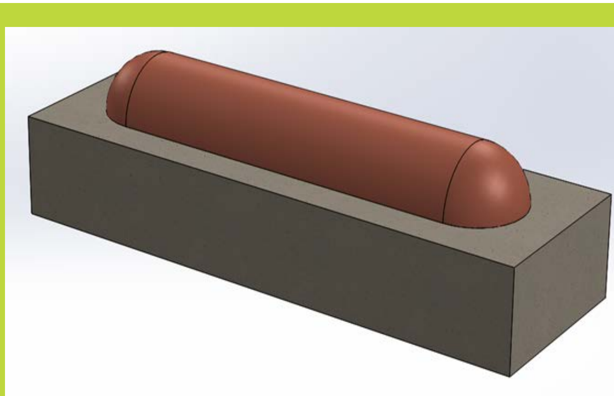
Copper: Natural Analogue

- Copper sheets in mudstones from South Devon, England
- Formed 200 million years ago
- Show little corrosion
- Copper remained stable for millions of years within clay-rich mudstone

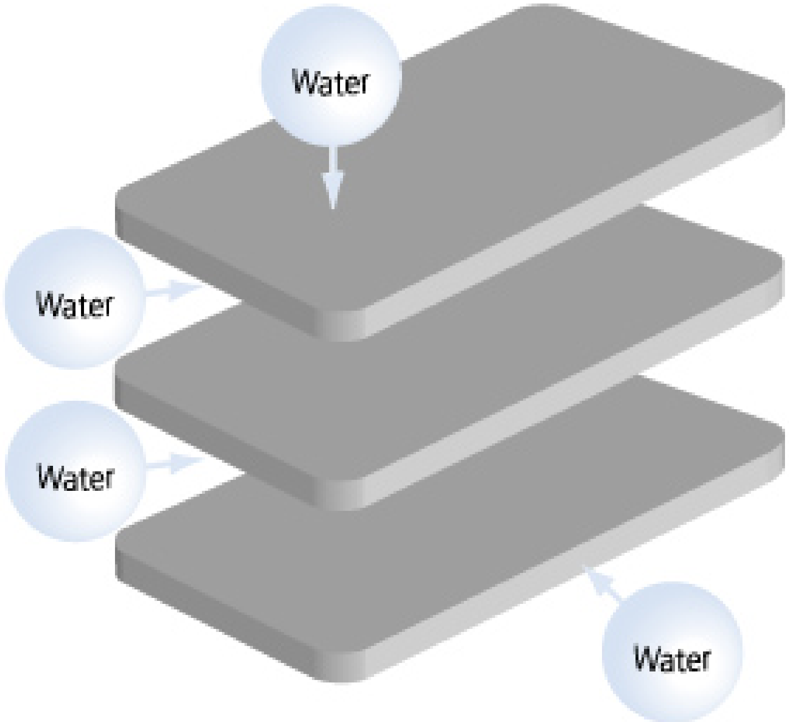
Engineered Barrier: Bentonite Clay

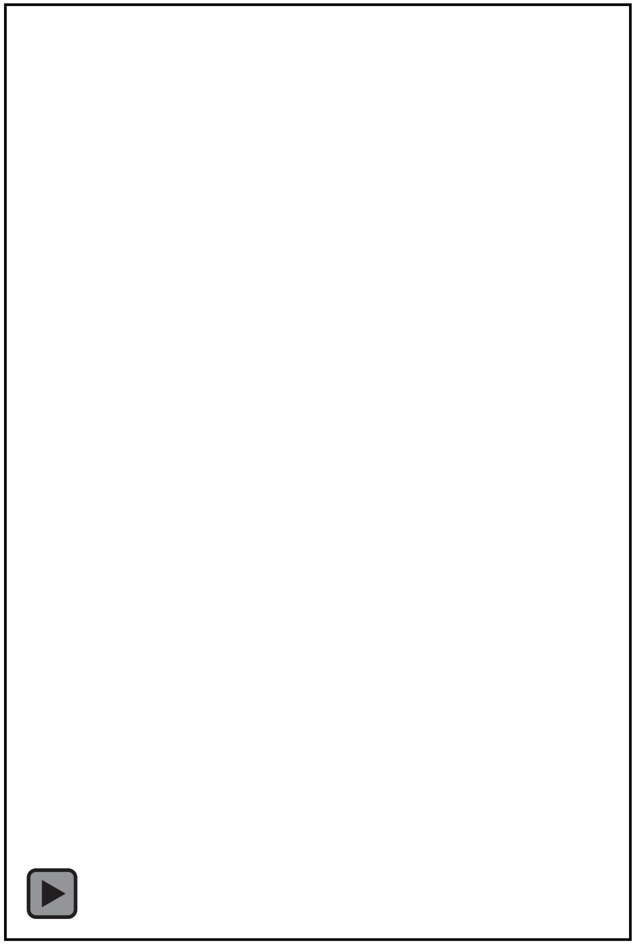
- Bentonite is a naturally-occurring, *<u>swelling</u>* clay material used in many industrial applications.
- Bentonite used to make shaped blocks for the used fuel containers.

Buffer Box



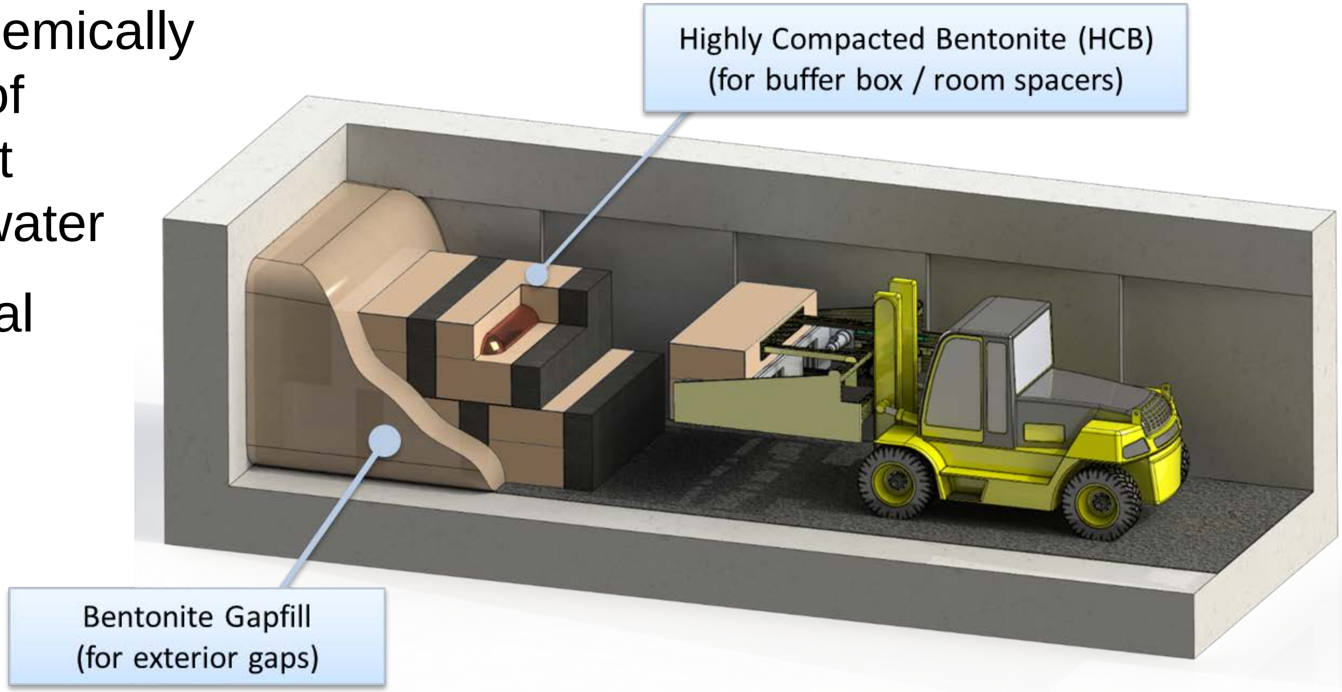
Bentonite Swelling: How Does it Work?



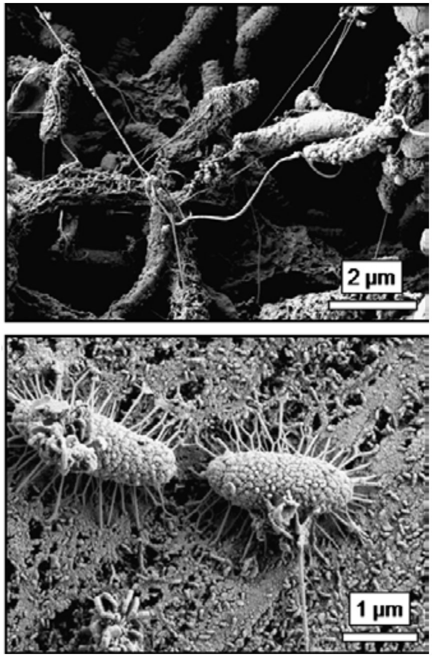


Engineered Barrier: Bentonite Clay

- Underground tunnels & rooms will be backfilled with bentonite
- Slows natural movement of water through the repository and towards containers
- If a container fails, clay can physically and chemically slow movement of radionuclides that may dissolve in water
- Prevents microbial growth



Why Engineer Against Microbes?



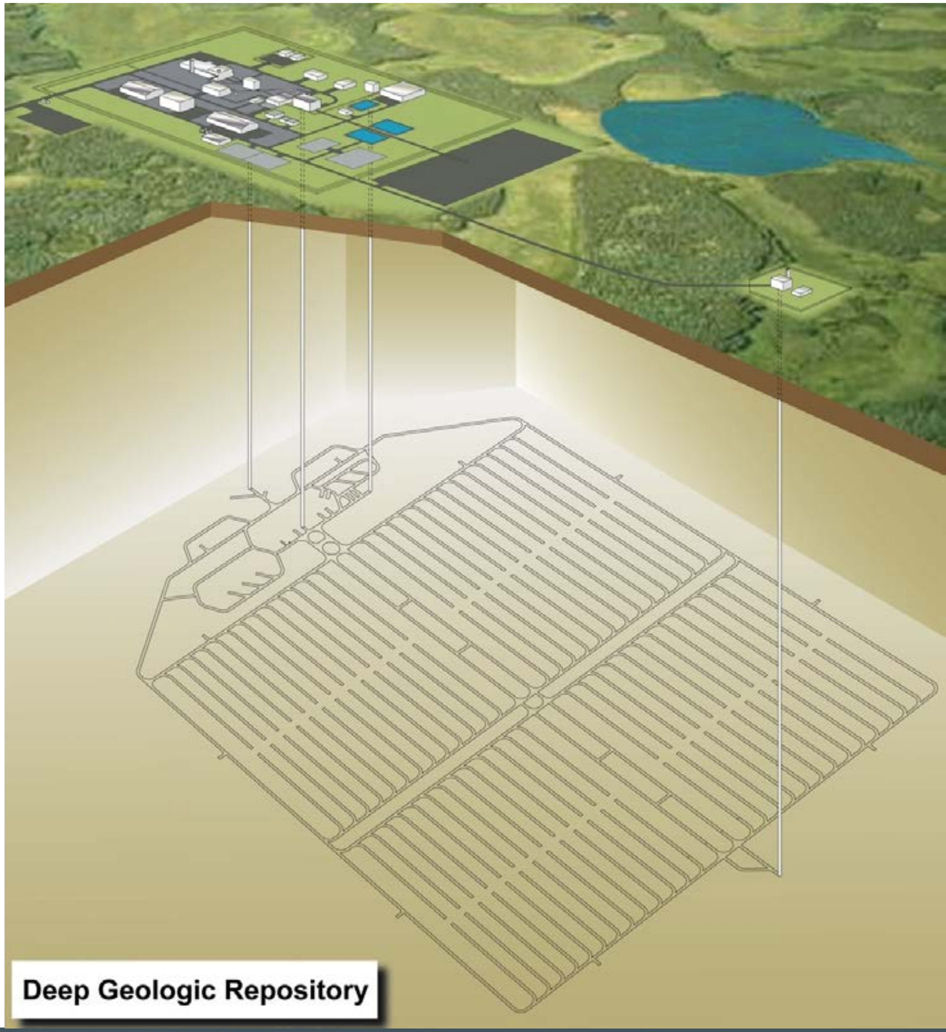
- When biofilms form microbes can produce corrosive chemicals leading to damage
- By swelling, bentonite closes off pores and restricts water from microbes

Clay: Natural Analogue

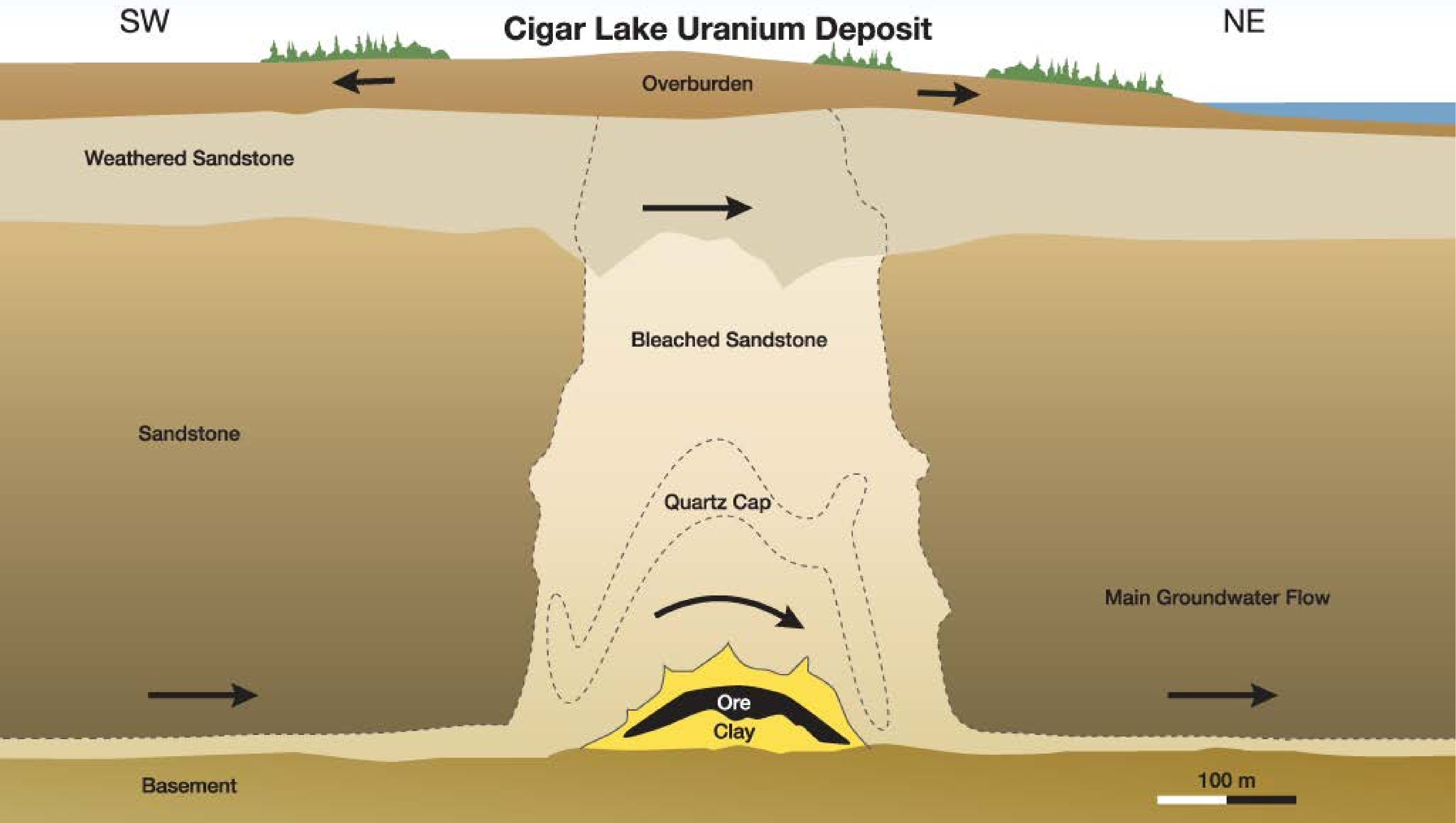
- The sequoia-like trees in Dunarobba forest, Italy, were buried in clay for 1½ million years
- They are still made of wood and have not decomposed as the clay has limited microbial growth

Natural Barrier: Geosphere (Host Rock)

- The host rock at depth forms a natural barrier.
- It will protect the repository from natural surface events and human activities.
- The host rock will isolate the used fuel from humans and the environment by limiting the movement of radionuclides if other barriers fail.



Geosphere: Natural Analogue



Key suitable host rock characteristics

- Sufficient volume of competent rock at sufficient depth
- Low groundwater movement at repository depth
- Favourable rock strength at repository depth
- Favourable chemical composition of rock and water at repository depth
- Absence of economically exploitable natural resources and groundwater resources
- Resilience to earthquakes
- Resilience to ice ages
- Geometry and structure should be predictable and amenable to characterization and interpretation

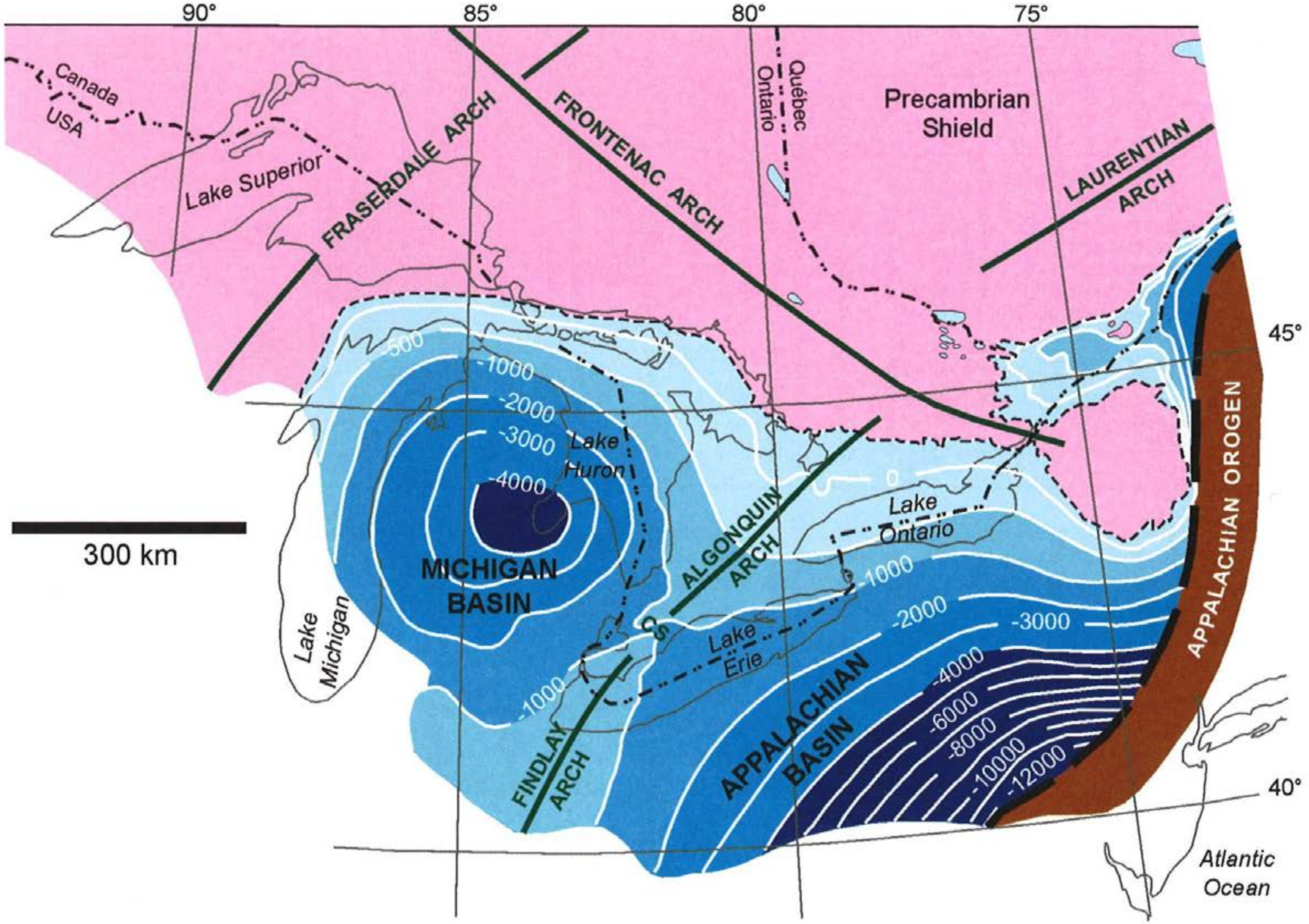
Summary

- Multiple barriers are the foundation of confidence for long term containment and isolation of used nuclear fuel
- Engineered barriers are important safety features and are the only ones we design
- Engineered barriers are complimentary to the natural barrier

Huron-Kinloss
Summary of Key Sub-Surface Geology Features

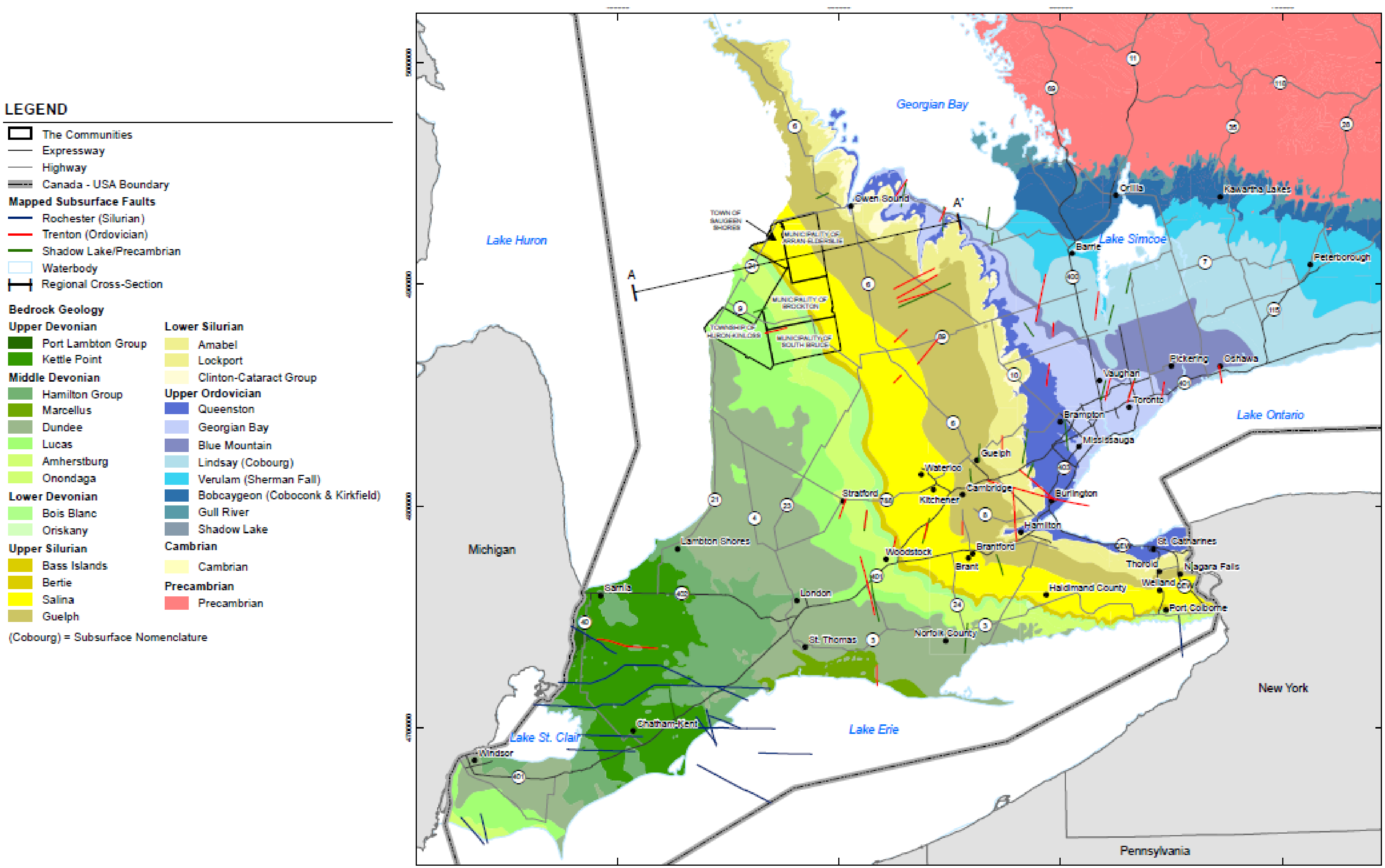
From: NWMO, 2014, Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel – APM-REP-06144-0108.

Geological Features of Southern Ontario



Contours represent thickness sedimentary basins in metres

Regional Surface Bedrock Geology



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Regional Geological Cross-section - Eastern Section of Michigan Basin

Legend

- Overburden

Bedrock Geology

Middle Devonian
- Lucas
- Amherstburg

Lower Devonian
- Bois Blanc

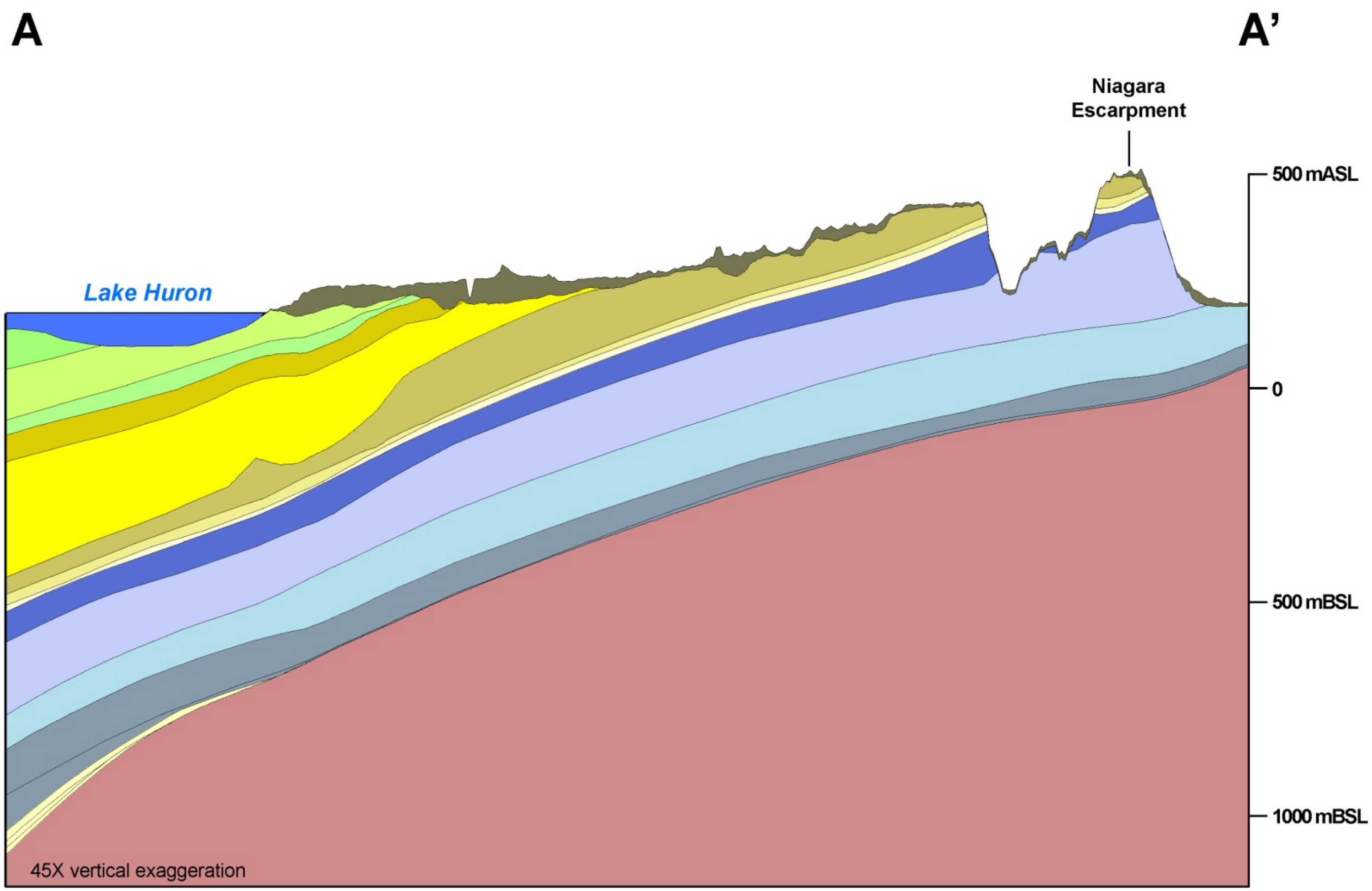
Upper Silurian
- Bass Islands
- Salina
- Guelph

Lower Silurian
- Lockport (Goat Island, Gasport)
- Clinton-Cataract Group (Fossil Hill, Cabot Head, Manitoulin)

Upper Ordovician
- Queenston
- Georgian Bay/Blue Mountain
- Trenton (Cobourg, Sherman Fall, Kirkfield)
- Black River (Coboconk, Gull River, Shadow Lake)

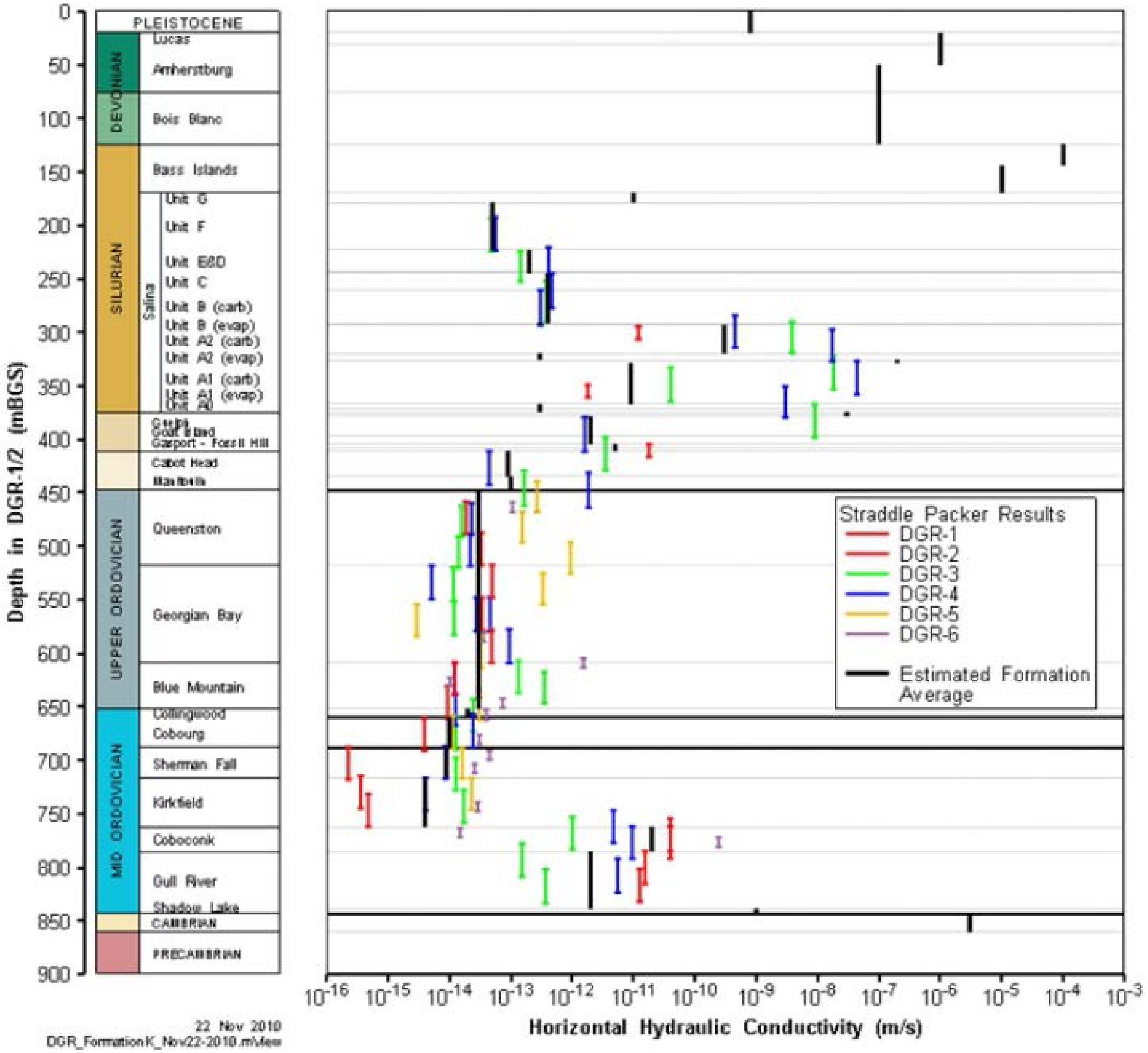
Cambrian
- Cambrian

Precambrian
- Precambrian

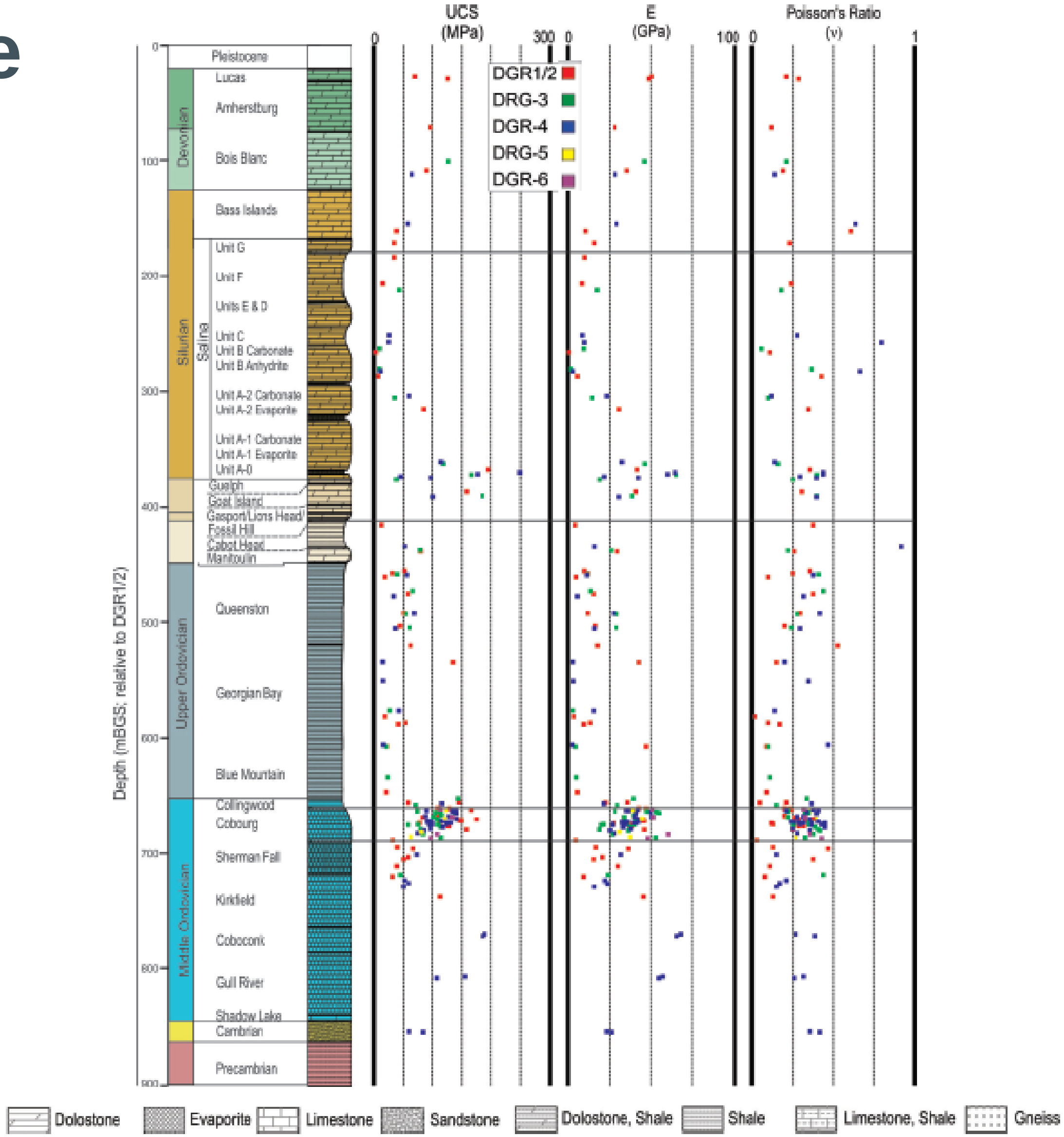


Section is about 150 km long with a <u>45x vertical exaggeration</u>

Hydraulic Testing at the Bruce Nuclear Site



Rock Strength Testing from Bruce Nuclear Site

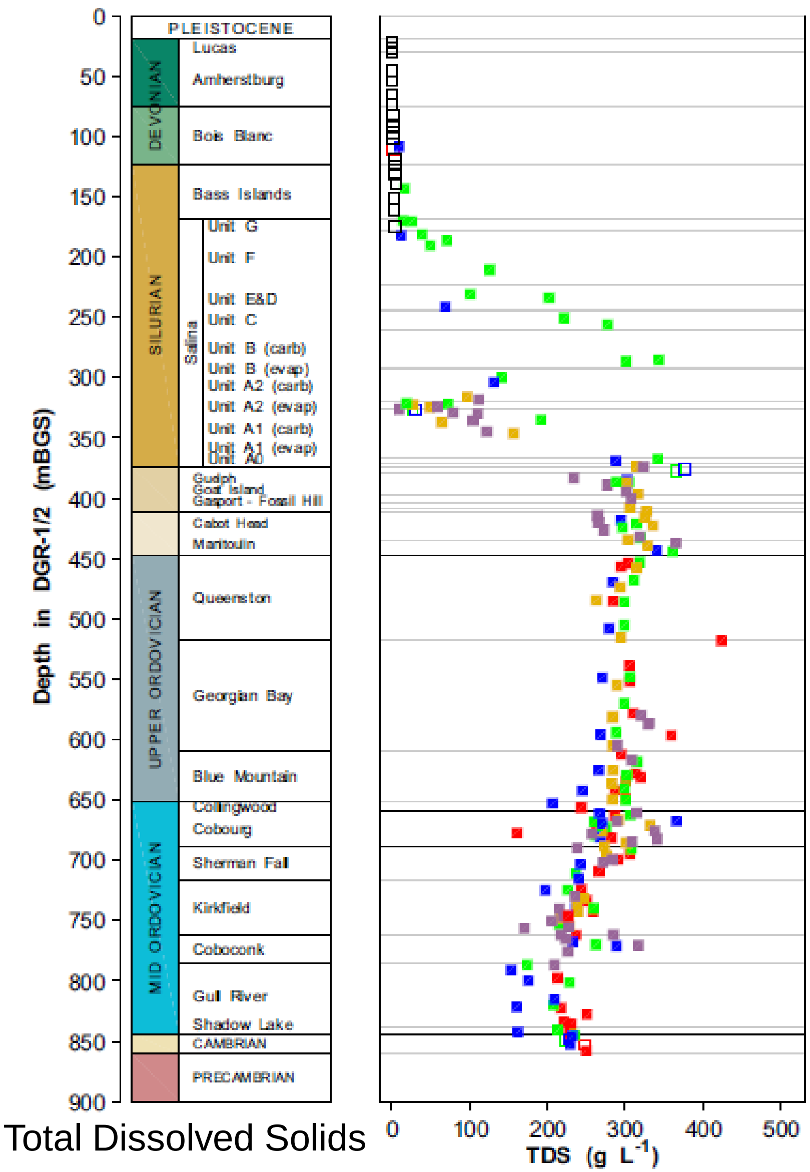


Groundwater and Porewater at the Bruce Nuclear Site

Consistent with Regional Hydrogeochemistry for S. Ontario (NWMO-DGR-TR-2011-12)

A shallow system (<200 mBGS) with fresh through brackish waters. Waters in this system have stable isotopic compositions consistent with mixing of dilute, recent or cold-climate (glacial) waters with more saline waters.

An intermediate to deep system (>200 mBGS) containing brines with elevated TDS values (200-400 g/L). The stable isotopic compositions of these waters are typical of sedimentary basin brines.



TDS = Total Dissolved Solids

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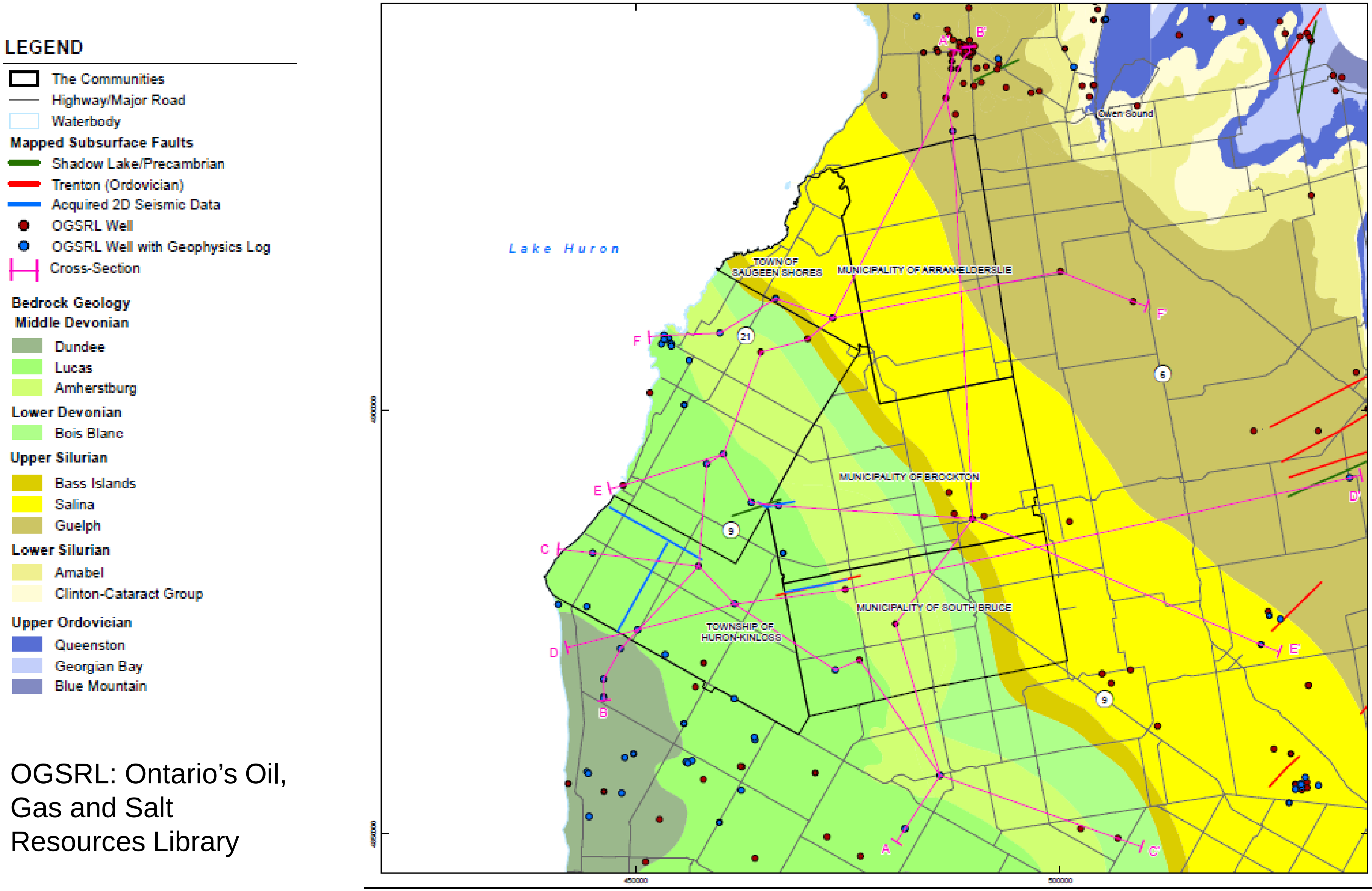
Potentially Suitable Host Rock Formation

- The initial screening (2012) identified the Upper Ordovician shale and limestone units as potentially suitable host rock formations.

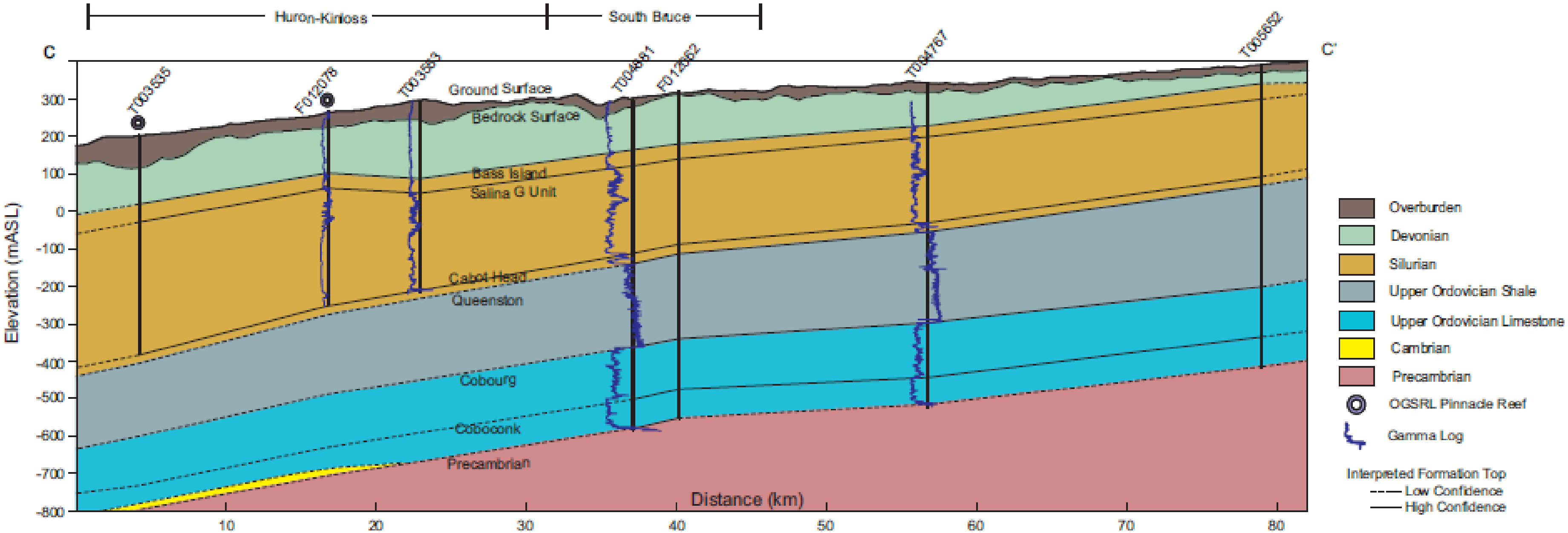
- Based on available geoscientific information, the Ordovician Cobourg Formation (argillaceous limestone) would be the preferred host rock as it has sufficient thickness and volume and favourable characteristics of very low hydraulic conductivity and high geomechanical strength.

Cross Sections and OGSRL Wells



OGSRL: Ontario's Oil, Gas and Salt Resources Library

Cross Sections C-C’



Potentially Suitable Bedrock Formation in Huron-Kinloss

- The bedrock geology beneath the Township of Huron-Kinloss consists of a laterally extensive and predictable Paleozoic sequence.
- Based on contour mapping, the depth to the top of the preferred Cobourg Formation is interpreted to range from approximately 683 mBGS in the northeastern portion of the Township to about 809 mBGS towards its southern portion.
- The Cobourg Formation has sufficient thickness and volume, and has the favourable characteristics of very low hydraulic conductivity and high geomechanical strength.
- Data from OGSRL well F012061 confirms that the Cobourg Formation within the Township is overlain by about 200 m of Upper Ordovician shale formations, which acts as an additional hydraulic barrier.

Potentially Suitable Bedrock Formation in Huron-Kinloss

Adapted from NWMO, 2011. Descriptive Geosphere Site Model, NWMO DGR-TR-2011-24.

Groundwater Age Estimates

The ages of shallow Devonian and Upper Silurian groundwater have been investigated by 14C dating. Although uncertainties exist, the ages range between about 4000 and 8000 years BP, suggesting the groundwater is relatively old Holocene groundwater.

Based on isotope analyses (^{129}I, He) from porewaters in Ordovician shales and the Cobourg Formation, groundwater ages are greater than 80 million years.

Thank you