Quantitative Assessments of Subsurface Energy Transition Opportunities in Nova Scotia

February 3rd, 2024

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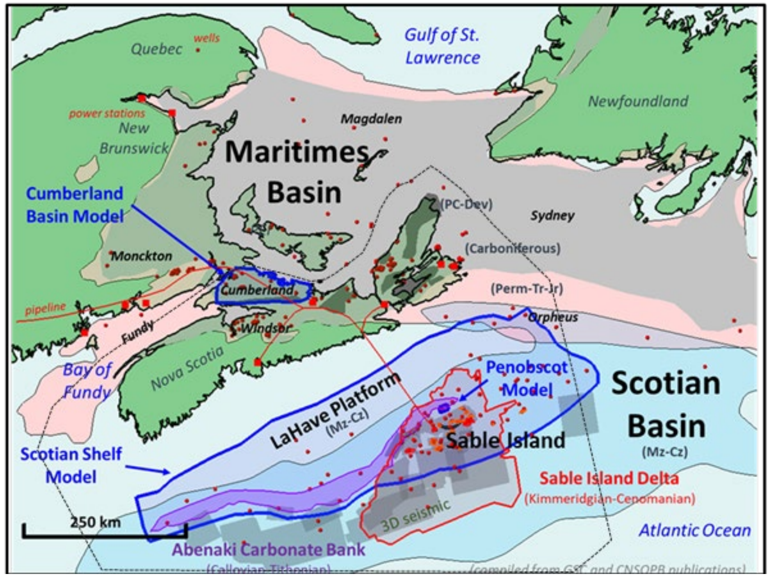
IPCC Special Report on Carbon Dioxide Capture and Storage (2005).
8,000-55,000 Gt capacity in deep saline aquifers (IEA, 2021) ~ 923 Gt capacity in depleted hydrocarbon fields (GCCSI, 2009)

Three Main Topics & Key Points

1. **Geological Carbon Storage** (Dedicated GCS - not EOR or CCUS)

- SCOTIAN SHELF DEEP SALINE AQUIFERS: North Sea – scale : 10s-100s Gt
  - NO NEED FOR STRUCTURAL OR STRATIGRAPHIC TRAPPING ---- BUT DO NEED A REGIONAL TOPSEAL
    - Migrating plume leaves CO2 behind ("RESIDUAL TRAPPING") ➔ Buoyancy decreases
    - ➔ Plume stops ➔ CO2 is immobile in pore centres ➔ Immune to seismicity or well failures



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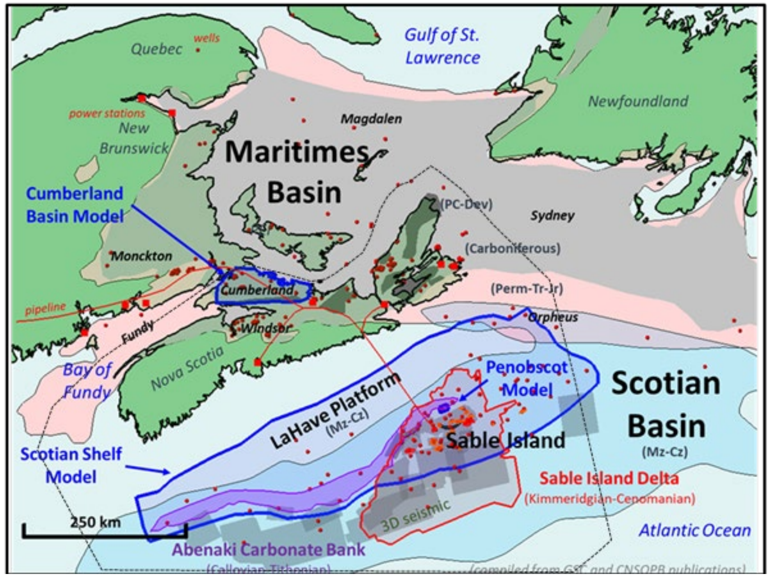
- MARITIMES BASIN: Poor potential: low porosity-permeability and risk of fractured seals



GCS * GCS *****

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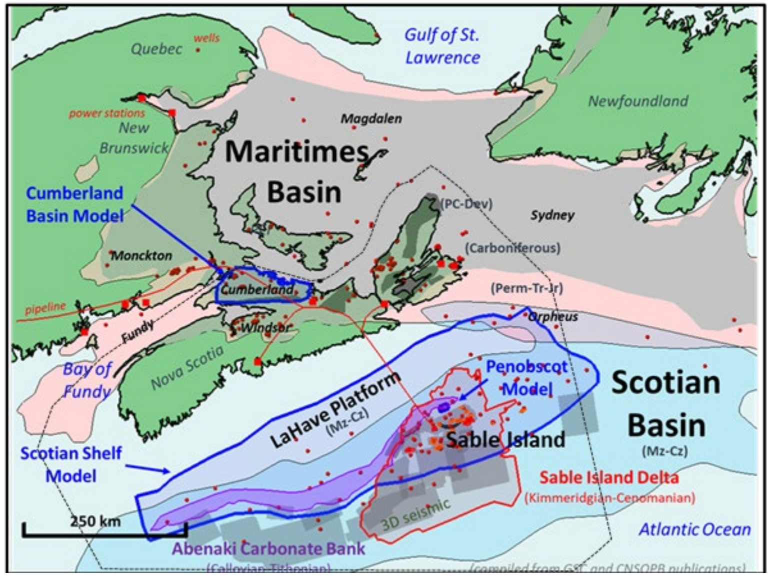
2. <u>Geothermal Power Generation</u> (Not district heating / cooling)

- MARITIMES: (~17-28^{o}C, poor PHI-K): Emerging opportunities - probably closed-loop
- SCOTIAN SHELF: (25-35^{o}C/km, good PHI-K). Expensive – anchored by “Mega-Wind”?



GCS *	GCS *****
Closed Loop ***	Closed Loop *
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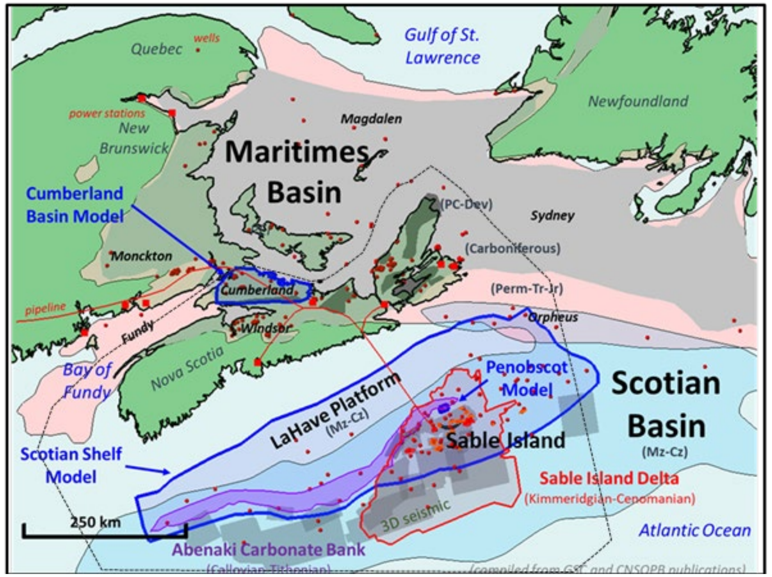
3. **Compressed Air & Hydrogen Storage in Salt Caverns**
   - CUMBERLAND BASIN: Outstanding opportunities load balancing wind power
   - SCOTIAN SHELF: Significant potential – as part of "Mega-wind" Project
     - CAES = Compressed Air Energy Storage; UHS = Underground Hydrogen Storage



Maritimes Basin	Scotian Shelf
GCS *	GCS *****
Closed Loop ***	Closed Loop *
Open Loop *	Open Loop ***
CAES UHS *****	CAES UHS ****

- **Where are we operationally?**
- **What are our best opportunities?**
- **Where are we technically?**
- **What’s needed?**
- **How do we move forward?**

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- **How do we move forward?**

Systematic Progressive Studies:

Conceptual → Qualitative → Quantitative → Economic → Policy & Regs → Commercial

Play & Prospect Inventory:

Play → Lead → Prospect → Drillable Prospect → Success / Failure

Resource Inventory:

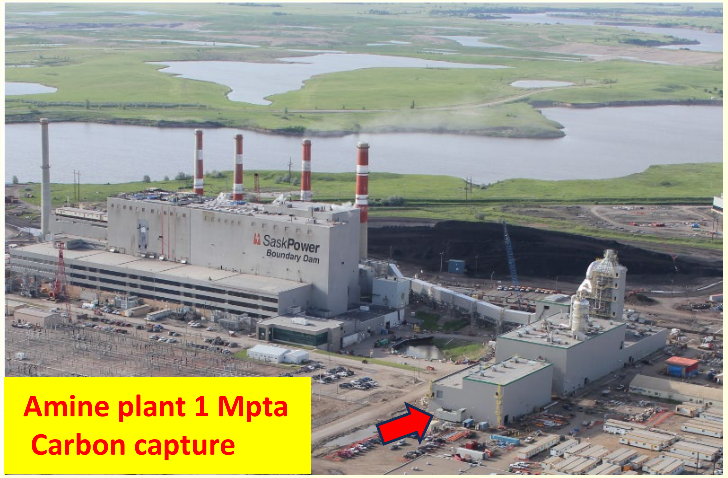
" Prospective" → "Contingent" → "Commercial" → "Stored"

High-Level View: GCS Globally & in Canada

- **Global GHG Emissions ~ 46 Gtpa* CO_2e**   **Canada ~672 Mtpa; NS ~14.9 Mtpa (Gov. Canada; CER, 2020)**
- **Current Global CO_2 Storage 43 Mtpa** (~30,000 tonnes CO_2 & H2S stored at Deep Panuke)
- **Need ~7.5 Gtpa storage by 2050* to meet international obligations**

- 1 Mtpa* is the capacity of 1 world-class carbon storage well (Sleipner, offshore Norway)
- 1 Mtpa is also the capacity of a major carbon capture plant (Boundary Dam ~$500 million)*

Boundary Dam, Saskatchewan, 750 MW



Tuft's Cove, Halifax, 500 MW

*** 10^9 tonnes per annum**
*** 10^6 tonnes per annum**
**** MIT factsheet, 2016***
**** GCCSI, 2022***
**** IEA / GCCSI, 2023***

High-Level View: GCS Globally & in Canada

- 7.5 Gtpa would require ~ 15,000 wells worldwide at ~0.5 Mtpa per well

- Pro-rated: ~220 wells in Canada (5 in Nova Scotia).
  - Capture & Storage would be expensive: ~$110 Billion capture. ~120 Billion infrastructure & wells.
  - Revenues could be higher ~ $420 Billion – at $125 per tonne for 30 years (Carbon Price C$170 in 2030)
  - Canada used 42.5 billion litres of gasoline in 2022

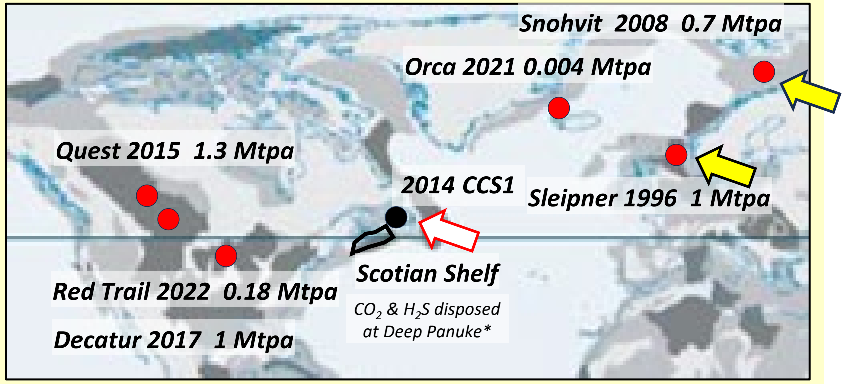
- 220 capture facilities at $500m each
- 220 wells at $50m each
- $10 billion infrastructure every 20 wells

	2020 Emissions	Storage 7.6/46	Storage	Rate per well	Wells	CAPEX						CAPEX	Revenue
						Capture		Wells		Infrastructure		Total	30y - $125/t
	Mtpa		Mtpa	Mtpa		$B / Mtpa	$ Billion	$m/well	$ Billion	$B/20wells	$ Billion		$ Billion
Canada	672	0.165	111	0.5	222	0.5	111	50	11	10	111	233	416
Nova Scotia	15	0.165	2.5	0.5	5	0.5	3	50	0	10	3	5	9

Where are we operationally?

<u>GCS</u>

- **1 unsuccesful GCS project onshore**
  - **CCS 1 well in Cape Breton (no PHI-K)**
- **Sleipner & Snohvit (Norway) are very good analogues for our best opportunity offshore**



Operational GCS Facilities (GCSSI, 2022)
CCS Propectivity (IPCC, 2005)

- 30 CCS plants worldwide (43 Mtpa[1])
- Pore-space land-grabs in Alberta & GOM

*estimated 50,000 tonnes CO2 stored
DPA: 0.18% of produced gas is H2S
DPA: 3.44% is CO2 (but <3% is sales spec.)
147 BCF cum. prod.

[1] GCSSI 2022; [2]2020 figures (CER, 2023)

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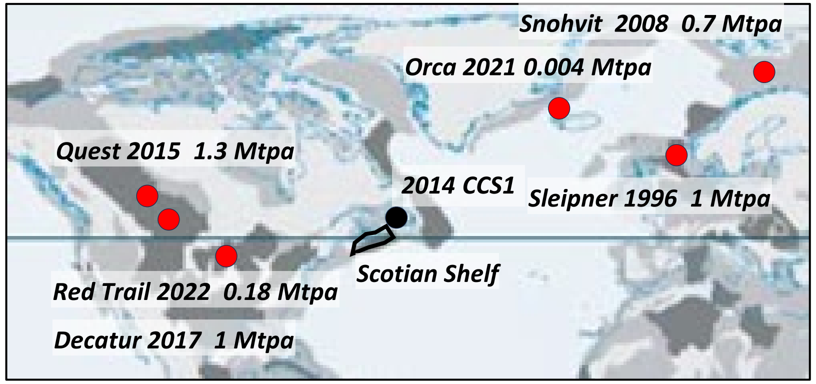

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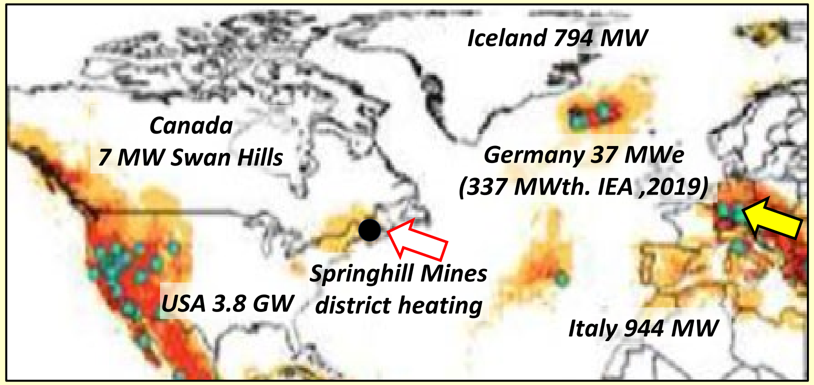
Geothermal Power

- 0 geothermal power generation projects
- Limited by plate tectonics
  - 0 geothermal power plants in Nova Scotia
- North German Basin & Upper Rhine Graben are best analogues (INRS, 2020)



Geothermal Power Generation (Statisa, 2023)
“Suitability” & Power Plants (Como & Trumpy, 2020)

- 175 power plants worldwide[3] (16 GW installed[4])
- 1 in Canada (CER, 2023)

[3] Wikipedia; Huttrer, [4] Huttrer, 2020 (320 x Tuft’s Cove)

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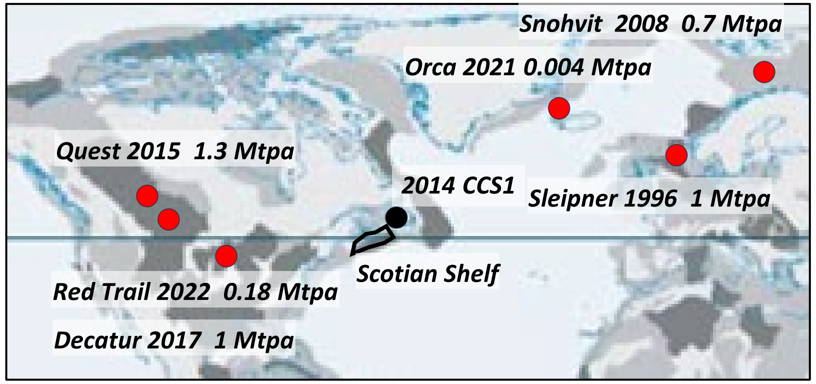

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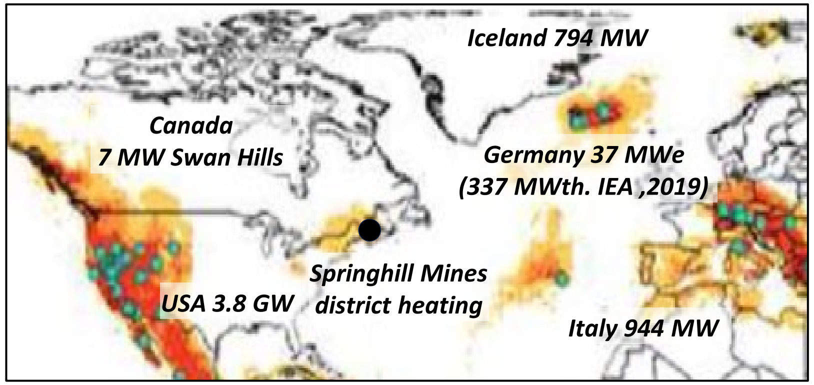

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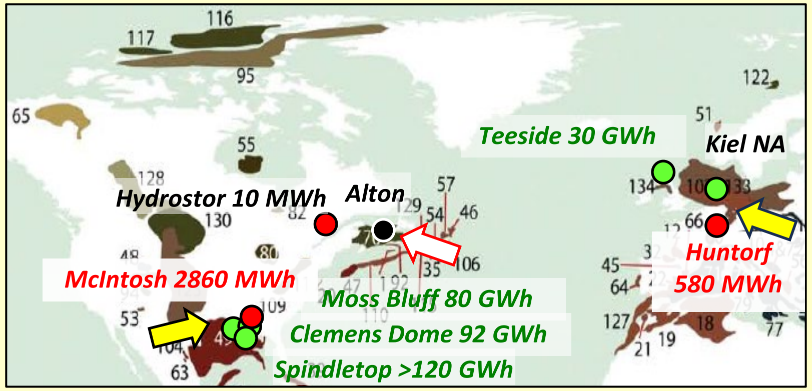
Salt Storage

- 1 unsuccessful storage project in Nova Scotia
  - Alton CH4 storage (community objections)
- 2 large-scale analogues for compressed air and 5 hydrogen in Europe & USA Gulf Coast:
  - UHS much larger energy storage capacity than CAES

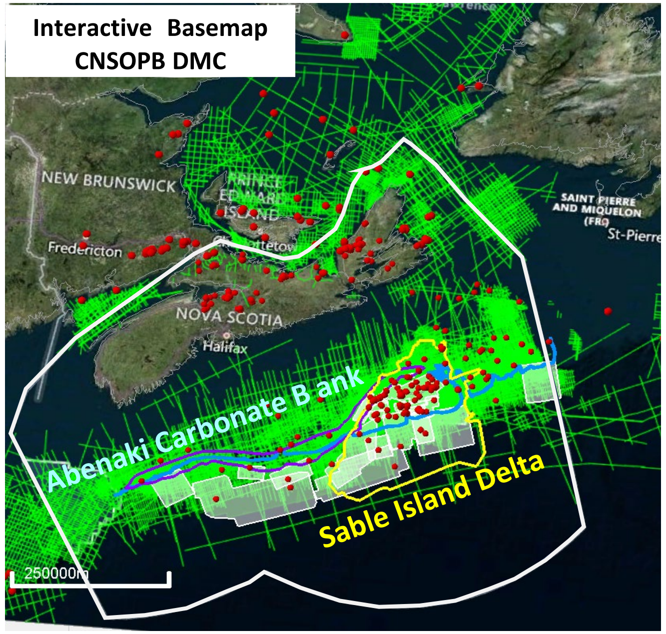


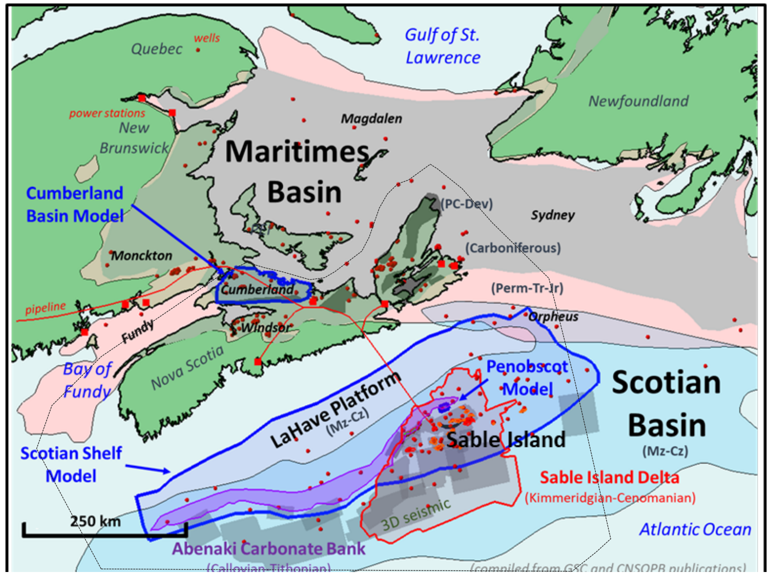
CAES & UHS Energy Storage in Salt Caverns
Halite-entraining Basins (Warren, 2010)

- 2 major CAES salt plants worldwide (3.4 GWh)[3]
- Plus Hydrostor in Ontario (10 MWh)[3]
- 4 UHS salt plants worldwide (>202 GWh).[5]
- + 3 in aquifers, + 2 in depleted gas reservoirs[5]
- ~750 Total Underground Storage facilities (2017[6])
- 104 salt caverns, 75 aquifers. 492 depleted fields

[5] Jahanbakhsh, 2024; [6] Cedigaz, 2017

Where Are We Technically?





Compiled from GSC & CNSOPB publications

Excellent regional data base

- ~**470** wells (>27,000 drillholes in NS database)
- **26** HC fields, seeps, salt mines, coal mines
- 2D & 3D seismic data

Excellent legacy studies and modern studies

- SOEP, LASMO, ENCANA Field development plans
- GSC, NS DNRR, CNSOPB, OERA / NZA
- **Beicip-Franlab, INRS, Petrel-Roberston, AEGIR, Dunsky**
- Dalhousie, St. Mary's etc

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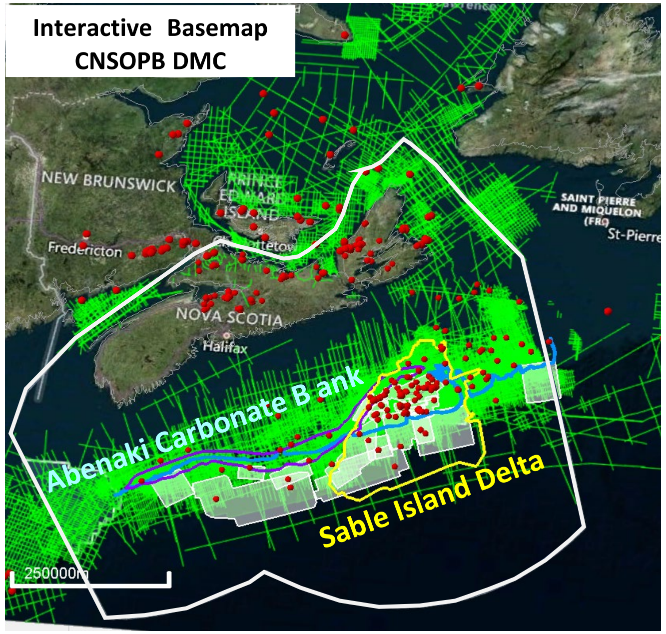

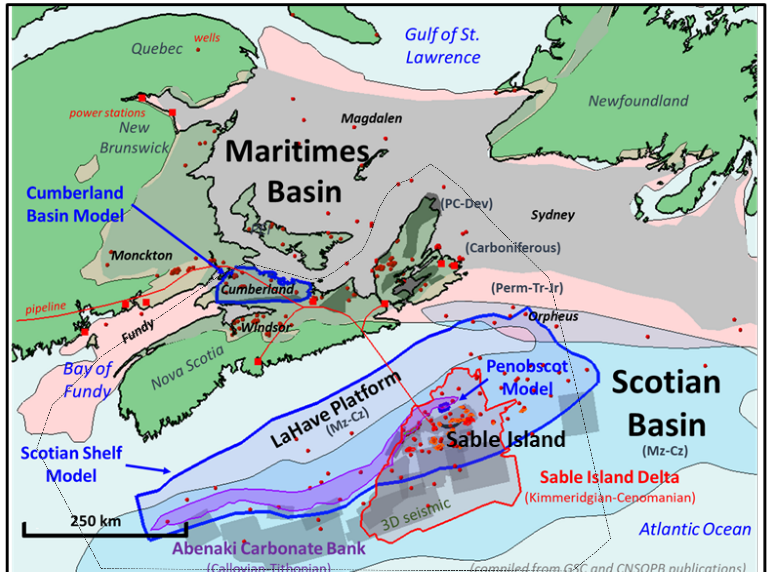

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Key Online Data Bases

- **CNSOPB Data Management Centre**
- **GSC BASIN DATA BASE**
- **Rock Quality Maritimes Basin: GSC Bibby & Shimeld, 2000**
- **Rock Quality Scotian Basin: Beicip PFAs 2011, 16,17,23**

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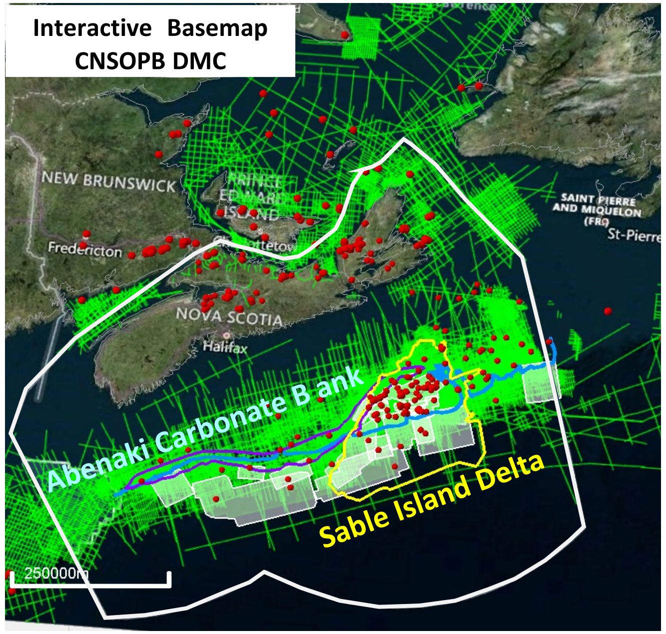

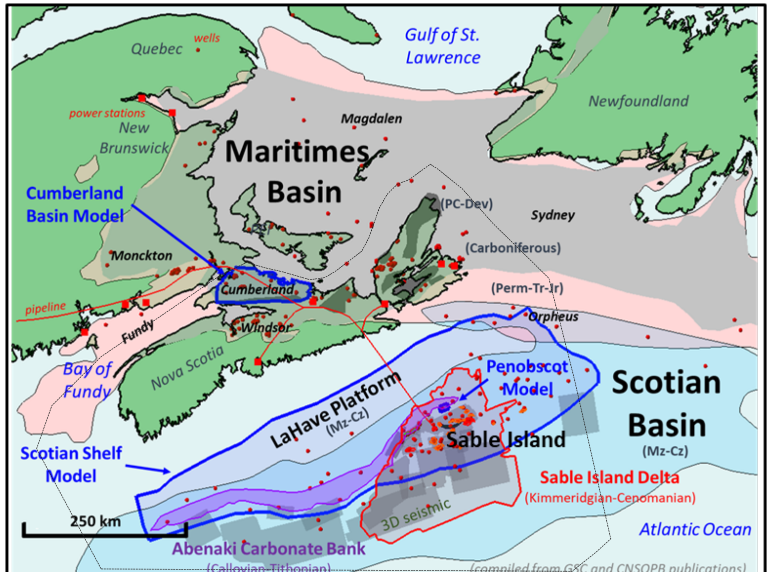

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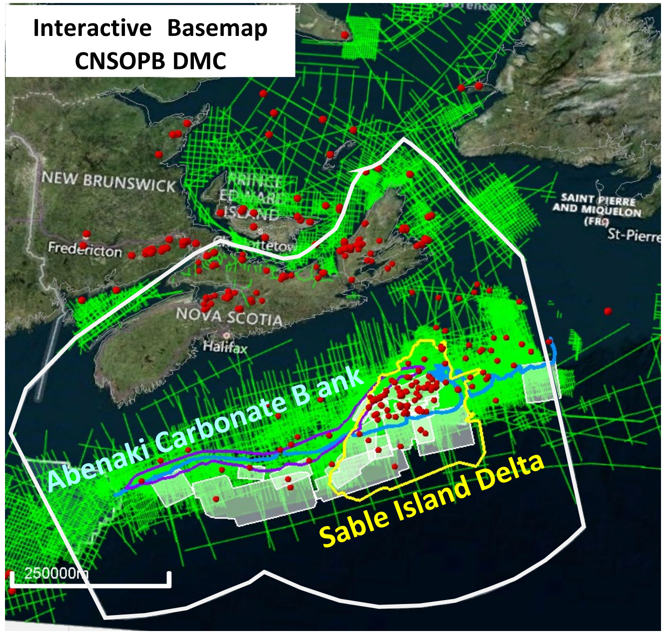
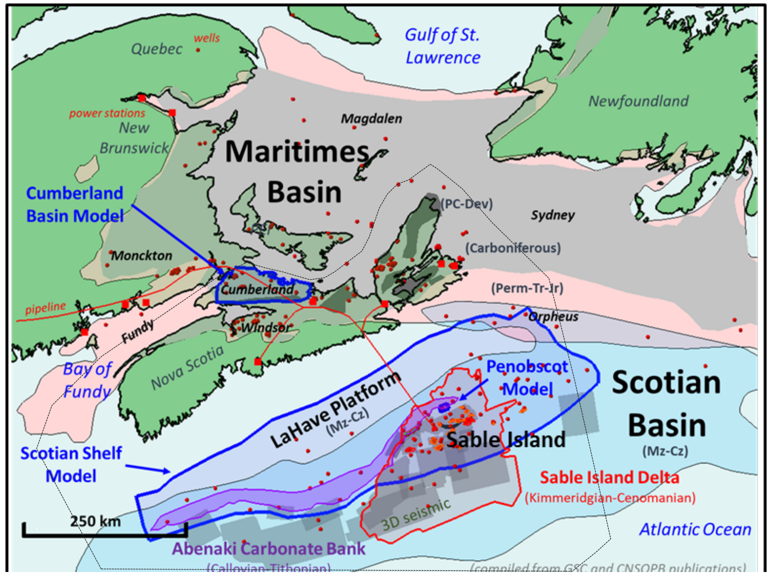
Key Regional Studies

- **Carbon Storage Studies: mostly Qualitative**
  - Bachu, 2003, IPCC, 2005; Wach et al, 2010, GSC 2023,
  - **Exceptions: dynamic modeling pre-CCS1 & O'Connor, 2019; 2021 DNRR, Dal., EAGE static models**
- **Geothermal Studies: mostly Quantitiative**
  - Grasby et al, 2012; INRS, 2020; **Dunsky 2023 (GSHP)**
- **Onshore Salt:** Boehner, 1986;
- **Offshore Salt:** CNSOPB SCOPE & PFAs
- **Load-balancing idea:** Dusseault & Wach (2020)
- **Maritimes Basin:**
  - e.g., Gibling et al, 2019. 2016 Sydney Basin PFA
  - DNRR well & seismic schedules, geol. mapping

  Magdalen Basin:
  - e.g., GSC (Atkinson et al), 2023
- **Sydney Basin:**
  - e.g., OERA Beicip- Franlab PFA, 2016
- **Fundy Basin:**
  - e.g., Wade et al, 1996
- **Cumberland Basin:**
  - **e.g., Waldron et al, 2005 & 2013**
- **Scotian Basin:**
  - **Awesome 1991 GSC Atlas & 2011 Beicio-Franlab PFA**
  - **Almost all shelf exploration wells drilled before 1991**

What's Needed?





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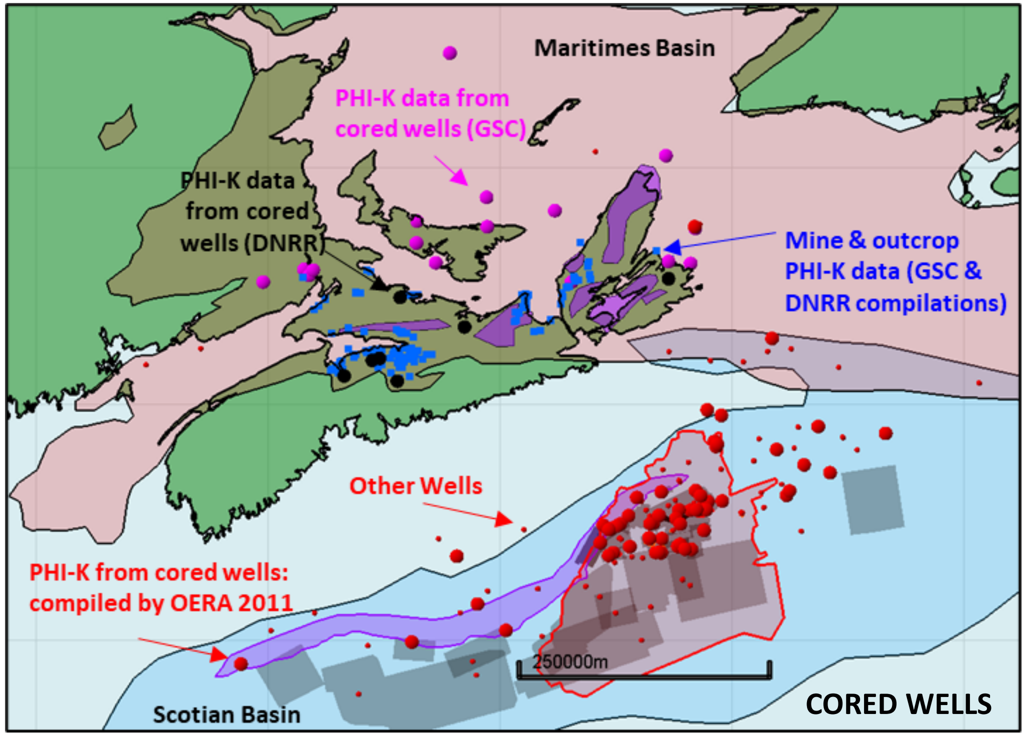
Static & Dynamic Geocellular Models, Maps & Quantitative Assessments

Energy Transition "Play Elements"

- **Rock Quality: Reservoirs / Aquifers: effective porosity–permeability (PHI-K),**
- **Rock Quality: Seals / Fractures**
- **Structure**
- **Temperature**
- **Pressure (+ need pressure management regulations in addition to pore-volume regs.)**

Reservoirs / Aquifers (DNRR & Dalhousie) – Legacy Data

- Lots of core data and petrophysics
- Nice depositional pattern maps from wells & seismic
- Need models & porosity–m and permeability–m maps



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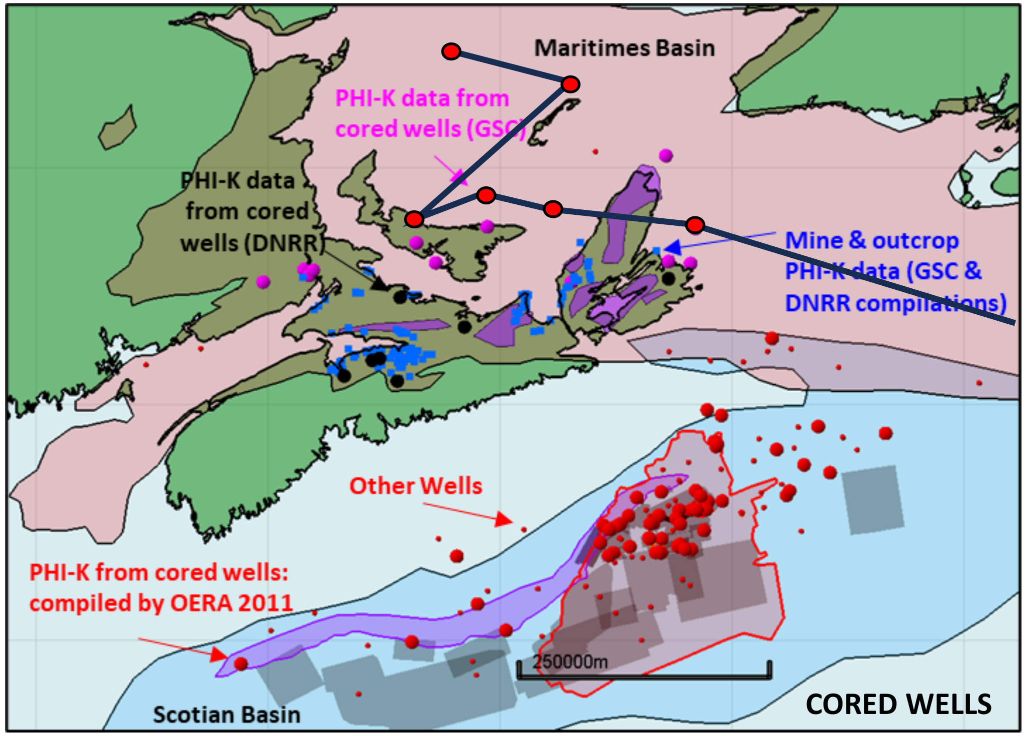
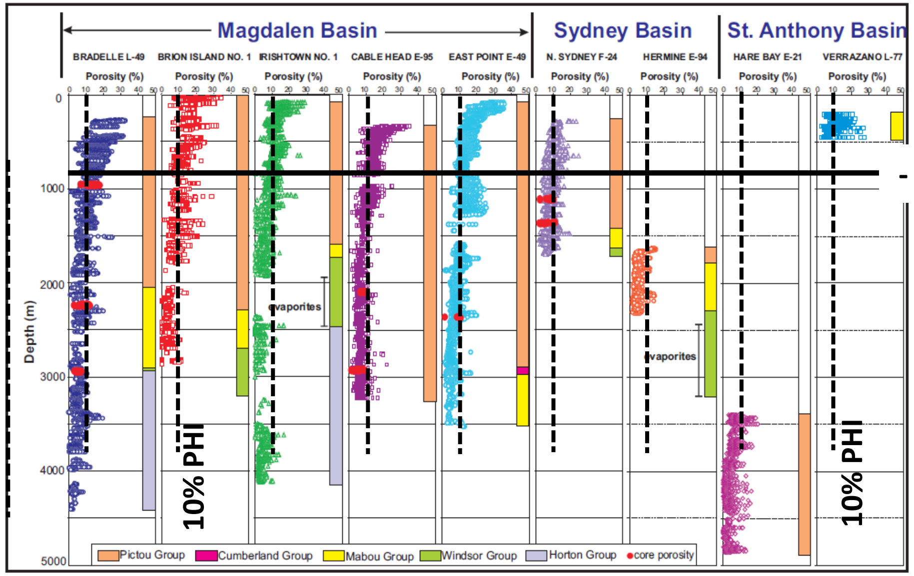


Maritimes Example – Core & Log Porosity : Hu and Dietrich (2010)

- Rapid porosity degradation with depth – sporadic secondary porosity
- Lack of connectivity - problematic for GCS (pressure) & open-loop (recharge)



10-30% porosity above

- 800m supercritical CO_2 depth

< 10% porosity below

- Spotty secondary porosity >10%
- Connectivity issues?
- Pressure consequences?

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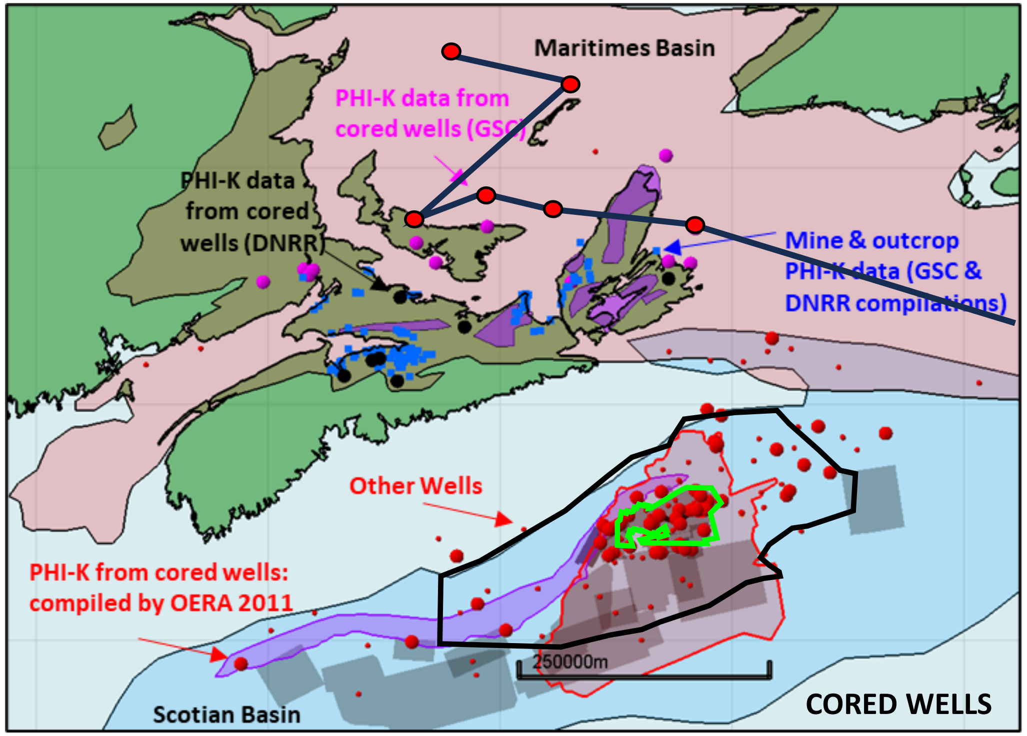

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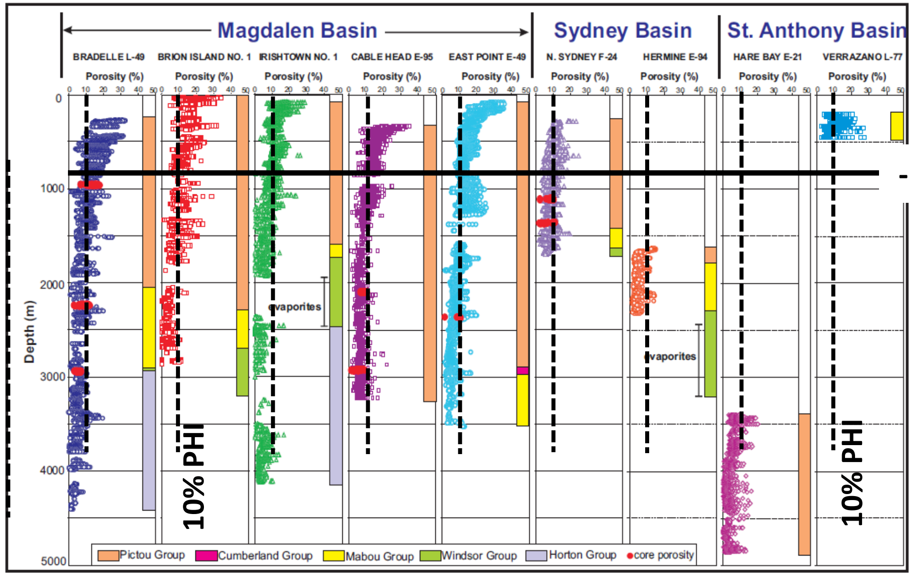

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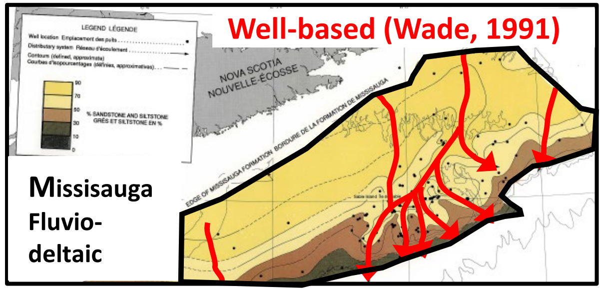
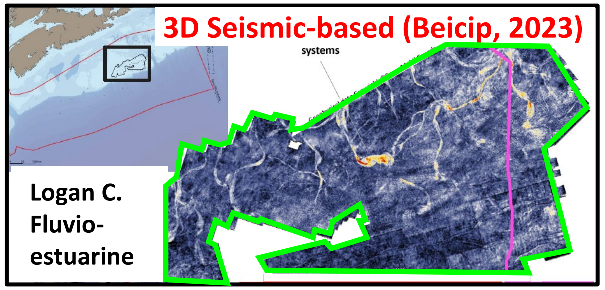
Scotian Shelf Examples: 1991 GSC Atlas & 2023 Beicip-Franlab

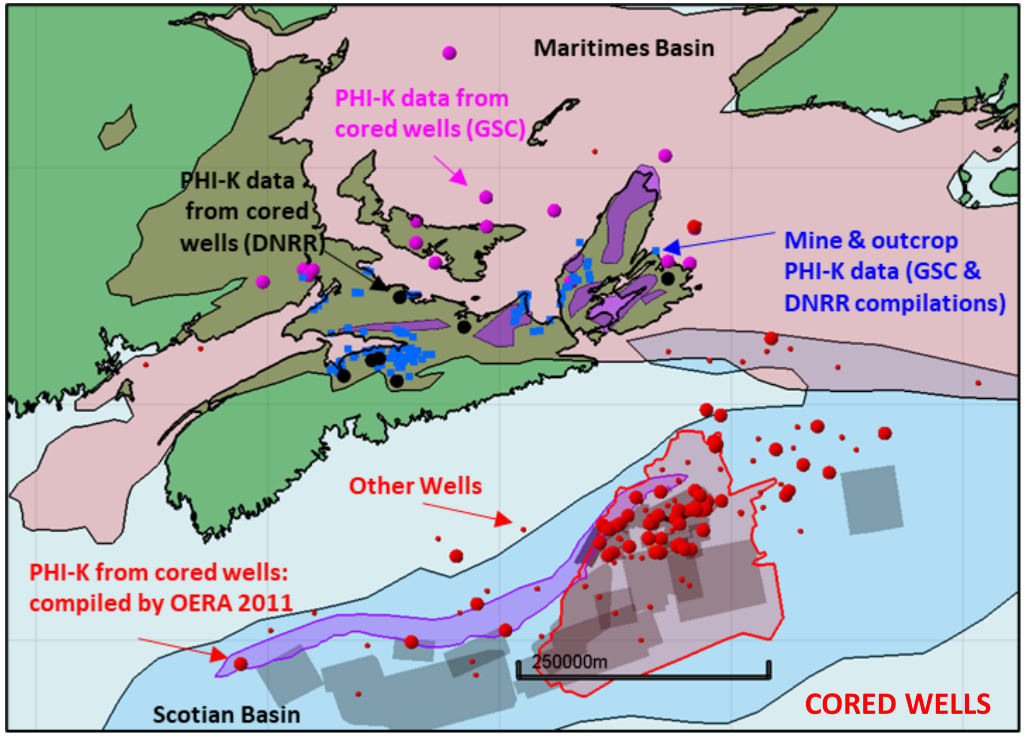
- Excellent regional structure & depositional patterns
- Channel systems might provide updip leakage conduits for CO_2

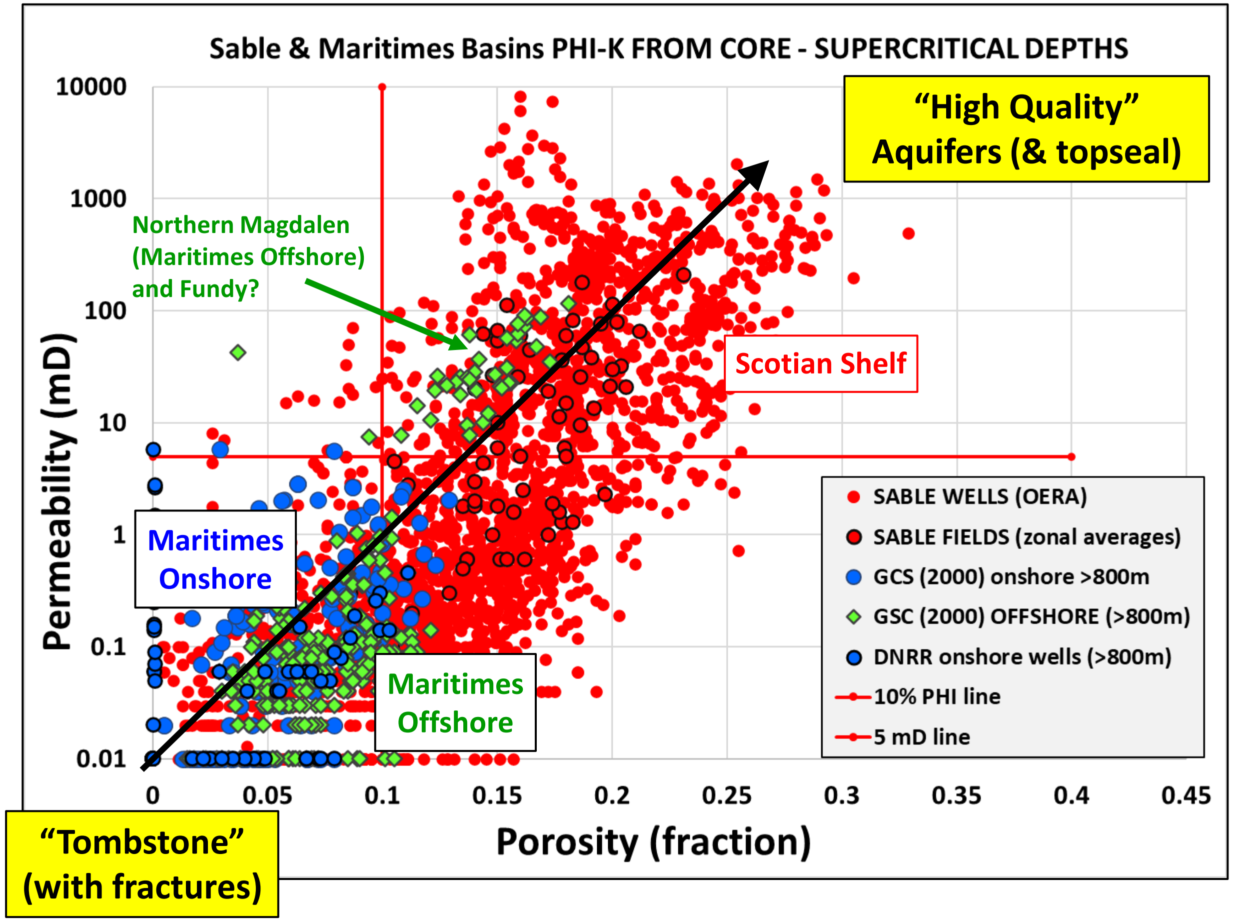




Reservoirs / Aquifers (DNRR & Dalhousie) – PHI-K Data from Cores

- Core Data

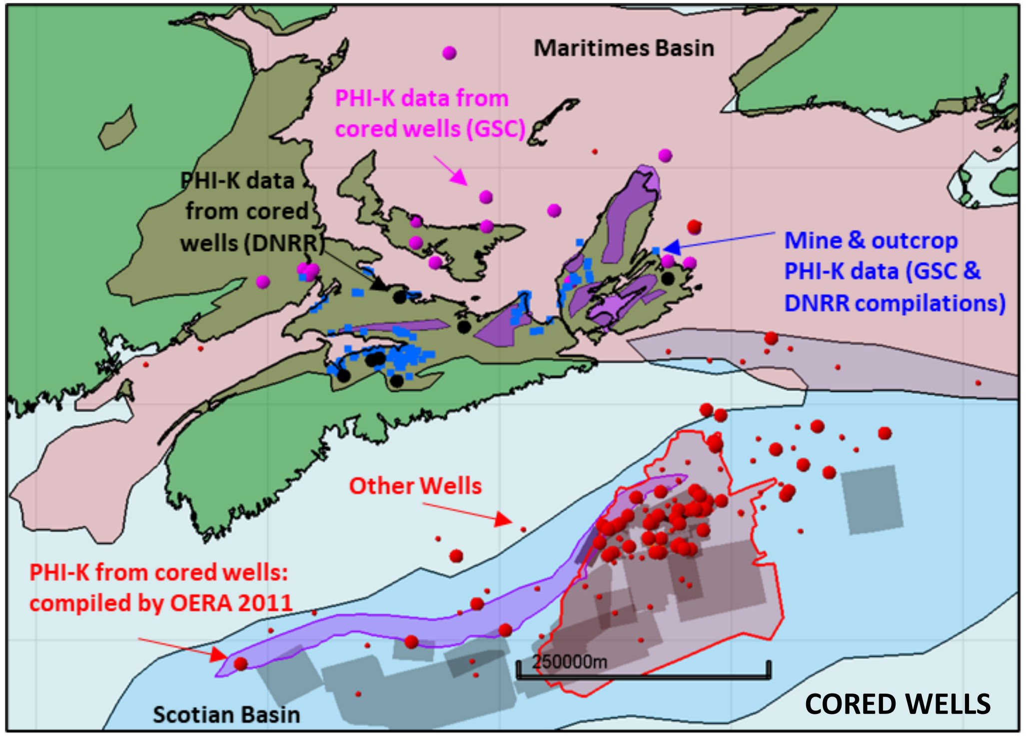


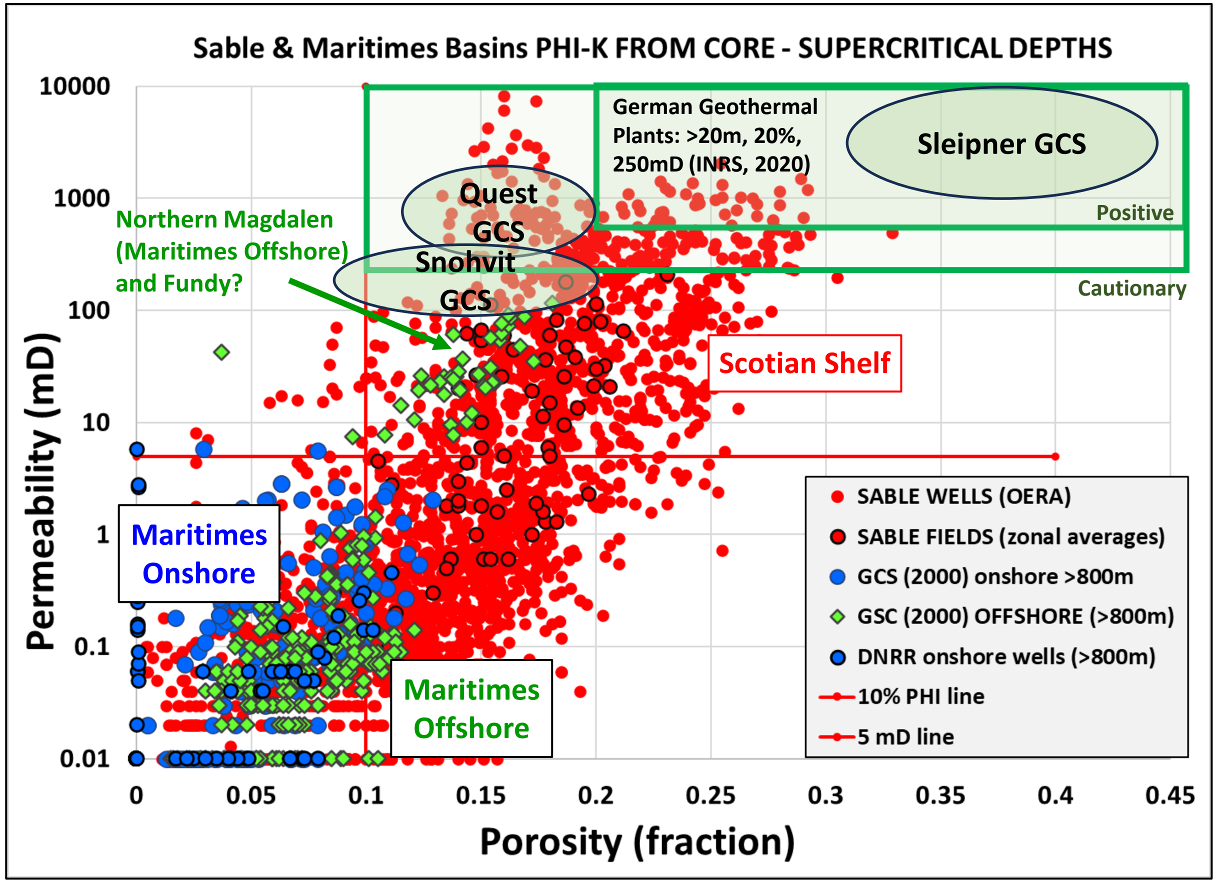


- Scotian Shelf:
  - World-class aquifers (& also topseal - Cenozoic muds and marls)
- Maritimes Basin:
  - Challenged aquifers (PHI-K) and seals (open fractures?)
  - indirect evidence from & pressure / stress data

Reservoirs / Aquifers (DNRR & Dalhousie) – Best Practices / Operational Projects

- **Core Data**





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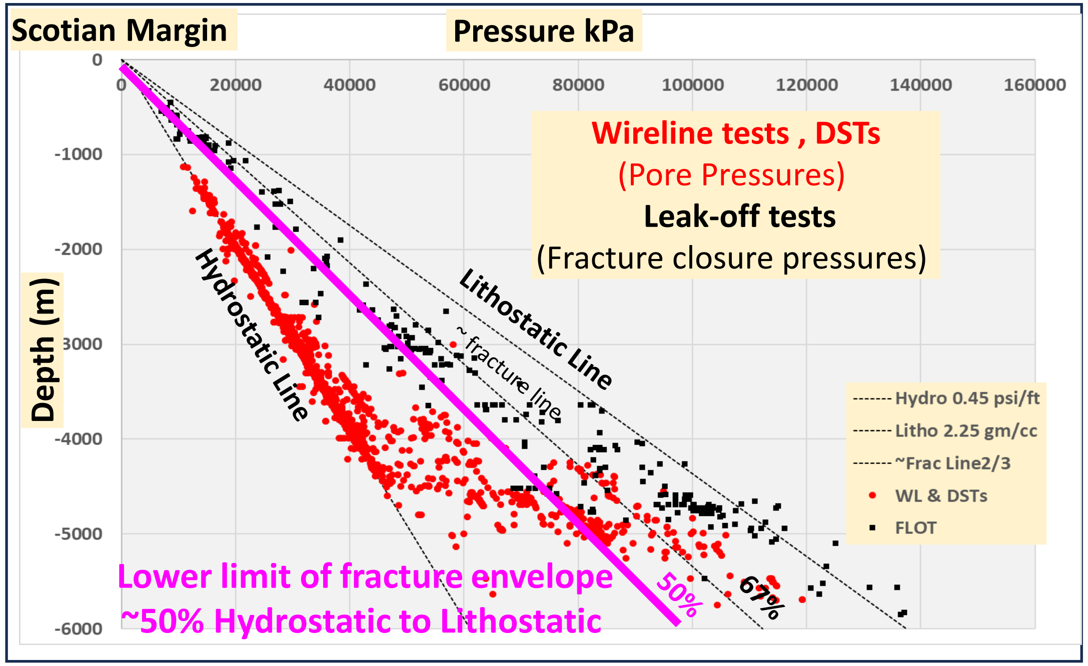
BEST PRACTICE FOR THE STORAGE OF CO2 IN SALINE AQUIFERS
Chadwick et al, 2008. (BGS & NERC & multiple organizations)
Positive Indicators : >50m, >20% phi, > 500mD
Cautionary Indicators: <20m; <10% phi, <200mD

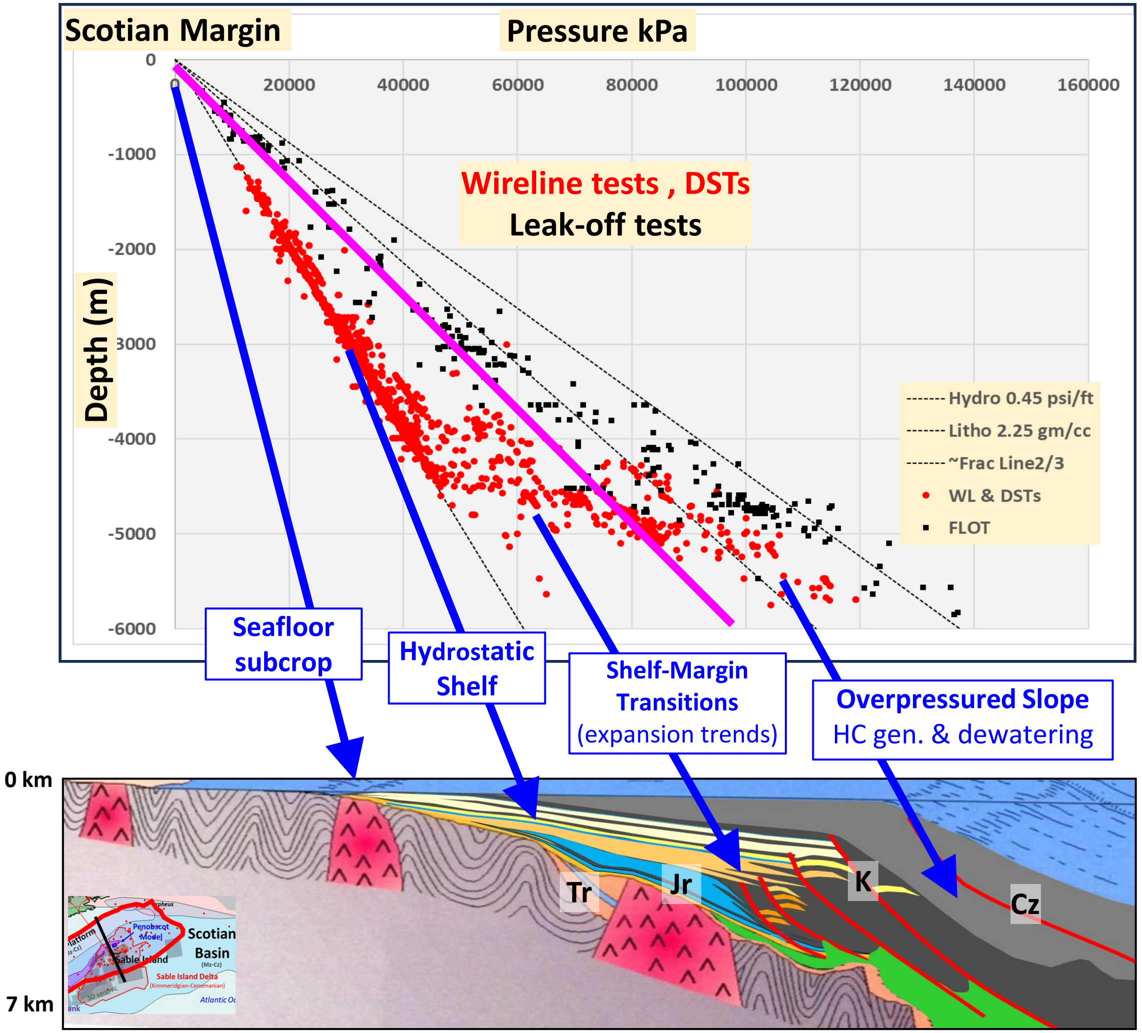
Pressure Data - Scotian Margin



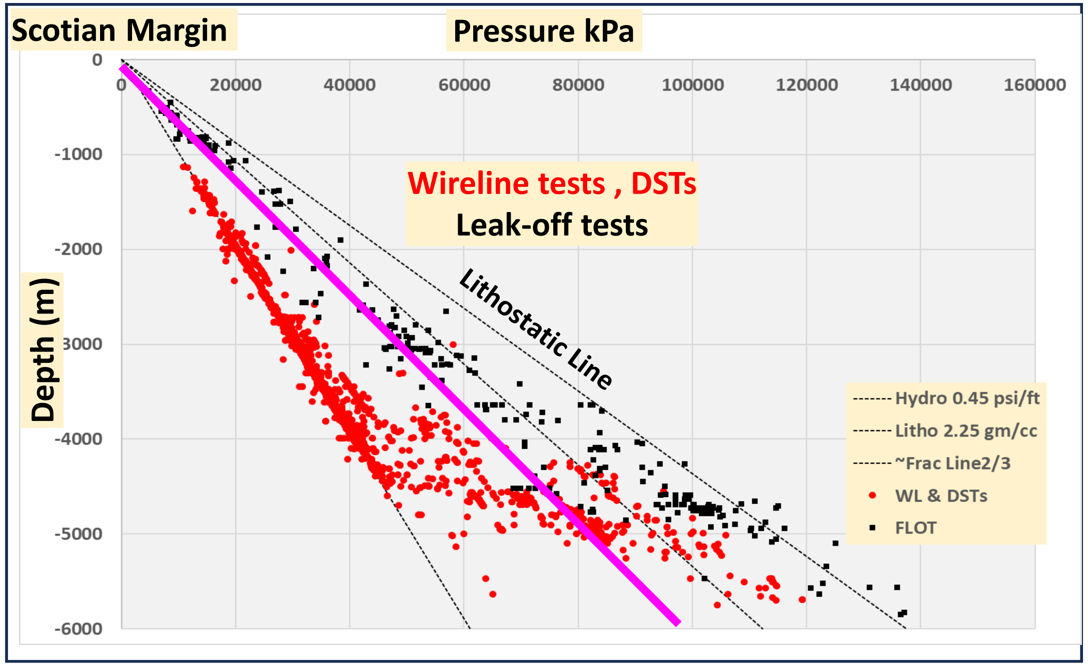
Scotian Margin:

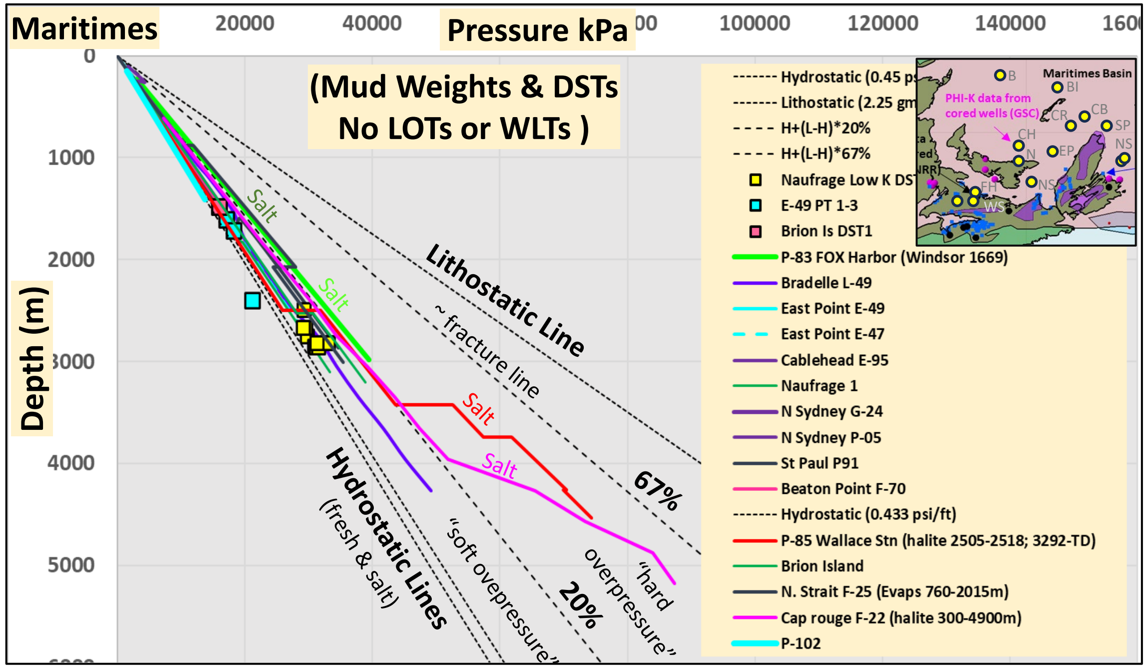
- **Excellent data set – wireline tests & leak-off tests**
- **Leak Off Tests indicate lower limit of fracture envelope may be ~ ½ way between hydrostatic and lithostatic lines**
- **Important RATIO for GCS injectivity and containment - and capacity**

Pressure Data - Scotian Margin



Pressure Data - Scotian Margin & Maritimes Basin





Scotian Margin:

- Excellent data set – wireline tests & leak-off tests
- Leak Off Tests indicate lower limit of fracture envelope may be ~ ½ way between hydrostatic to lithostatic lines
- Well understood system – from pressure entry to exit

Maritimes Basin (from wireline log headers & well reports):

- Much more limited data set – harder to understand

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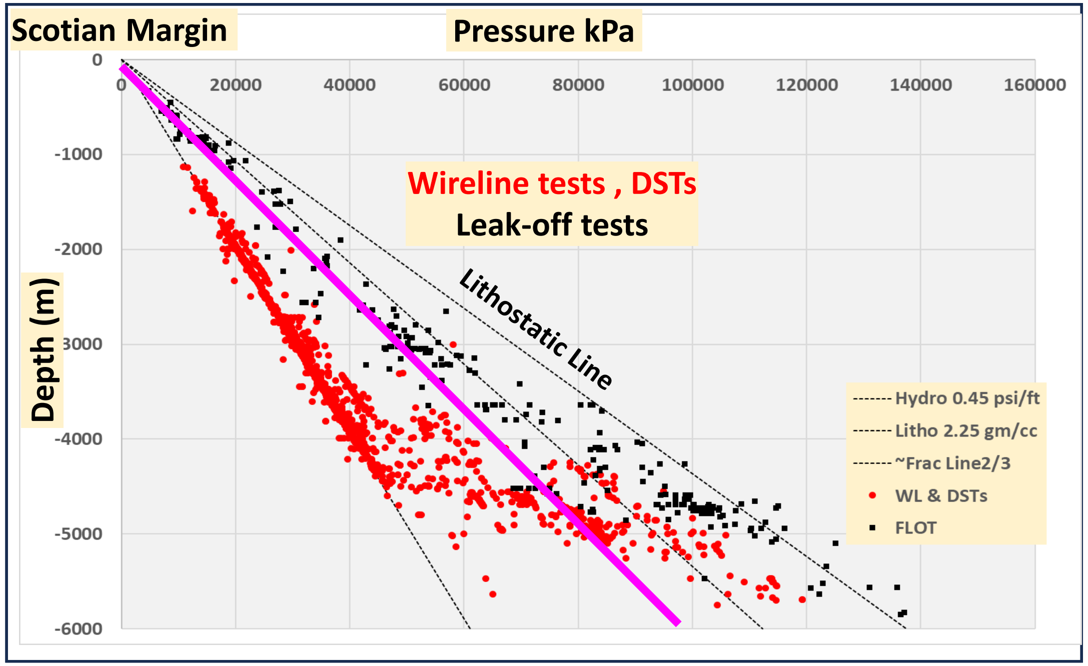

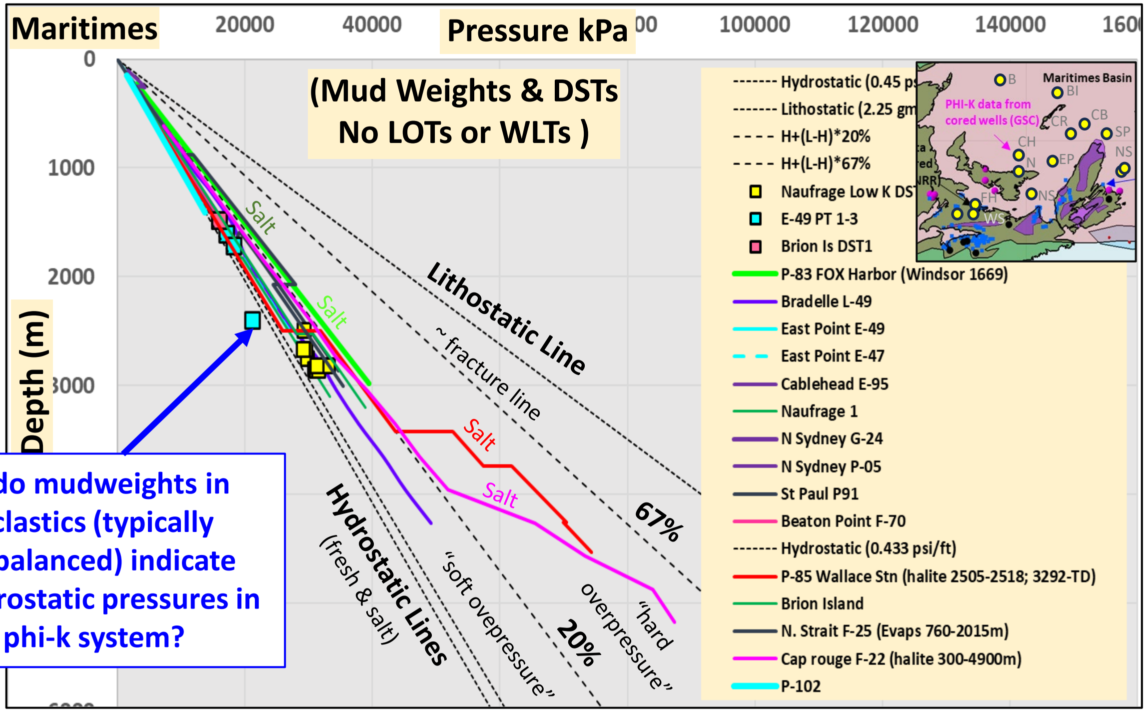

Why do mudweights in silici-clastics (typically over-balanced) indicate ~ hydrostatic pressures in a low phi-k system?

Scotian Margin:

- Excellent data set – well understood system
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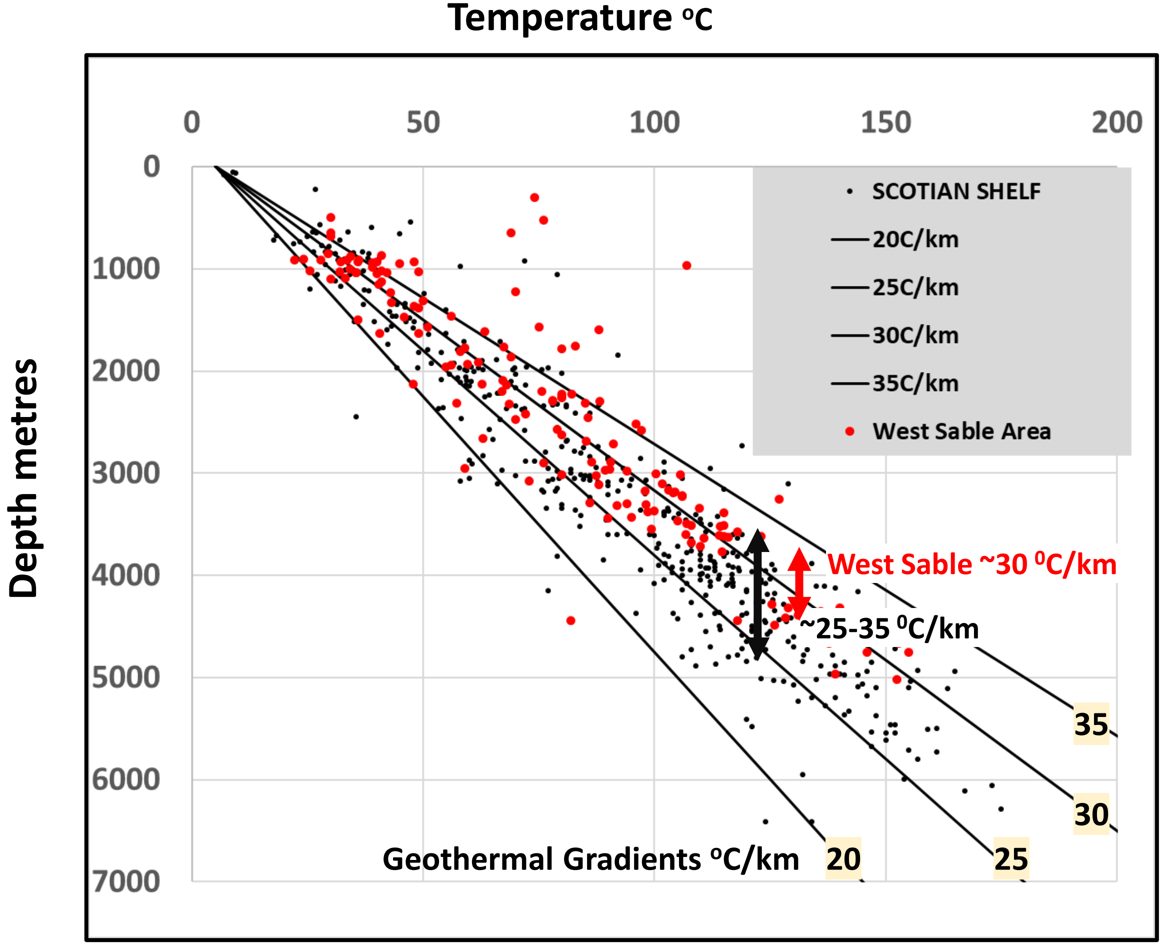
- Well understood system – from pressure entry to exit

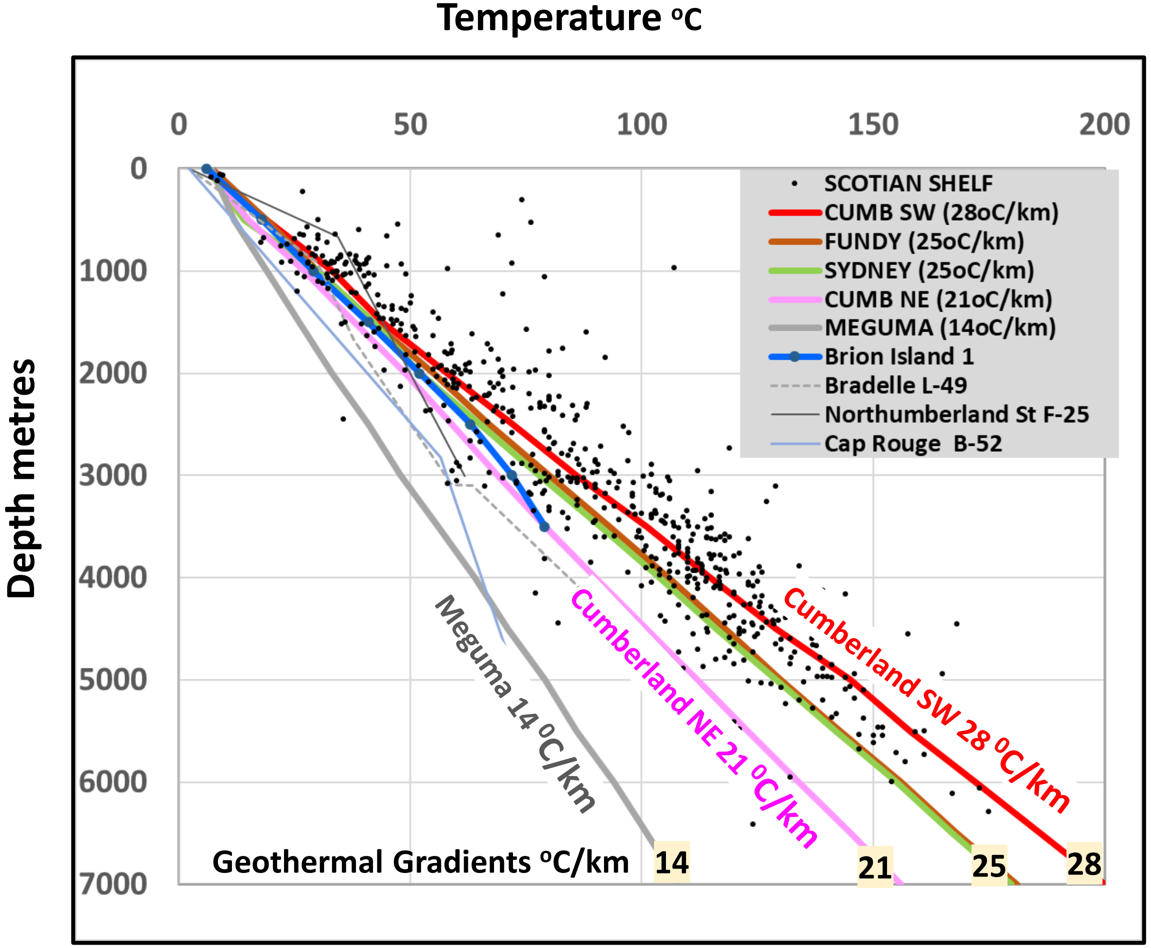
Maritimes Basin (from wireline log headers & well reports):

- Much more limited data set – harder to understand
- Long-term Darcy equilibration following structural inversion (200 m.y. +)?
  - Pervasive or local open fractures?
  - Trans-tensional segments in strike-slip regime – or salt-related extension
- Risk - too fractured for GCS containment?

  - not enough fracturing for open-loop geothermal recharge?

Temperature Data - Scotian Shelf, Maritimes Basin and Meguma





Scotian Shelf:

- Edited but uncorrected – from BASIN
- ~25-35 ⁰C/km (underestimate)
- West Sable area ~30 ⁰C/km

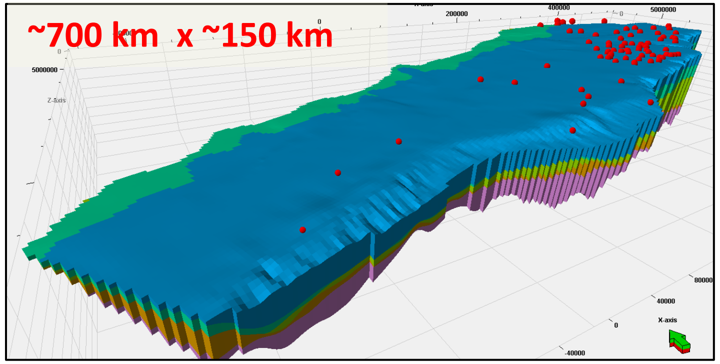
Meguma And Maritimes Basin (INRS Report , 2020):

- Maritimes 21-28 ⁰C/km (corrected)
- Brion Island (Raymond et al, 2022)
- Magdalen wells BHTs from logs

Scotian Shelf: 3D Modeling

Scotian Shelf Model

- **Multiple versions Dal., DNRR, EAGE**



Structural Framework

- **Built from published OERA 2011 & GSC 1991 horizons**
- **7 horizons, 6 zones, 750 layers**
- **2 km x 2 km; 32 million cells**

Porosity – from 80 + wells & core

- Populated with sonic porosity
- ~ 60% of pore volume in Sable Island Delta
- applied Vshale & 10% phi cut-offs

Temperature & Pressure – 120 wells

- Populated from GSC BASIN data base
- Temps not corrected (underestimated)
- Pressures from mud weights (overestimated)

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Scotian Shelf Model

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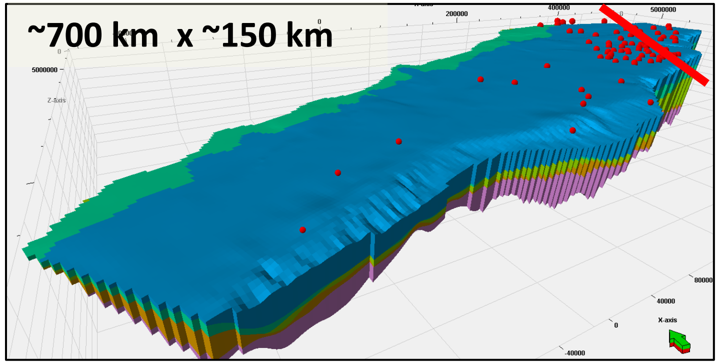

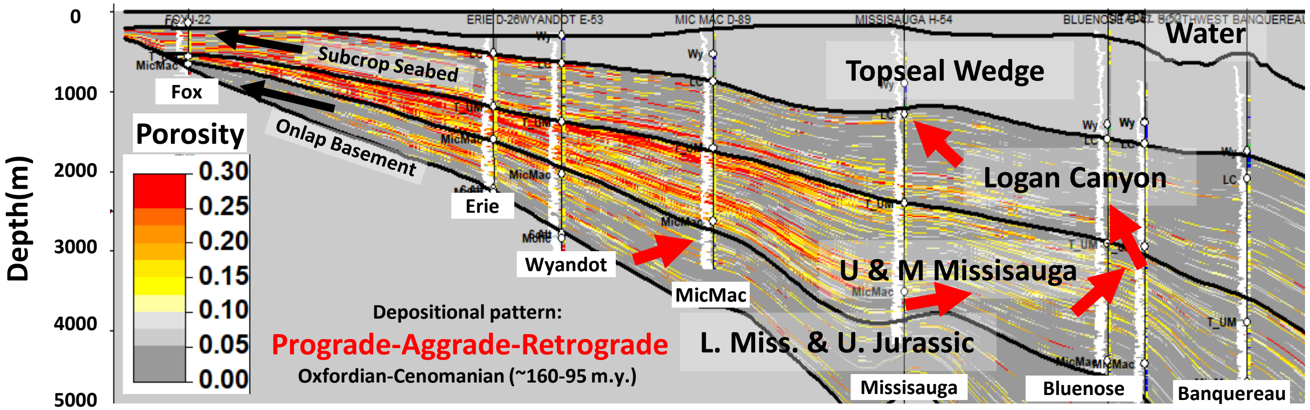

Effective Porosity

- Fundamental for GCS & geothermal
- Storage Volume & Connectivity - Injectivity are key
- And topseal (containment)

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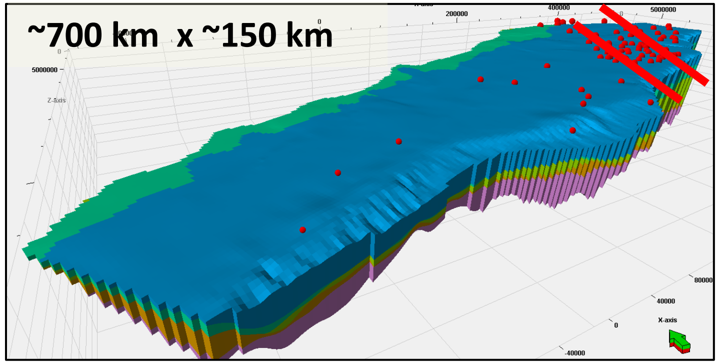

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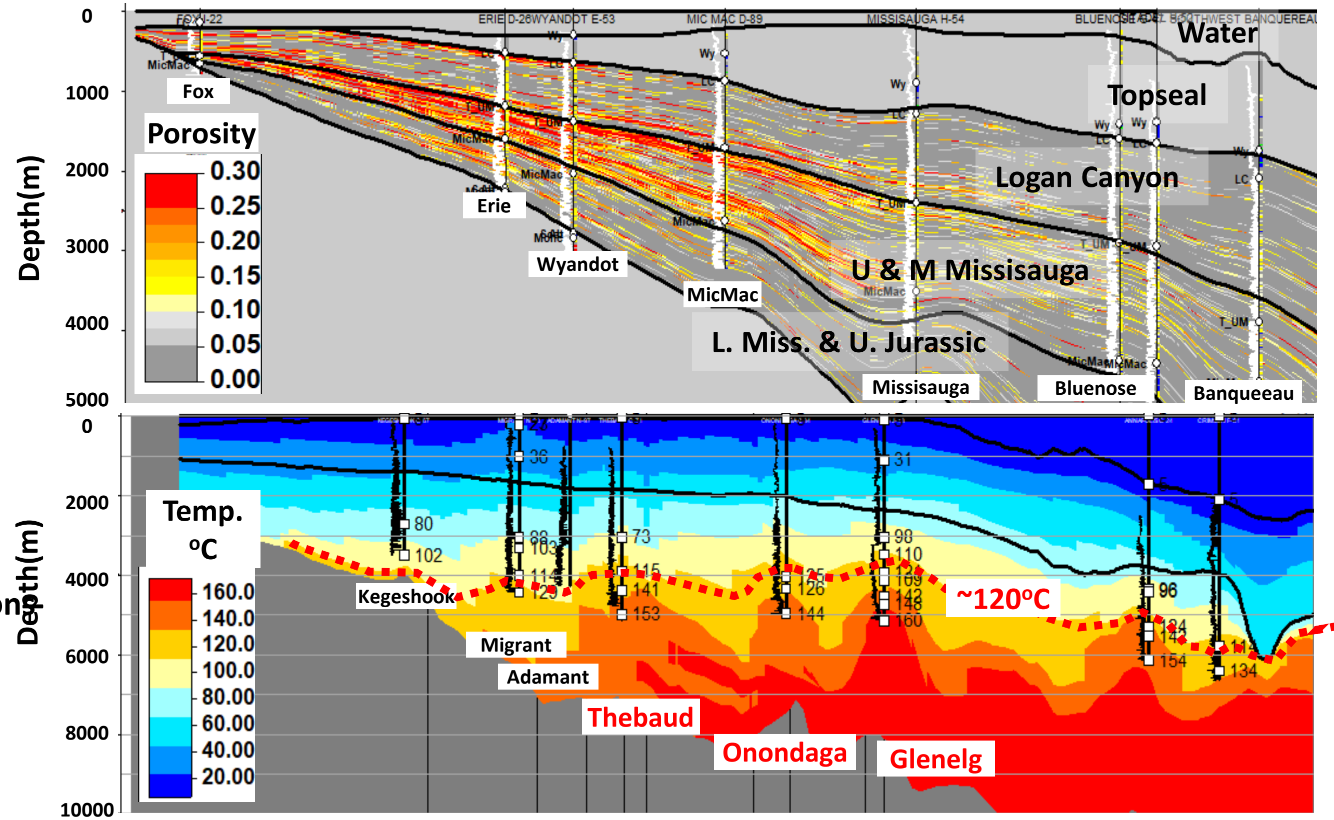

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- **Need ~ 80-120ºC for binary power plants**

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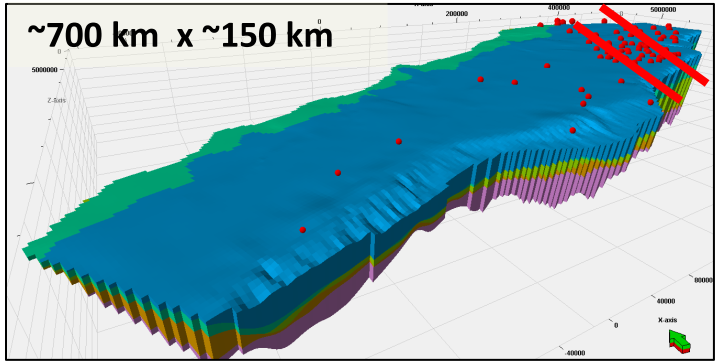

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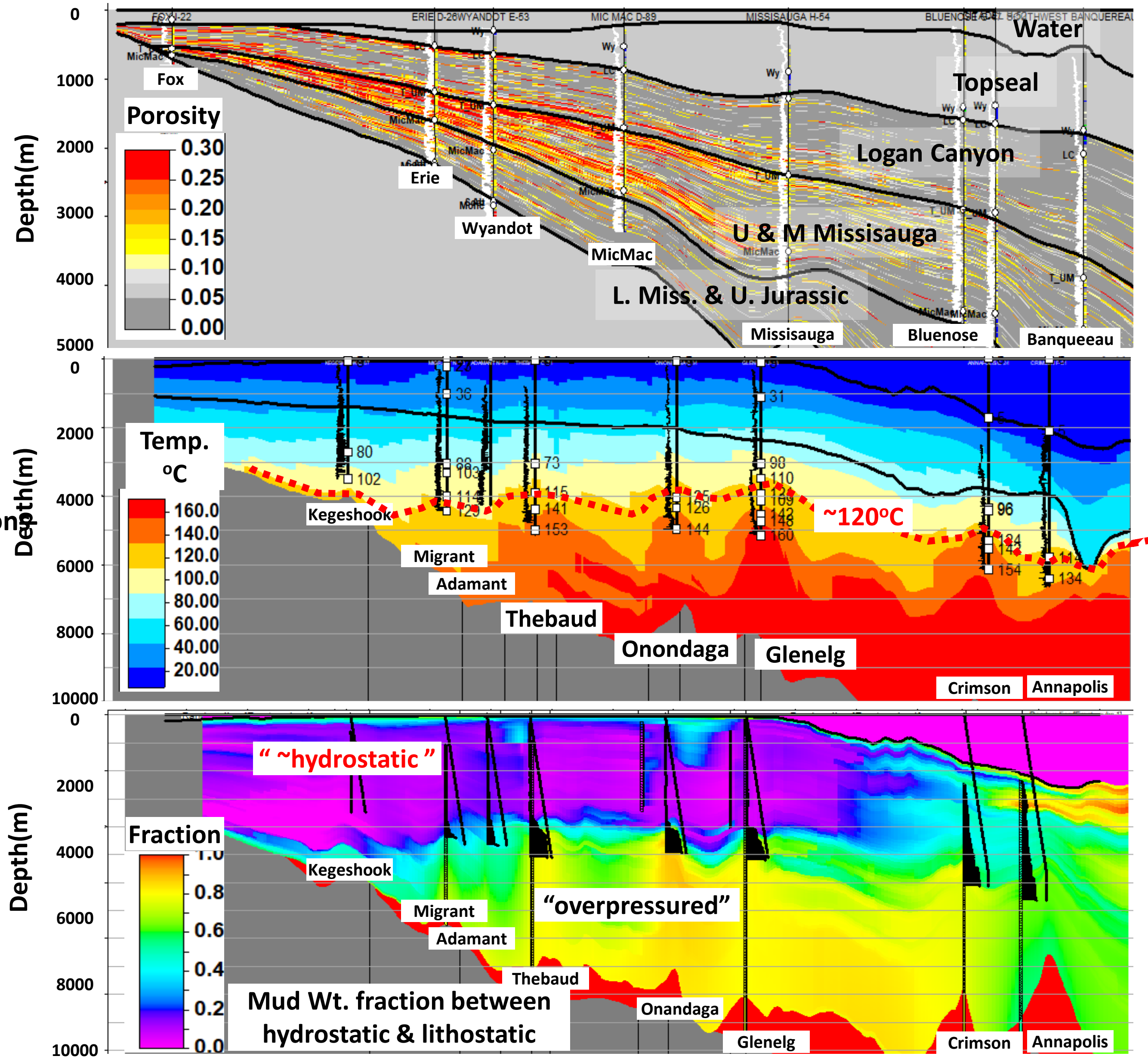

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Temperature

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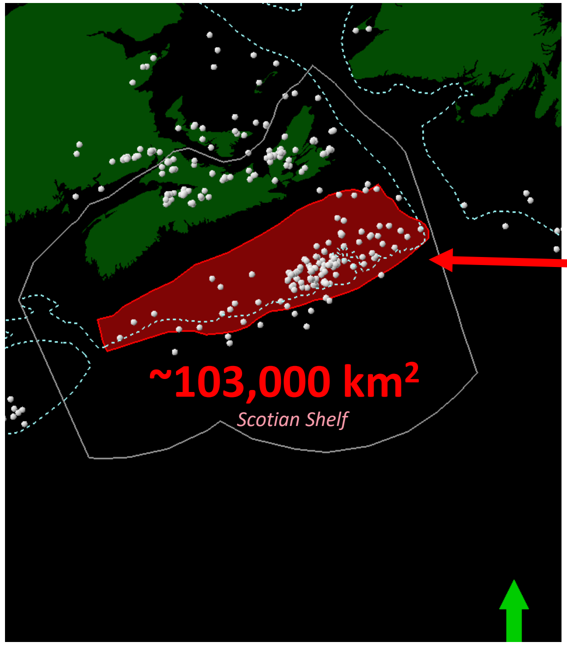
- **Need ~ 80-120^{0}C for binary power plants**

Pressure

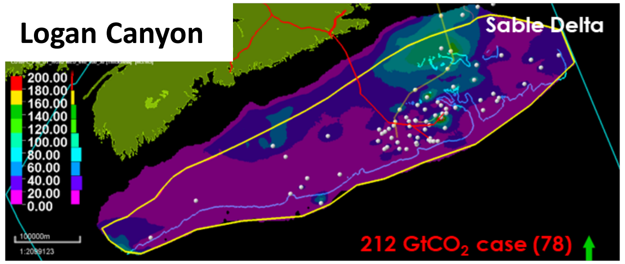
- **Key for GCS injectivity, storage & containment**
- **Confinement causes pressure build up & reduced storage**
- **Topic for dynamic modeling (next talk)**

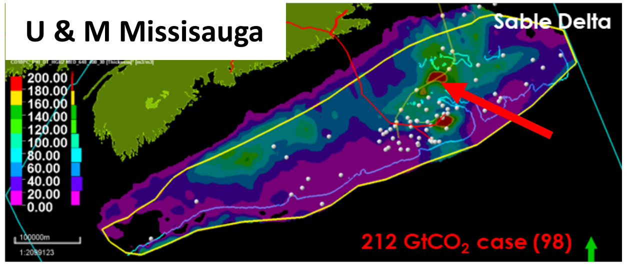
Scotian Shelf: 3D Modeling (DNRR & Dal. 2021)

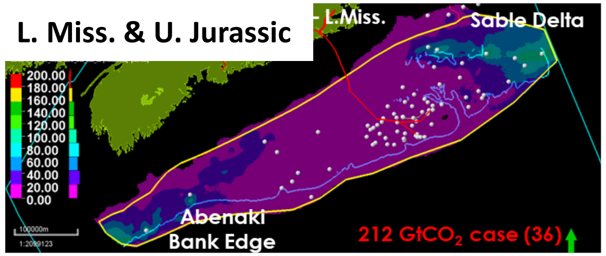


2021: N.S. Preliminary Atlases

- **Porosity-metre maps**
- Up to 200 por-m in U&M Miss. Equivalent to 1000m at 20% or 20 times Hibernia reservoir



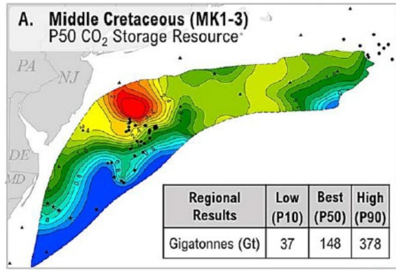


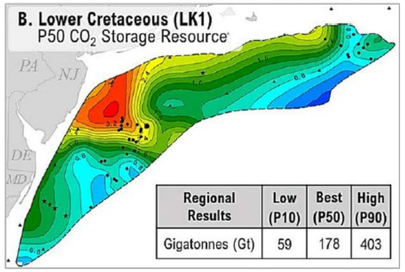


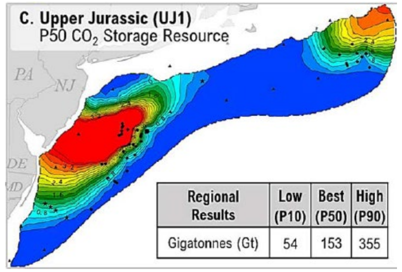
- **Dal/DNRR: Low-Medium-High Ranges (with & without cut-offs)**
- **Dal/DNRR: 7 – 151 - 1280 Gt CO_2 (area-thickness based)**
- **NS DNRR: 15 - 154 - 618 Gt CO_2 (model based with cut-offs)**
- Base Case – similar to North Sea

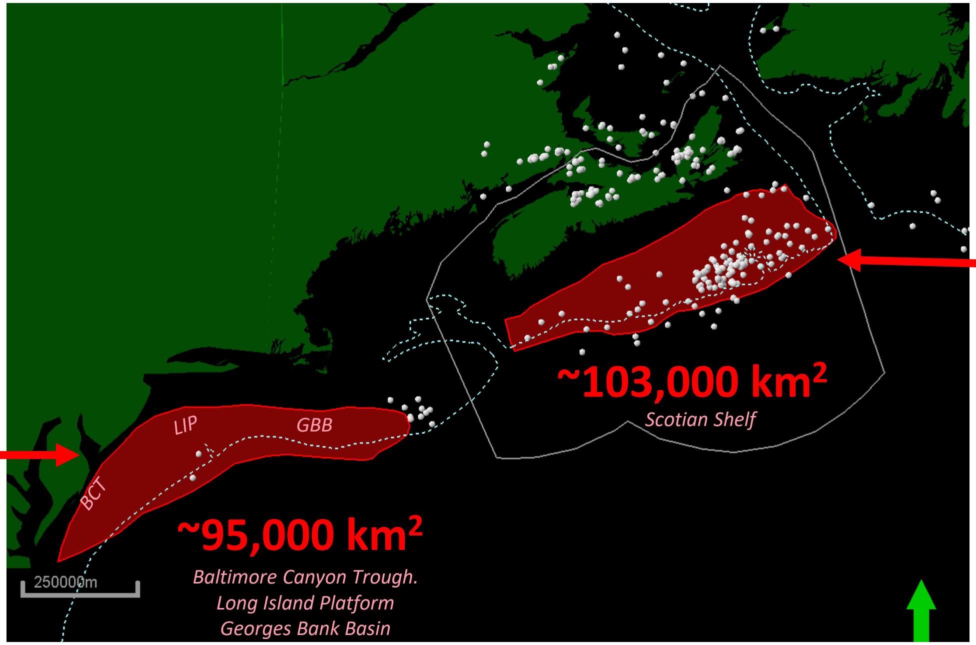
Scotian Shelf: compared to "Doppelganger" NE USA Study

2019: US DOE / Batelle Atlas
- Resource Density Maps
- Mt CO_2 / km ^{2}









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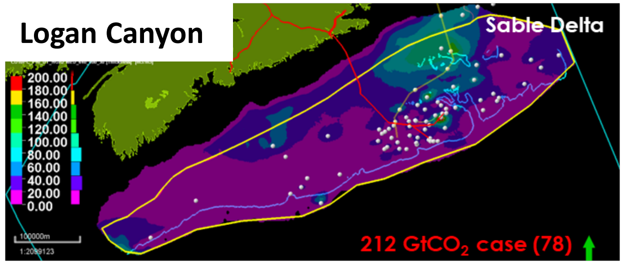

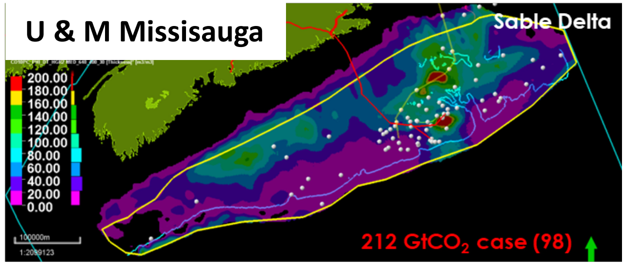

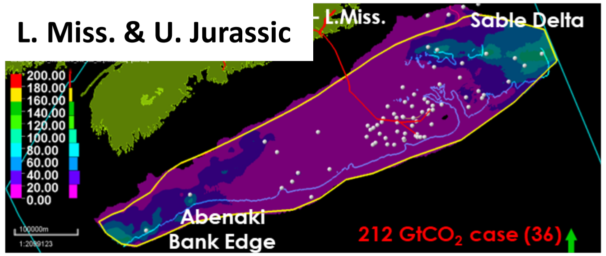

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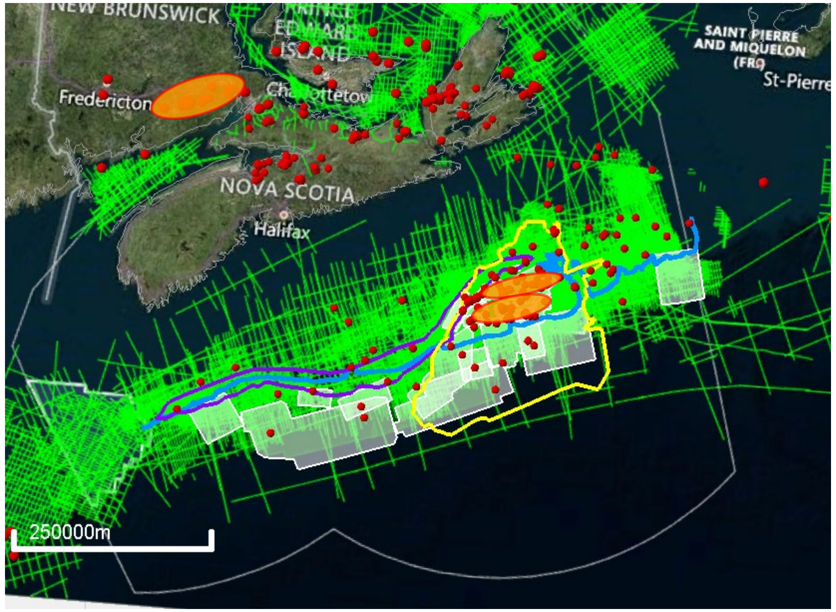
- US DOE: 150 - 479 - 1136 Gt CO_2 (P10, P50, P90)
- Same geology, same methodology, similar results
  - Higher storage efficiency factors & less stringent depth-porosity cutoffs

Nova Scotia & New Brunswick GCS in "Depleted" Fields

- Total GCS 113 Mt
    - Potentially useful, but very small by world standards
- GOM 15 Gt; UK 8 Gt; Norway 13 Gt
    - From atlases
- Calculated via material balance:
    - Produced volumes (CNSOPB)
    - Formation Volume Factors (CNSOPB)
    - 75 % storage efficiency (IEA)



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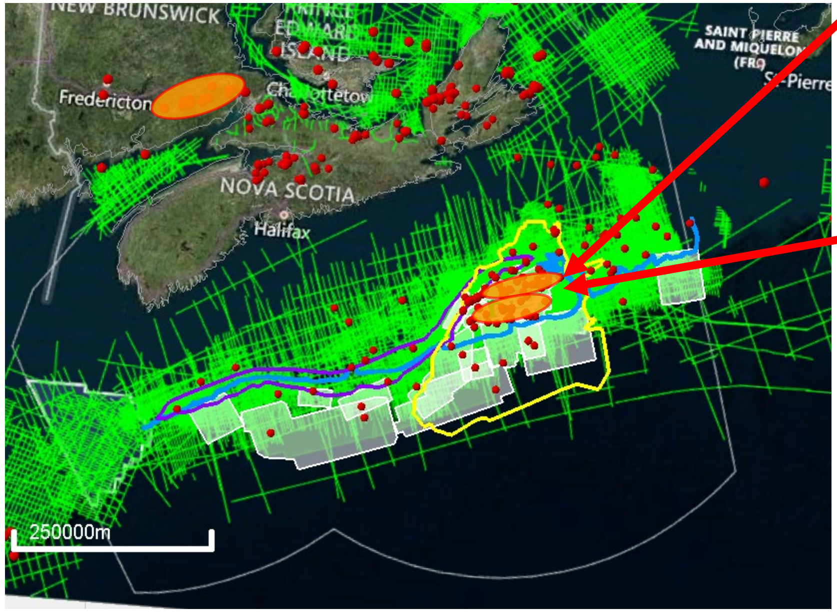
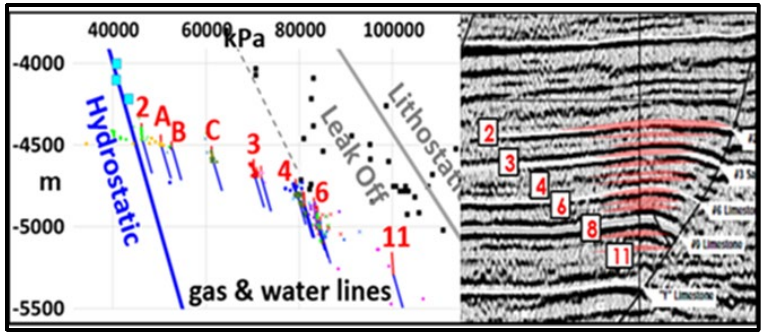
Sable Gas Project (5 fields)

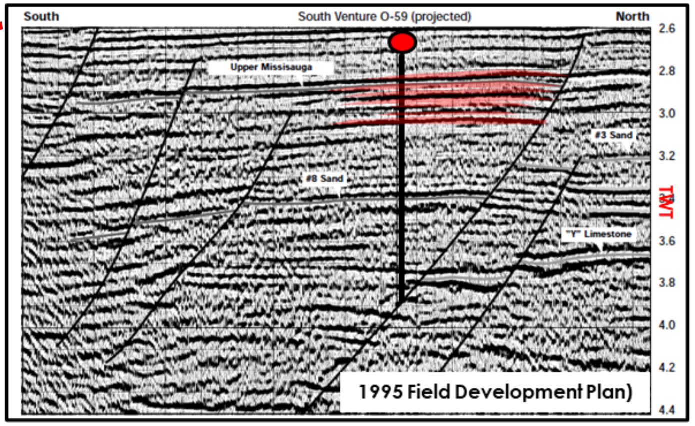
- Shelf-margin rollover anticines above listric faults
- Best options: simple shallow hydrostatic reservoirs
- Alma (31 Mt) & N.Triumph (15 Mt) S. Venture (16 Mt) & Venture Sand 2
- Venture (21 Mt) & Thebaud (21 Mt) - overpressured



Venture Field



South Venture Field



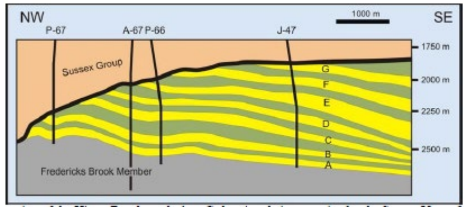
From SOEP field development plans (CNSOPB).

Nova Scotia & New Brunswick GCS in “Depleted” Fields

New Brunswick Tight Oil and Gas fields

- McCully, Stoney Creek, Dover
- Nitroglycerine & propane fracking

McCully Field



LeBlanc et al, 2011

Log PHI 4-8%. Air K .01-4 mD

In situ K 0.02-0.07 mD

Stoney Creek

(~ 1940, St. Peter,2020)

- Total GCS 113 Mt
  - Potentially useful, but very small by world standards
- GOM 15 Gt; UK 8 Gt; Norway 13 Gt
  - From atlases
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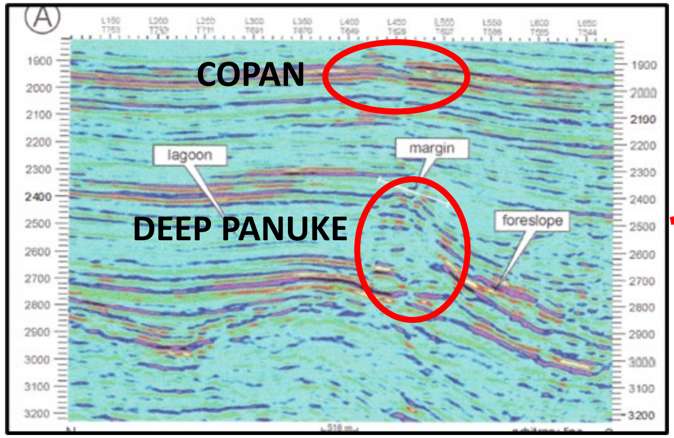
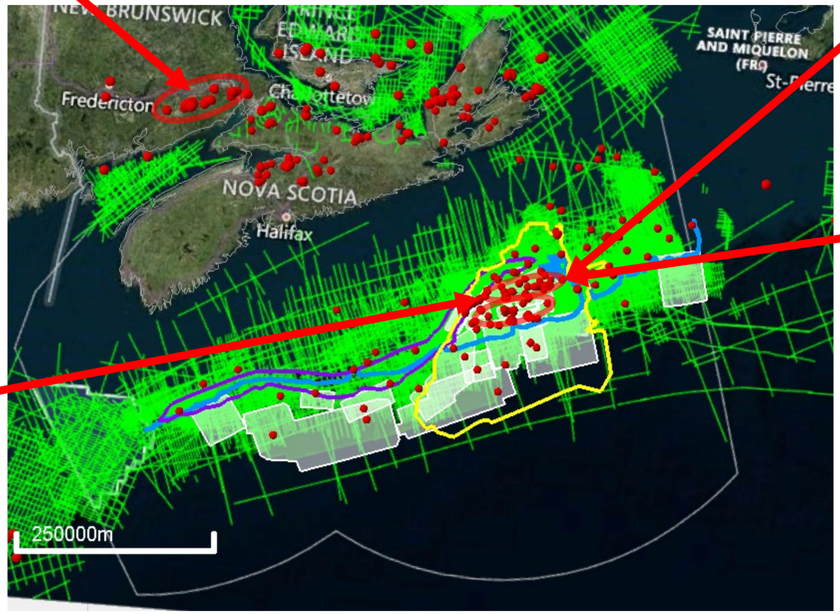
- Venture (21 Mt) & Thebaud (21 Mt) - overpressured

CoPan (4.6 Mt) & Deep Panuke (5.5 Mt)

- Both too small as depeleted fields
- Small silici-clastic drapes
- Minor production from carbonate bank margin



From Encana field development plans (CNSOPB).



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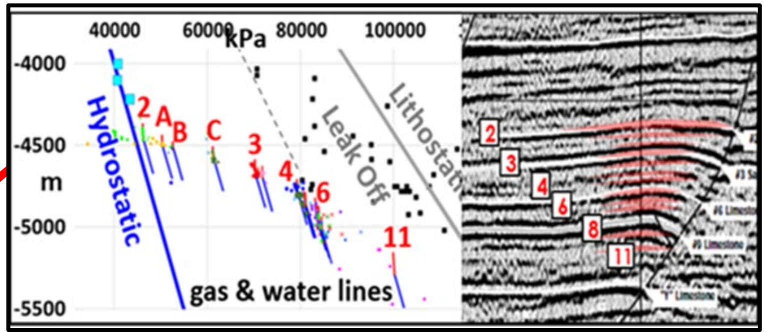

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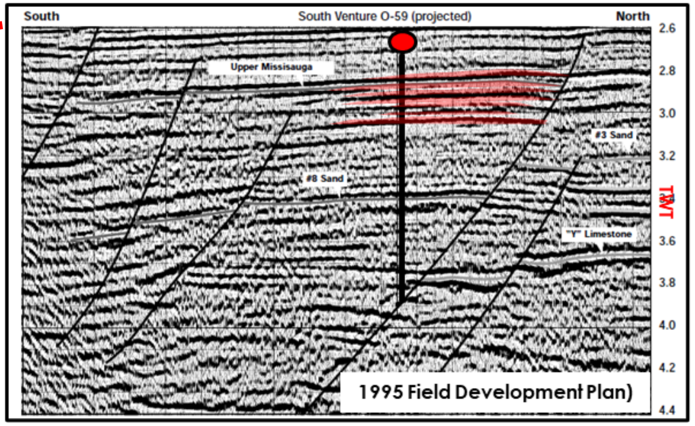
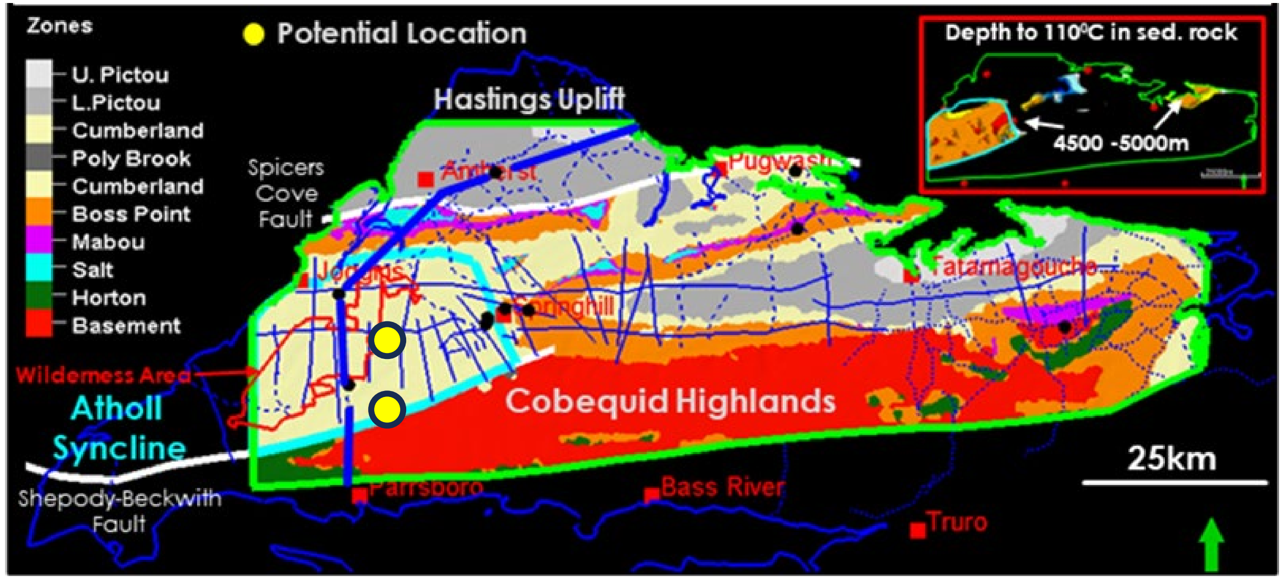


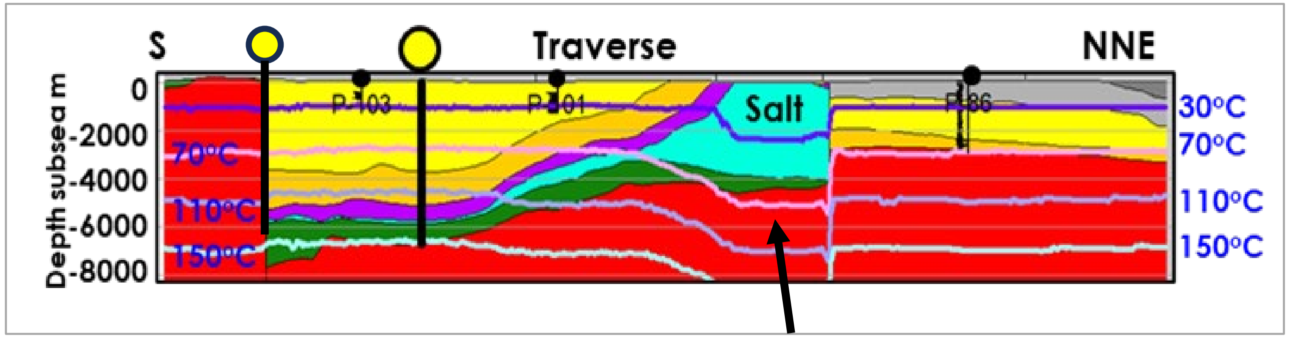
From SOEP field development plans (CNSOPB).

Cumberland Basin: 3D Modeling & Geothermal Calculations

Cumberland Basin (DNRR)

- **One of four Maritimes Basin models at DNRR**
- **Framework:** surface geology, wells, 2D seismic & simplified Waldron intepretations
- **Properties:** lithology, porosity, thermal conductivity, radiogenic heat generation
- **Calculated: Temperature, EIP, Power** via surface heat flow, Fourier's Law, & radiogenic heat **(Bedard et al., 2019 – St. Lawrence Lowlands)**





Increased heat loss to surface in salt – lose about a km of drill depth to power threshold

Cumberland Basin: Geothermal Results and Opportunities

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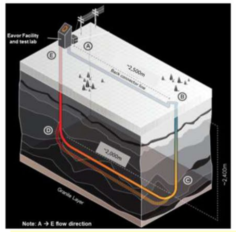
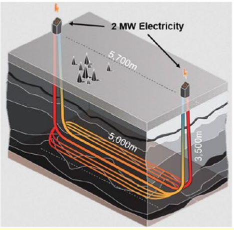
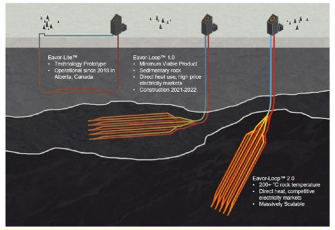
- Properties: lithology, porosity, thermal conductivity, radiogenic heat generation
- Calculated: Temperature, EIP, Power via surface heat flow, Fourier's Law, & radiogenic heat (Bedard et al., 2019 – St. Lawrence Lowlands)

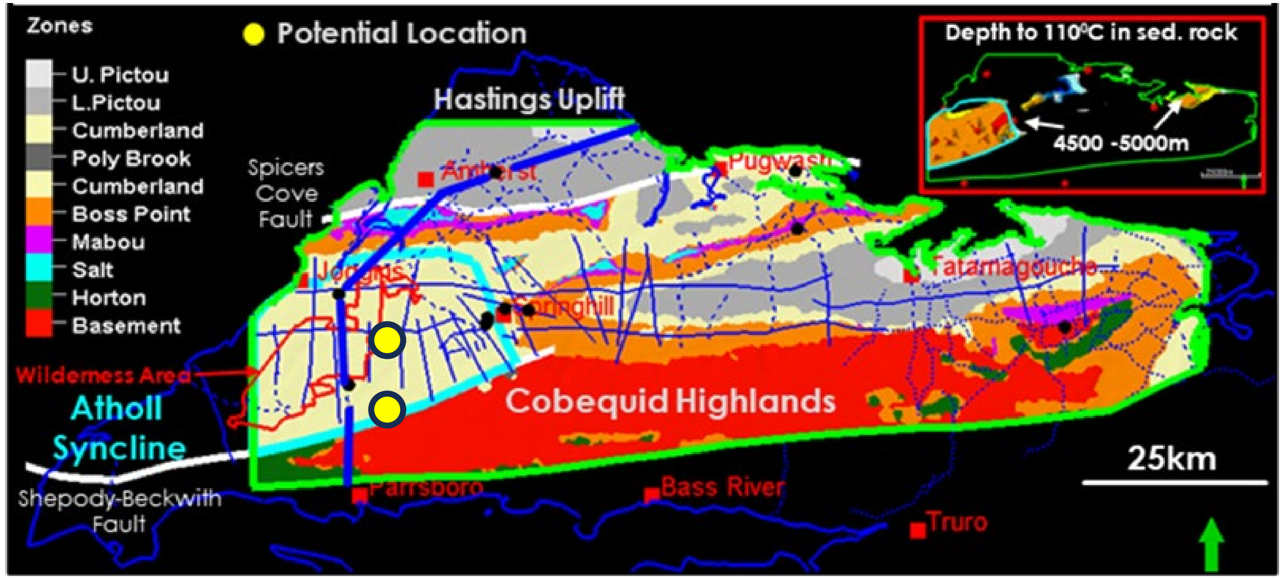
- **Energy In Place ~800 EJ and Power 13 GW (>120°C, <10km, 0.2 RF)**
- **Potential for 5-10 MW closed-loop projects**
  - Eavour "loops": Alberta company
  - Heavily funded by the EU & industry

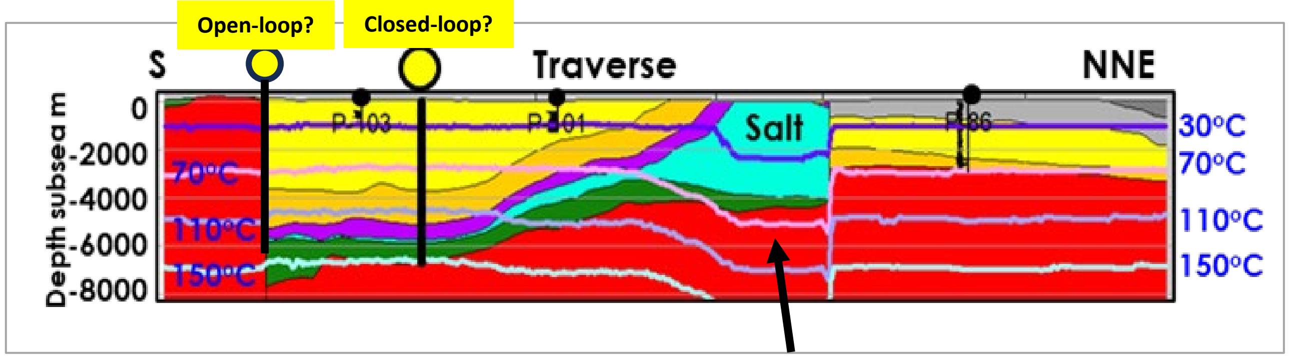






- **Or, a "fracture-hunt" near bounding faults?**
- Basis for Salt Storage & Springhill Mine projects





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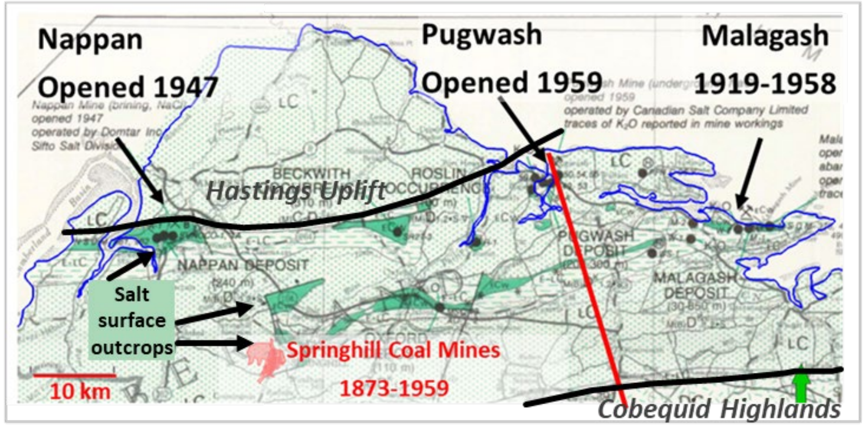
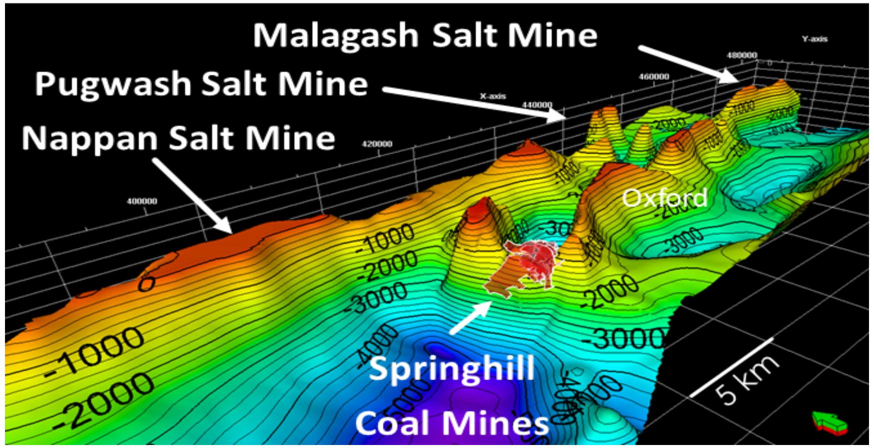
Cumberland Basin: Energy Storage & Renewables (EAGE) - Summary



Boehner, 1986

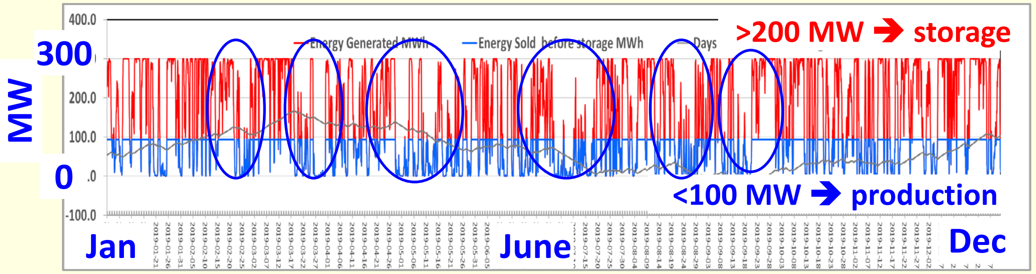


DNRR salt model

2023 EAGE Minus CO2 Student Challenge

Load-balance 300 MW of wind/solar energy with salt storage

- **Teams favoured wind power over solar**
- **Used yearly wind power charts to balance production & storage**



- **Winning team used solar to balance 10-20 day calm spells**
- **Split on compressed air versus hydrogen (safety / capacity)**
- **Considered new and old caverns at Nappan & Oxford**

- **With sensible numbers two leading teams came up with +ve discounted cash flow economics (at 10-20 cents / kWh)**
  - **Important additional considerations: SHE, community relations and resource bookings (UNFC, SPE etc)**

- **Winners UMBB (Boumerdes, Algeria) & IFP School (Paris)**
  - **Won cash prizes & a trip to present their projects at the EAGE Global Energy Transition Conference opening session**

Marita Bradshaw –Geoscience Australia

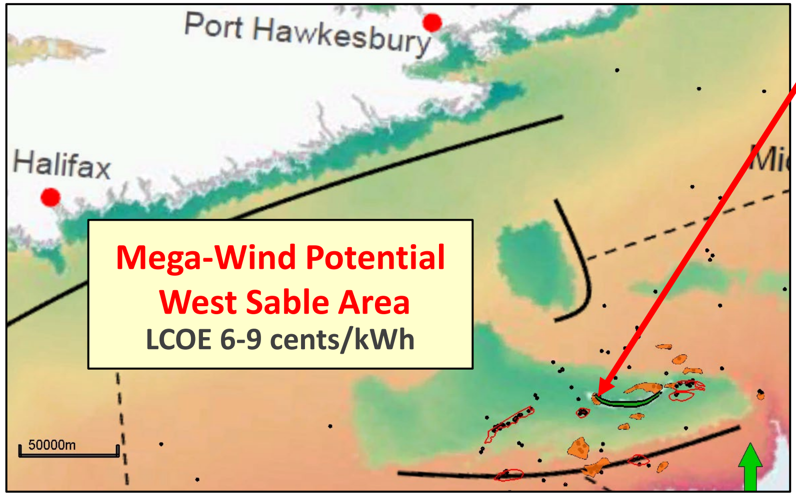
Caverns typically formed by solution mining - shape controlled by varying a gas cushion at top of cavern

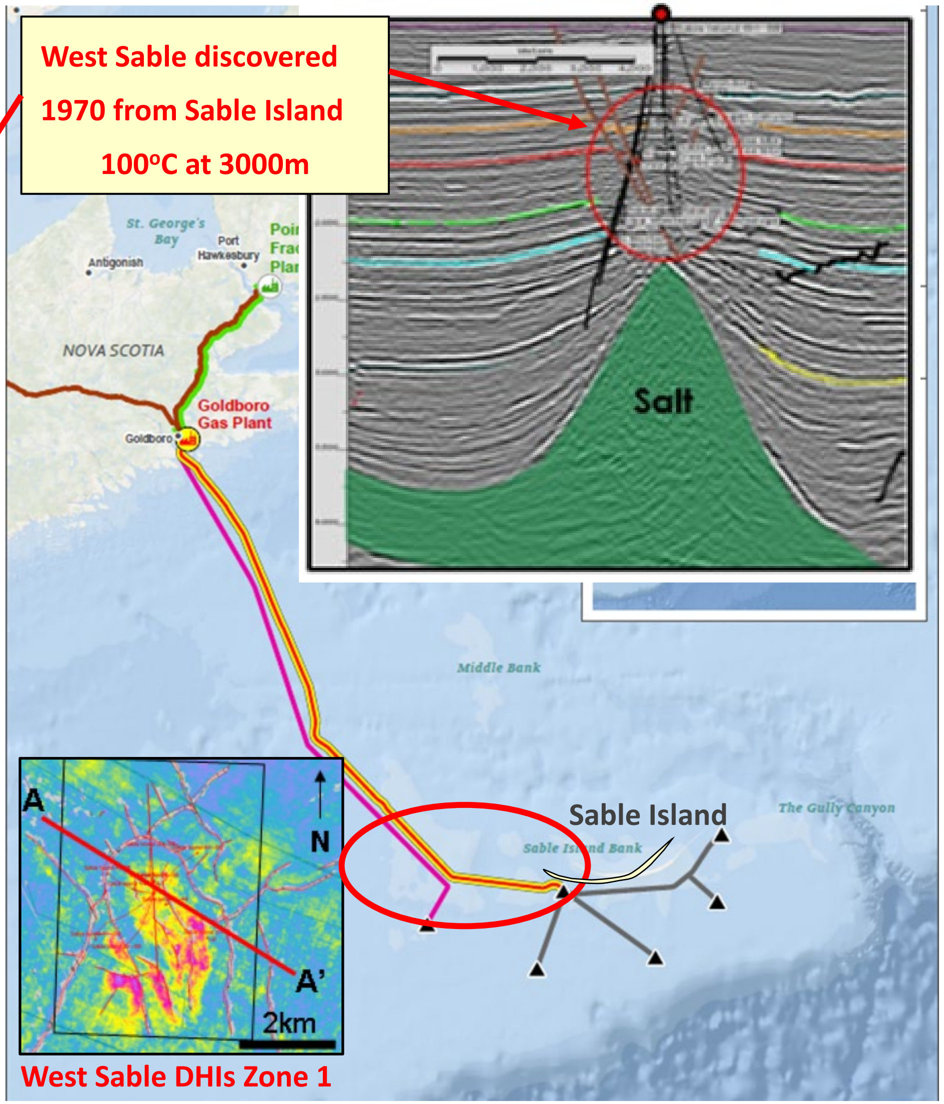
Paris, November 2023

Scotian Shelf – West Sable: Offshore “Mega-Project” anchored by “Mega-Wind”?

AEGIR (NZA) Wind Study 2023 – stimulates interest west of Sable Island

- potential for 1000 turbines
- 15 MW each (15 GW)
- <60m water depth,
- ice-free
- low bird & fishing density





Could Integrate

- Hydrogen or Compressed Air Storage in W. Sable salt diapir
- GCS potential
- Open-loop geothermal potential
- Carbon-neutral development of small stranded reserves
- Lithium?

Might use Sable Project “industrial archaeology”

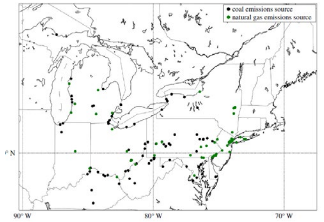
- Abandoned pipelines, legacy site surveys & designs

CBC news Oct 16th- Peter Nicholson “Catching the Wind” Report. 2023 Aegir: Value Mapping Nova Scotia’s Offshore Wind resources.*

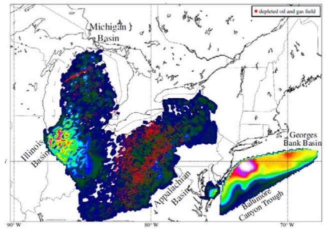
Scotian Shelf – Hypothetical "Sable GCS Project": Costs

- Reasonable idea of costs in the USA mid-west and NE.
- Schmelz WJ, Hochman G, Miller KG. 2020 (Rutgers)
- Looked at 138 power stations spatially matched to storage

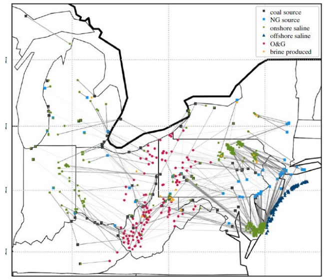
Emissions Sites



Storage Sites



Spatial Matching



Capture $/t

plant type	cost	high/low
coal	47	55/37
natural gas	76	114/49

Transport $ /t per 250 km).

location	pipeline capacity	high	low
onshore	3 Mt	7.4	4.4
	10 Mt	3.8	2.3
	30 Mt	2.3	1.3
offshore	3 Mt	15.3	7.4
	10 Mt	4.9	3.5
	30 Mt	2.5	2.0

Storage $/t

location	reservoir type	cost	high/low
onshore	oil and gas	5	13/1
	saline	6	15/3
offshore	saline	18	25/8

Scotian Shelf – Hypothetical "Sable GCS Project": Costs & Revenues (Undiscounted)

- Reasonable idea of costs in the USA mid-west and NE.
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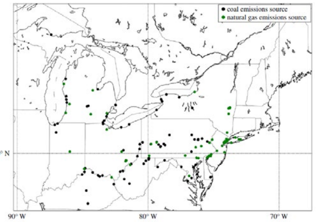
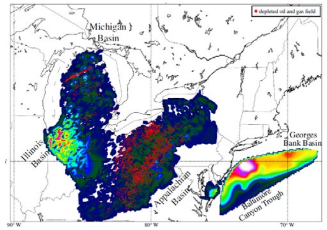
- Looked at 138 power stations spatially matched to storage

Emissions Sites



Storage Sites



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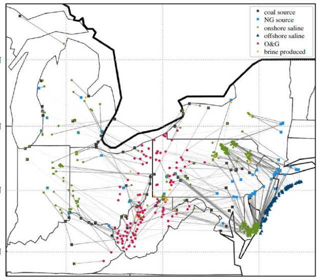

Capture $/t

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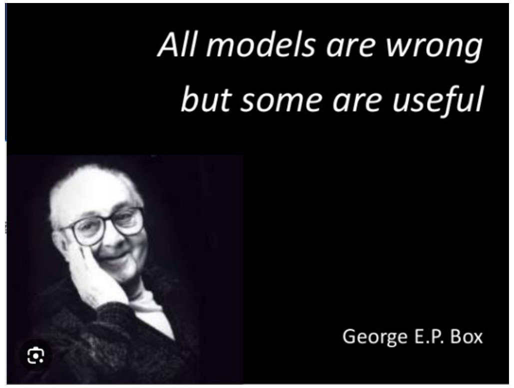
Hypothetical 20 well "Sable GCS Project"

- Based on Rutgers' study costs could be ~$20 Billion
  - (67% coal plants)
- Revenues could be ~$30 Billion (2030 Carbon price)
  - $125/t Carbon price
  - 20 wells injecting 0.5 Mtpa / well for 25 years

Costs	Mtpa	wells	years	Mt	unit cost	$billion
Capture	0.5	20	25	250	57	14.167
Storage	0.5	20	25	250	18	4.5
Transport	0.5	20	25	250	2.5	0.625
Total						**19.292**
	Mtpa	wells	years	Mt	S/tonne	$billion
Revenue	0.5	20	25	250	125	**31.25**

“Sable GCS Project”: Discounted Cash Flow Economic Model



Cash flow model for a for a 20 well GCS project

- CAPEX of $5 billion over 5 years; OPEX $100 million per year; Revenue $1.25 billion per year.

Calculate Cumulative Net Cash Flow each year and the Internal Rate of Return (IRR in Excel)

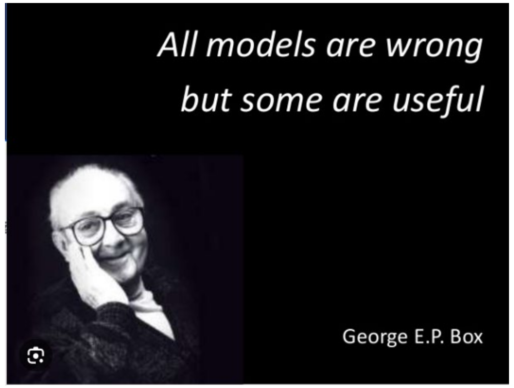
- Both metrics become +ve in year 9 “Payout”

Undiscounted

		Discount Rate	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capex	CAPEX USD Billions		-1.0	-1.0	-1.0	-1.0	-1.0																
Opex	OPEX USD Billions		-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	# WELLS							20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Mtpa per well							0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	USD per tonne							125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
Revenue	REVENUE USD Billions							1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
	Net Cash Flow each year		-1.1	-1.1	-1.1	-1.1	-1.1	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Cash Flow	Cumulative Net Cash Flow		-1.1	-2.2	-3.3	-4.4	-5.5	-4.35	-3.2	-2.05	-0.9	0.25	1.4	2.55	3.7	4.85	6	7.15	8.3	9.45	10.6	11.75	12.9
IRR	Internal Rate of Return (IRR)							-48%	-23%	-11%	-4%	1%	4%	7%	8%	10%	11%	12%	12%	13%	13%	14%	14%

9 “Payout”

"Sable GCS Project": Discounted Cash Flow Economic Model



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Undiscounted

		Discount Rate	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Capex	CAPEX USD Billions		-1.0	-1.0	-1.0	-1.0	-1.0																
Opex	OPEX USD Billions		-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
	# WELLS							20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
	Mtpa per well							0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	USD per tonne							125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125
Revenue	REVENUE USD Billions							1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
	Net Cash Flow each year		-1.1	-1.1	-1.1	-1.1	-1.1	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Cash Flow	Cumulative Net Cash Flow		-1.1	-2.2	-3.3	-4.4	-5.5	-4.35	-3.2	-2.05	-0.9	0.25	1.4	2.55	3.7	4.85	6	7.15	8.3	9.45	10.6	11.75	12.9
IRR	Internal Rate of Return (IRR)							-48%	-23%	-11%	-4%	1%	4%	7%	8%	10%	11%	12%	12%	13%	13%	14%	14%

9 "Payout"

Discounted - NPV_0 payout still occurs in year 9, but NPV_6 payout occurs in Year 11 and NPV_{12} pay out in Year 16

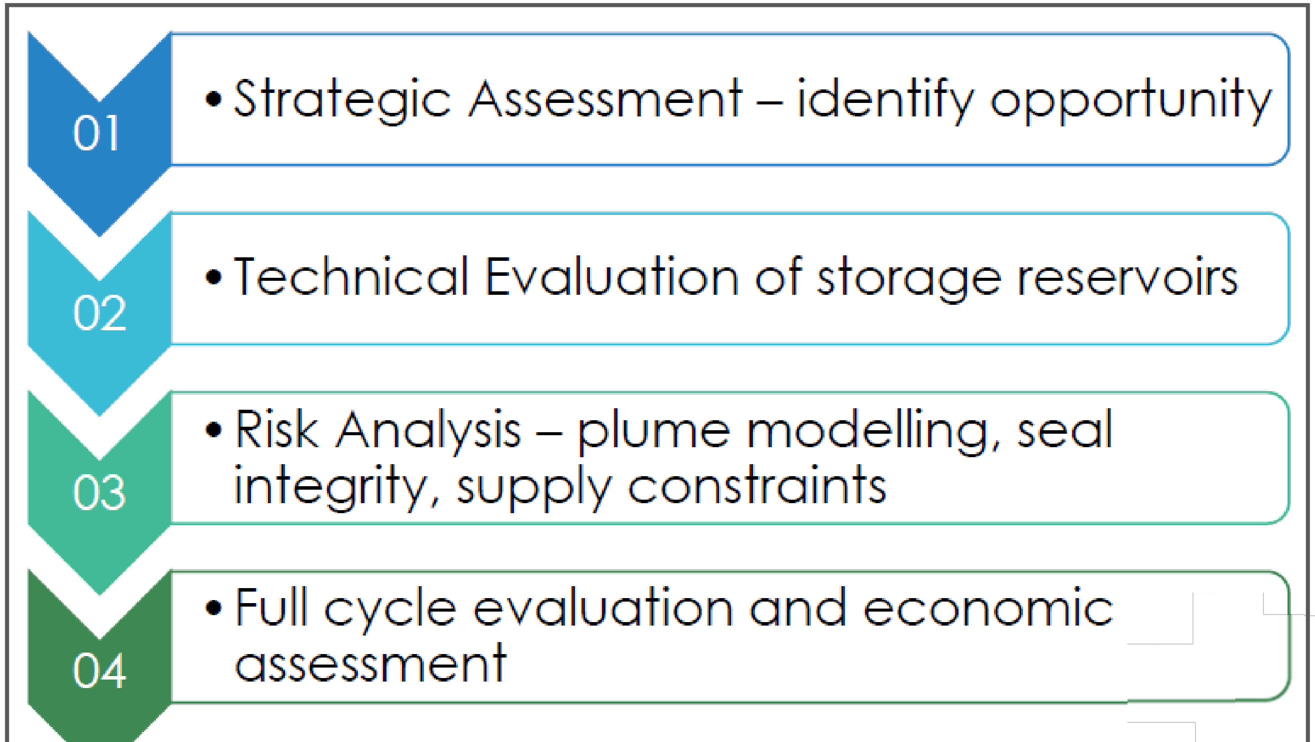
- Companies tend to view the discount rate as a **"hurdle rate"** they want to beat (based on their historical performance)

		Discount Rate	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
NPV_0	Net Present Value (NPV)	0%	-1.1	-2.2	-3.3	-4.4	-5.5	-4.35	-3.2	-2.05	-0.9	9	1.4	2.55	3.7	4.85	6	7.15	8.3	9.45	10.6	11.75	12.9
NPV_6	Net Present Value (NPV)	6%	-1.0	-2.0	-2.9	-3.8	-4.6	-3.8	-3.1	-2.3	-1.7	-1.0	-0.4	11	0.7	1.2	1.7	2.1	2.6	3.0	3.4	3.7	4.1
NPV_{12}	Net Present Value (NPV)	12%	-1.0	-1.9	-2.6	-3.3	-4.0	-3.4	-2.9	-2.4	-2.0	-1.6	-1.3	-1.0	-0.7	-0.5	-0.3	-0.1	16	0.2	0.4	0.5	0.6
NPV_{18}	Net Present Value (NPV)	18%	-0.9	-1.7	-2.4	-3.0	-3.4	-3.0	-2.7	-2.3	-2.1	-1.9	-1.7	-1.5	-1.4	-1.3	-1.2	-1.1	-1.0	-1.0	-0.9	-0.9	-0.8

?

How do we move forward?

- **Multiple Resource Schemes and Workflows**
- **Need to move beyond conceptual and qualitative studies to influence policy, regulations and commercial activity**



MacDonald, April 2023 (Halifax CCS Forum)

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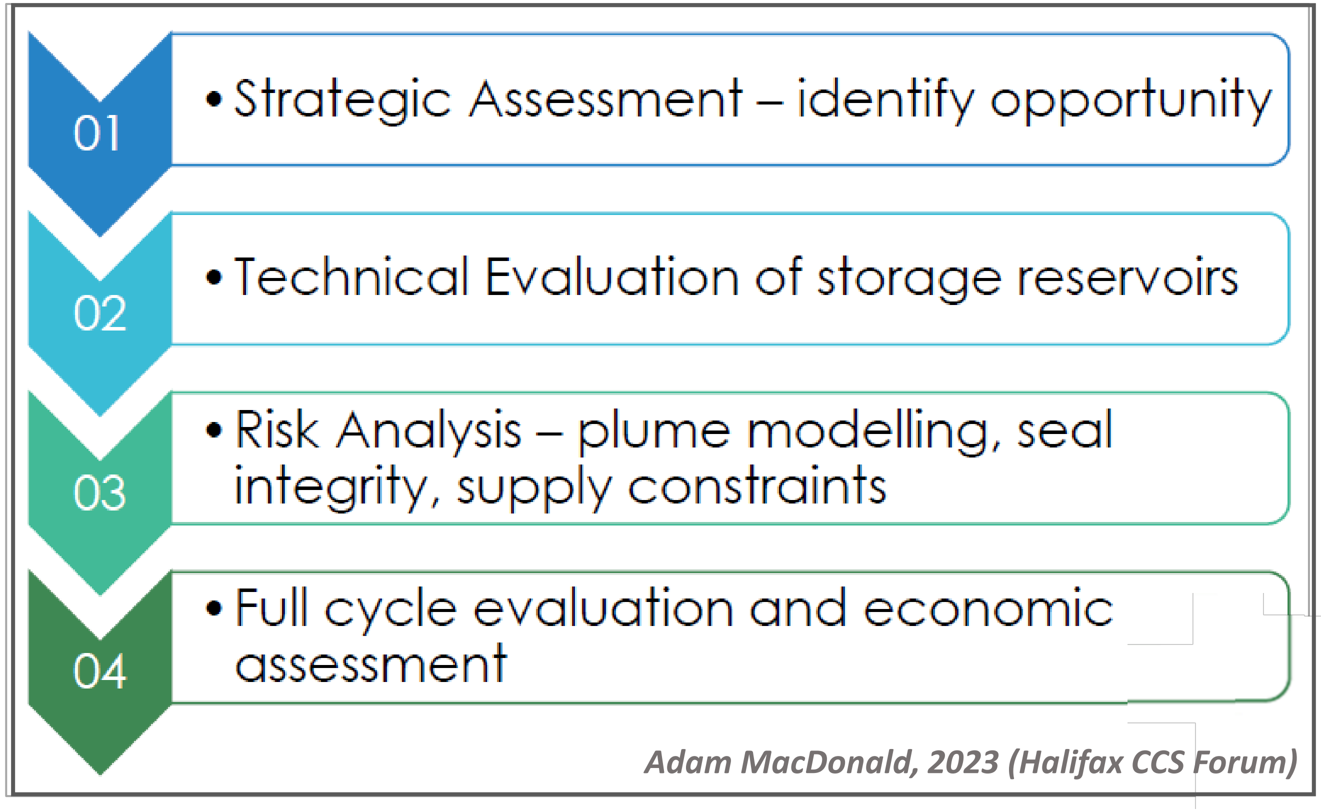
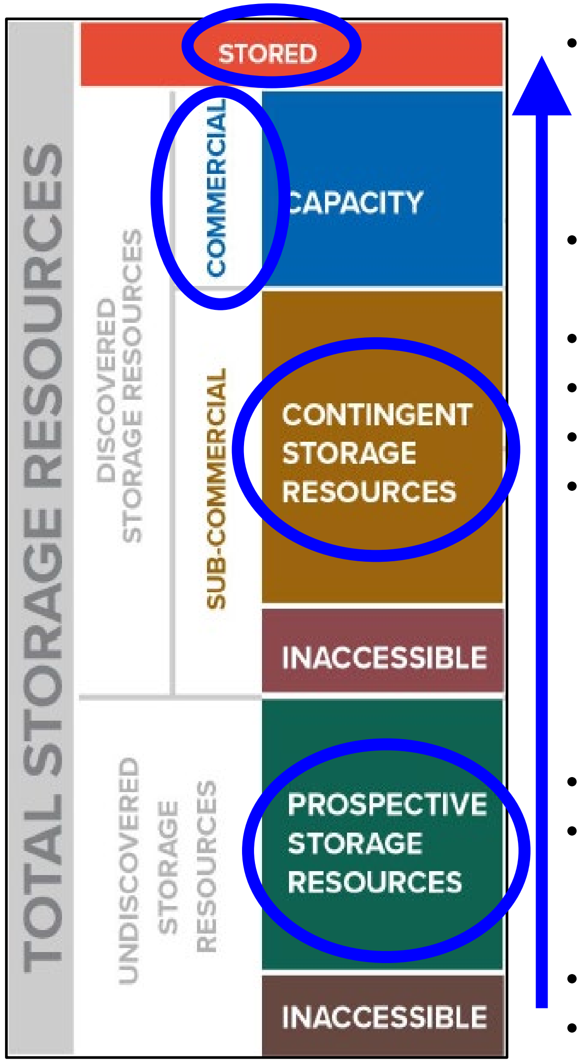


<u>Society of Petroleum Engineers (SPE)</u>

<u>Storage Resource Management System (SRMS)</u>



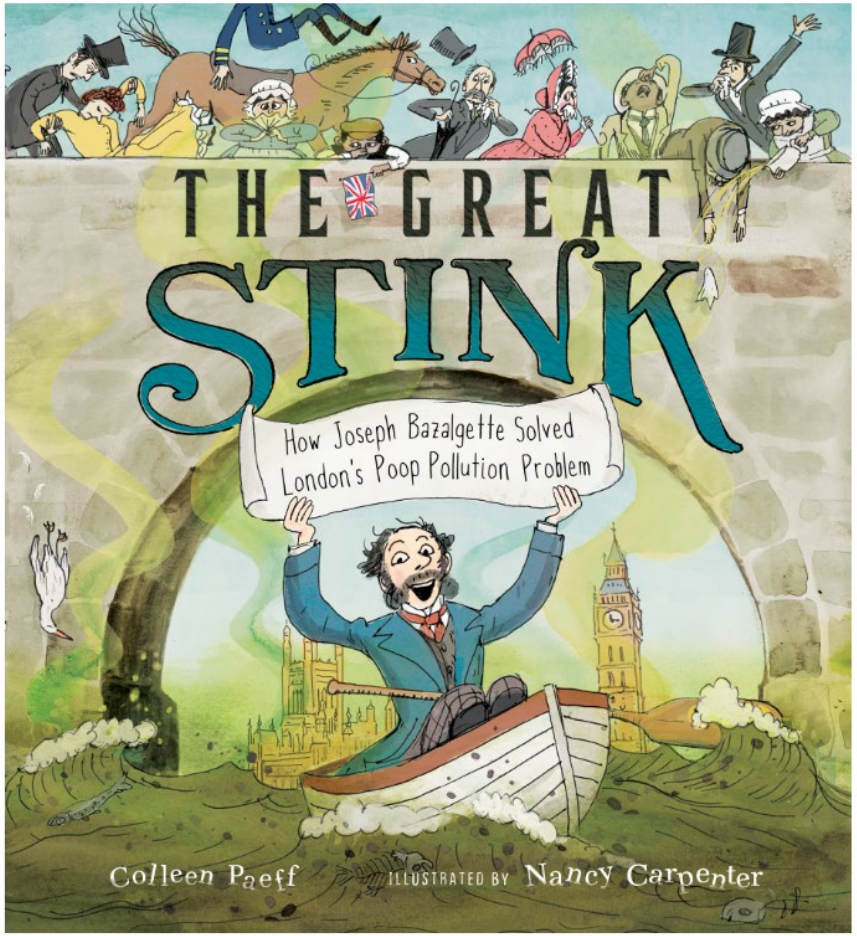
- **CO2 & H2S disposal (Deep Panuke)**
- **Wind / Salt (Cumberland)**
- **GCS (Scotian Shelf)**
- **Wind / Salt (W. Sable)**
- **Geothermal (W. Sable)**
- **Geothermal (Cumberland)**
- **GCS Magdalen Clastics**
- **GCS Fundy**
- **GCS Cumberland Clastics**
- **GCS Scotian Slope Clastics**

https://www.globalccsinstitute.com/wp-content/uploads/2020/07/Global-Storage-Resource-Assessment_-2019-Update_-June-2020.pdf

Wrap Up – Not our First Rodeo

- **Global water and wastewater treatment**
  - **Started big-time ~160 years ago**
  - **Projected Market > USD 497.5 Billion by 2030**

1858



Global Newswire – quote Precedence Research - a Canada/India based company and one of the leading providers of strategic market insights.

Wrap-Up

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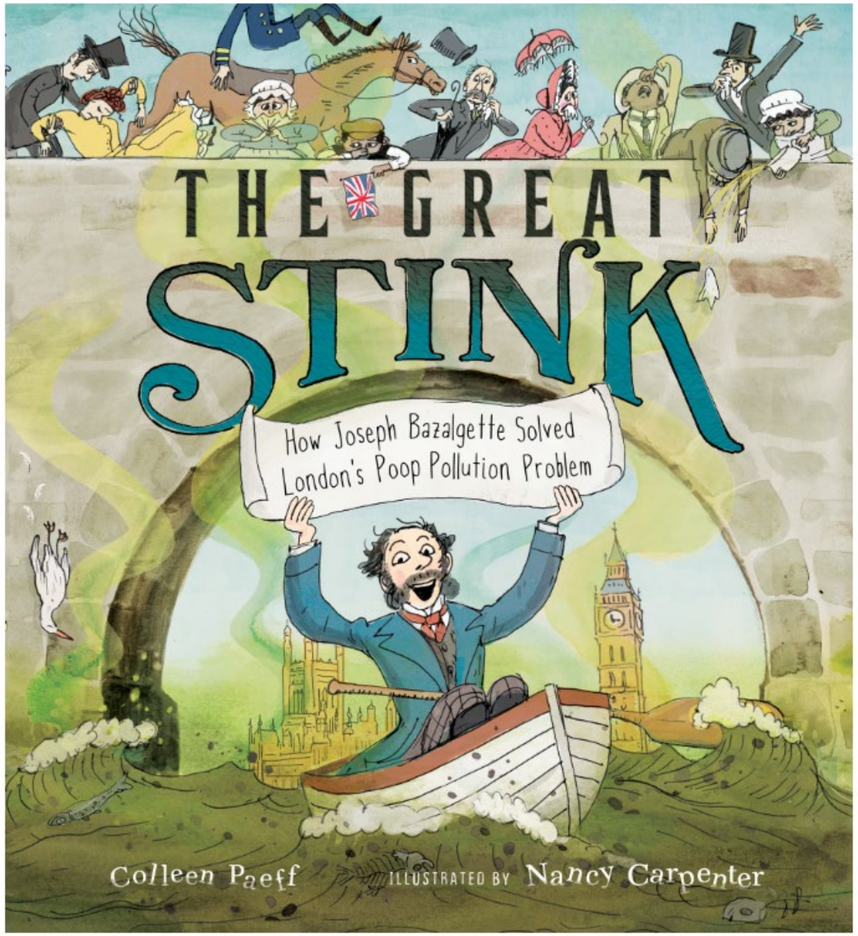

Final Thoughts

- **Should we treat CO_2 emissions as a waste disposal problem anyway?**
  (Costs about $100 / tonne to take garbage to the landfill).
- **On a cost-benefit basis, do we want to tackle climate change?**
- **Thanks to students, colleagues and friends at Dalhousie, the NS DNRR & the EAGE Student Affairs Committee**

Questions - Thank you!

Email: Billrichards888@hotmail.com

Global Newswire quote Precedence Research - a Canada/India based company and one of the leading providers of strategic market insights.