Basin & Reservoir Lab

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Dynamic Modeling of Buoyant Fluids in the Sable Subbasin: What's Next?

Presenter:
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Dalhousie University
October 2019

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HRM Climate Emergency

Request for Council's Consideration

X	**Included on Agenda** (Submitted to Municipal Clerk's Office by Noon Thursday)		**Added Item** (Submitted to Municipal Clerk's Office by Noon Monday)	☐	**Request from the Floor**

Date of Council Meeting: January 29, 2019

Subject: Climate Emergency

Motion for Council to Consider: That Halifax Regional Council request that staff prepare a report and recommendations and return to Council within 90 days with respect to:

1. The recognition by HRM Council that the breakdown of the stable climate and sea levels under which human civilization developed constitutes an emergency for HRM.

2. Opportunities to increase ambitions and/or accelerate timelines to:

   i. add new actions to help HRM achieve its climate targets; and

   ii. add new actions that would help reduce GHG emissions beyond the scope of HRM's current climate targets.

3. The incorporation into the Municipality's climate targets and actions the need to achieve net zero carbon emissions before 2050 and net negative carbon emissions in the second half of the century.

4. The establishment of a remaining carbon budget for corporate and community emissions commensurate with limiting warming to 1.5oC and an annual reporting process with respect to the expenditure HRM's remaining carbon budget.

5. The establishment of a "Climate and Equity" working group to provide guidance and support for the Municipality's efforts to transition off of fossil fuels in ways that prioritize those most vulnerable to climate impacts and most in need of support in transitioning to renewable energy.

Reason: There is a climate emergency declared by other Canadian Cities and it is time for Halifax to take a serious look at this issue.

Outcome Sought: Council approve this request for consideration.

Councillor Richard Zurawski	*District 12*

Key Points / Outline

- **Commercial hydrocarbon production in the Sable Subbasin has been, or is being, decommissioned**
- **Numerous discovered and undiscovered hydrocarbon opportunities are small and likely non-commercial**
- **There is a strong legacy of subsurface and surface expertise that will dissipate without future activity**
- **Carbon Capture and Storage in underground reservoirs / aquifers is proven technology globally,**
  - Most extensively onshore as Enhanced Oil Recovery projects in hydrocarbon traps
  - Also as pilot CCS projects offshore and onshore into 'deep saline aquifers' that do not rely on conventional trapping
  - Has been achieved offshore, entirely using buried pipelines and facilities ('overtrawlable')
- **CO_2 is trapped in deep saline aquifers largely due to:**
  - Residual trapping - 'micro trapping' due to small heterogeneities (drainage / imbibition hysteresis)
  - Dissolution - with associated water density increase and sinking of CO_2
- **The Scotian Margin has world class potential for CCS in deep saline aquifers (IPCC 2005 report on CCS) and significant potential in depleted hydro-pressured reservoirs. Onshore Nova Scotia lacks suitable reservoirs.**
- **In this study we integrate static & dynamic modeling (Petrel / Eclipse courtesy Schlumberger)**
  - CH_4 injection (to understand trap integrity / adequacy)
  - CO_2 injection above traps to scope out migration & timing in deep saline aquifers
  - Plus scoping economics poster

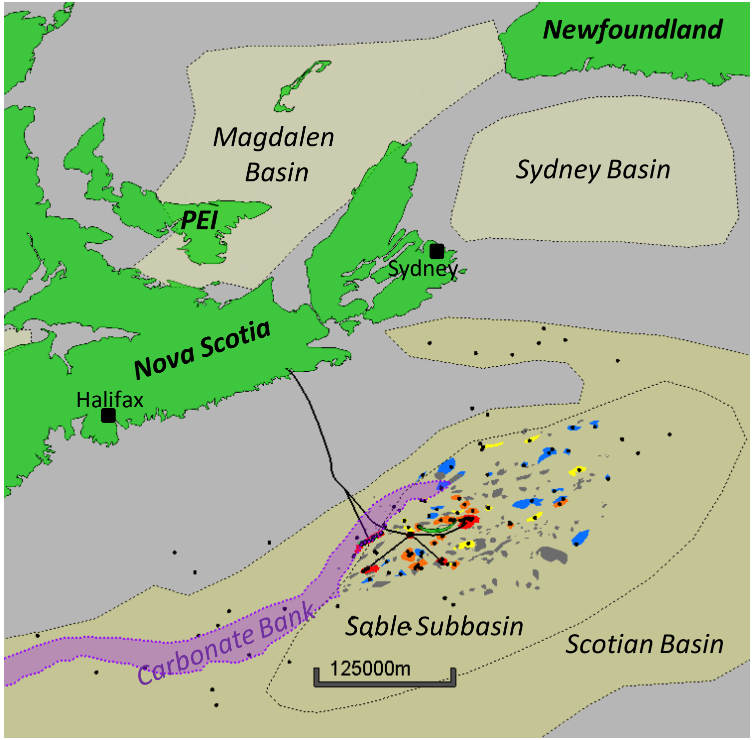
‘State-of-Play’ - Sable Subbasin

Only commercial hydrocarbon subbasin offshore Nova Scotia

- **Exploration since 60’s, ~all shelf prospects mapped by NSPD in 1999**
  - ~4 TCF proven resources (~150 TCF Southern N. Sea)
  - Undiscovered estimates as high as 120 TCF ignore well-known risks
  - 8 commercial fields now depleted (~2.3 TCF & ~45 MBO)
  - 15 undeveloped fields, ~33 wet structures, ~100 undrilled closures
- **Extensive public data bases and interpretations: GSC, DOE, CNSOPB**
- **Geology is well understood - except source rocks**

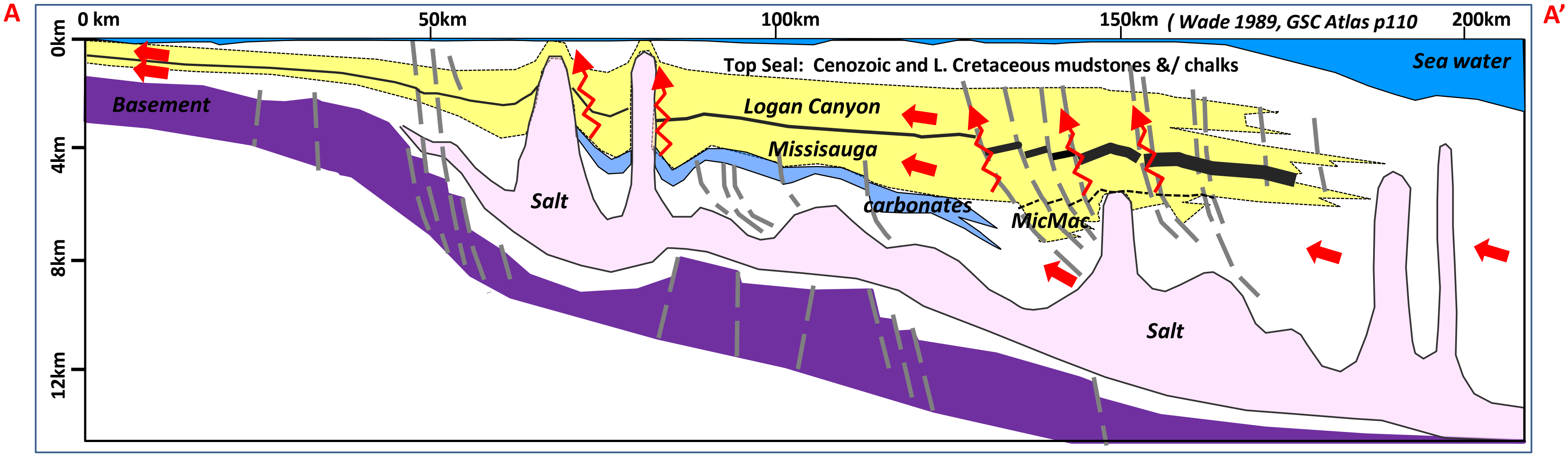
Why?

- **Only sub-basin with evidence of a significant source rock (ie: fields)**
  - Deltaic / marginal marine gas-prone source rocks inferred
  - No evidence of prolific restricted basin source rocks that generate world class oil reserves on other Atlantic margins – function of sediment influx, plate tectonics & oceanic circulation
- **‘Leaky system’: low-relief traps that leak updip towards Nova Scotia**
  - “Rollover anticline” traps in Jurassic- Cretaceous Sable Island Delta contain high-NTG reservoirs prone to cross-fault leak
  - “Drapes” and “reef margin” traps on downdip flank of Jurassic Abenaki Carbonate Bank have limited seals

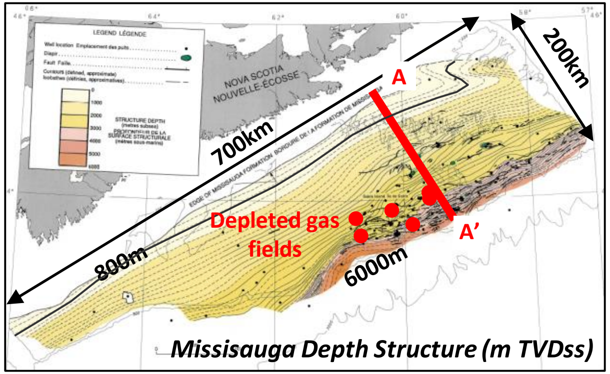


Sedimentary Basins (after Williams & Keen, 1990)
Fields and Closures (after NSPD, 1999)
Scotian Basin Wells and Pipelines
Closures: red / orange=developed / undeveloped,
yellow / dark blue = wet with & without shows, gray = undrilled.

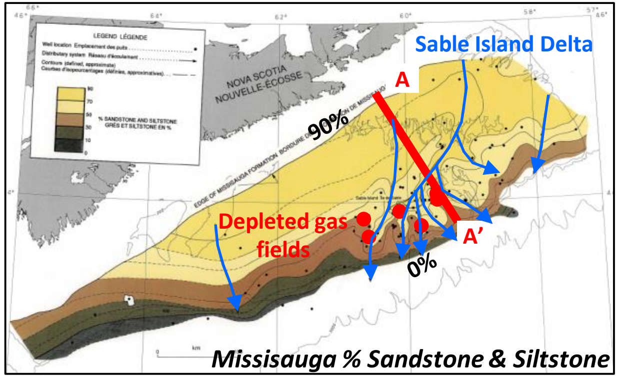
Sable Subbasin – Shelf-Slope Geology & Play Elements



(GSC East Coast Basin Atlas Series: Cant, 1991)



Missisauga Depth Structure (m TVDss)



Missisauga % Sandstone & Siltstone

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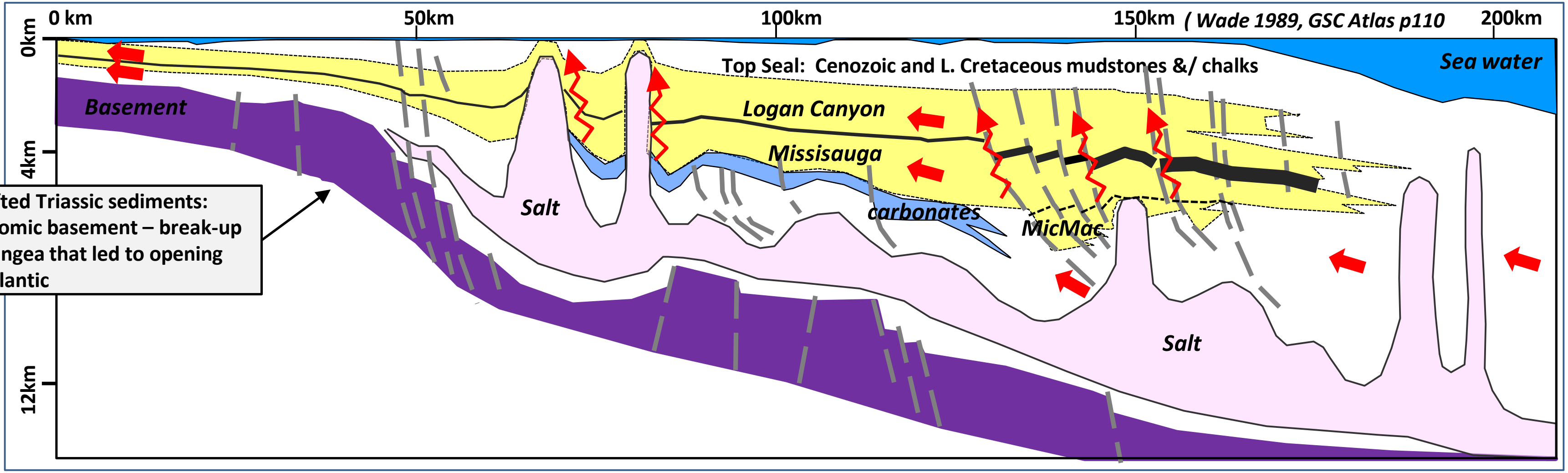

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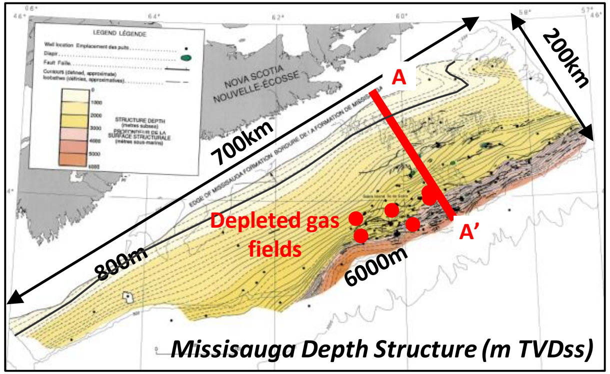

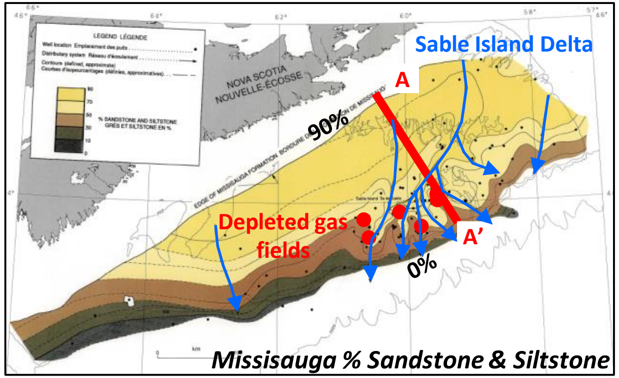

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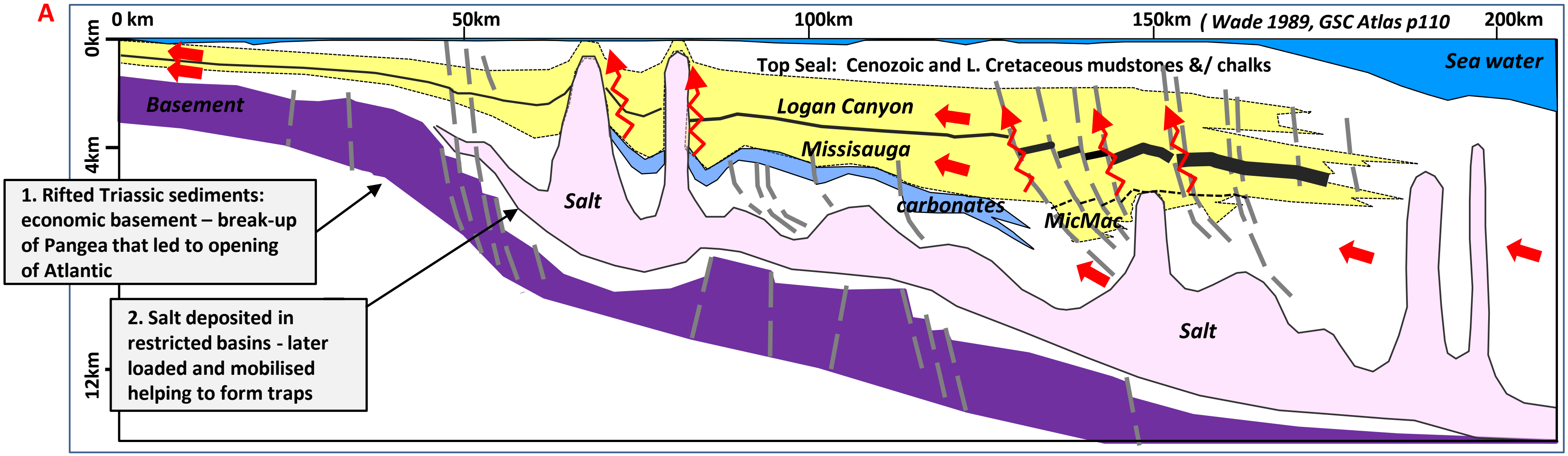

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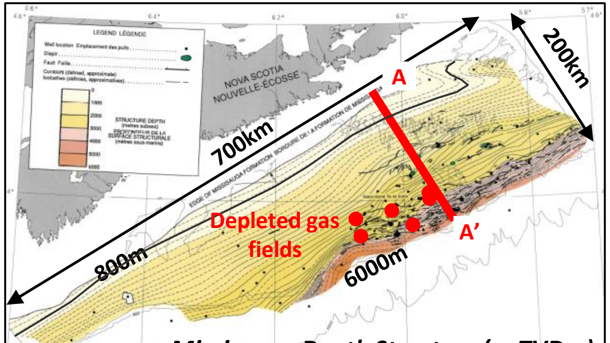

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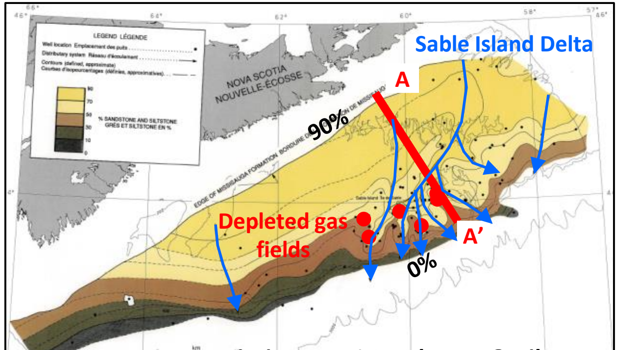

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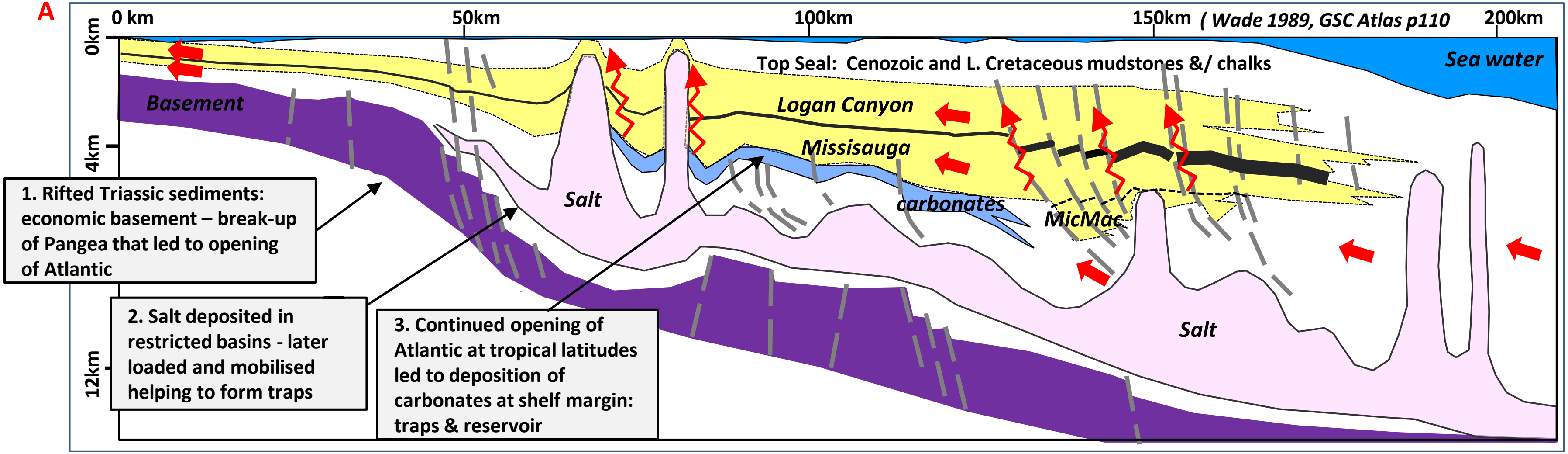

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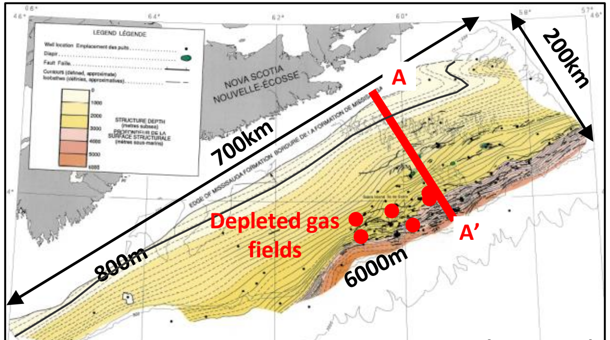

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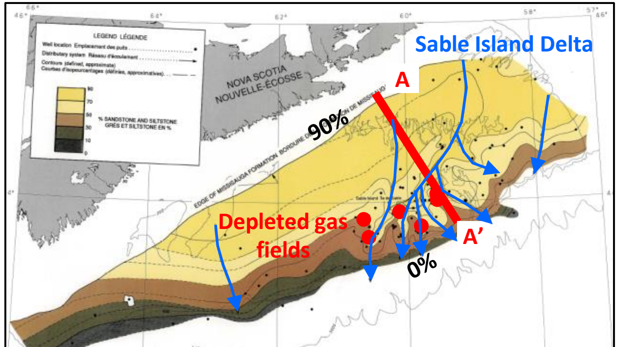

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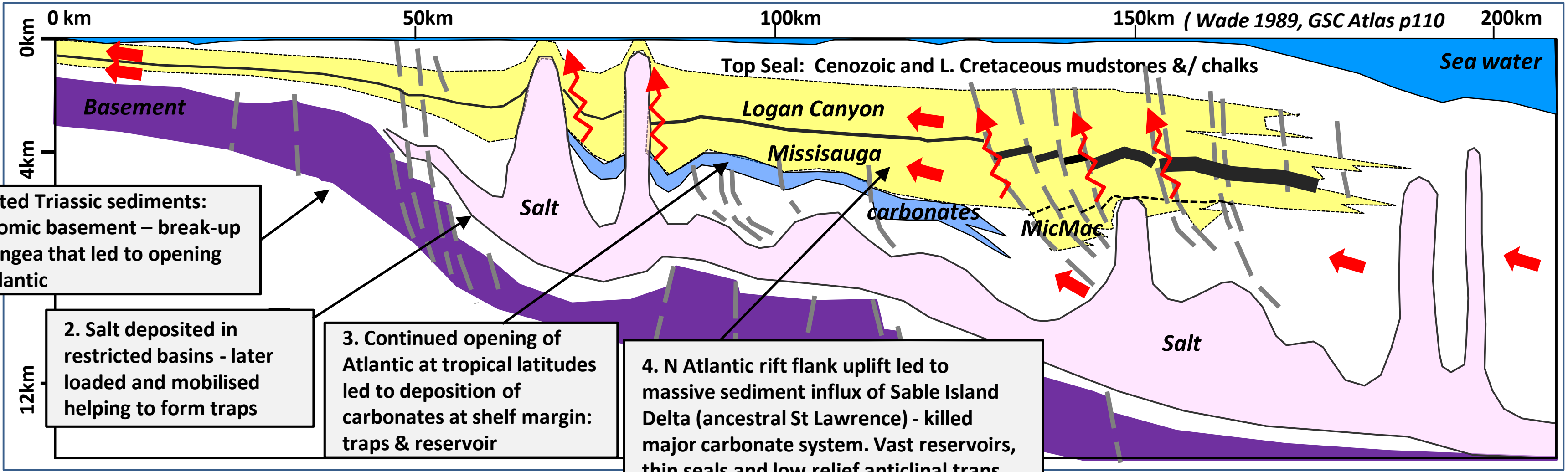

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2. Salt deposited in restricted basins - later loaded and mobilised helping to form traps

3. Continued opening of Atlantic at tropical latitudes led to deposition of carbonates at shelf margin: traps & reservoir

4. N Atlantic rift flank uplift led to massive sediment influx of Sable Island Delta (ancestral St Lawrence) - killed major carbonate system. Vast reservoirs, thin seals and low relief anticlinal traps due to loading, faulting and rotation.

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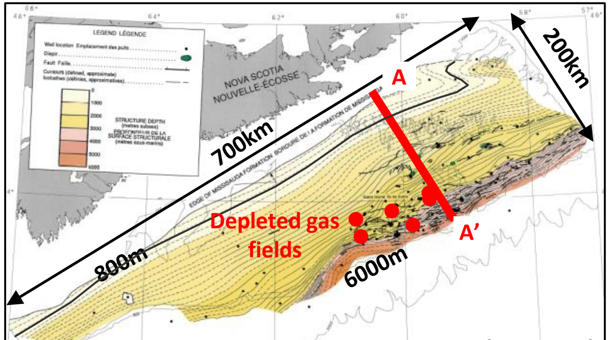

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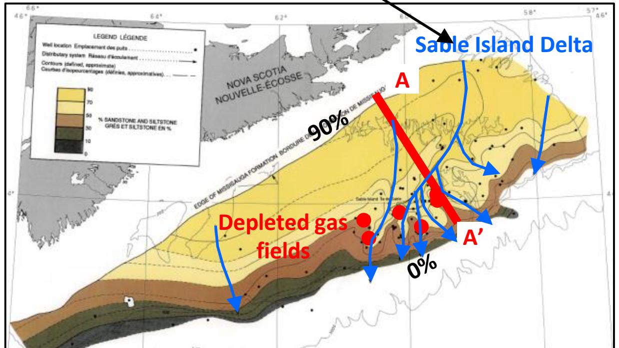

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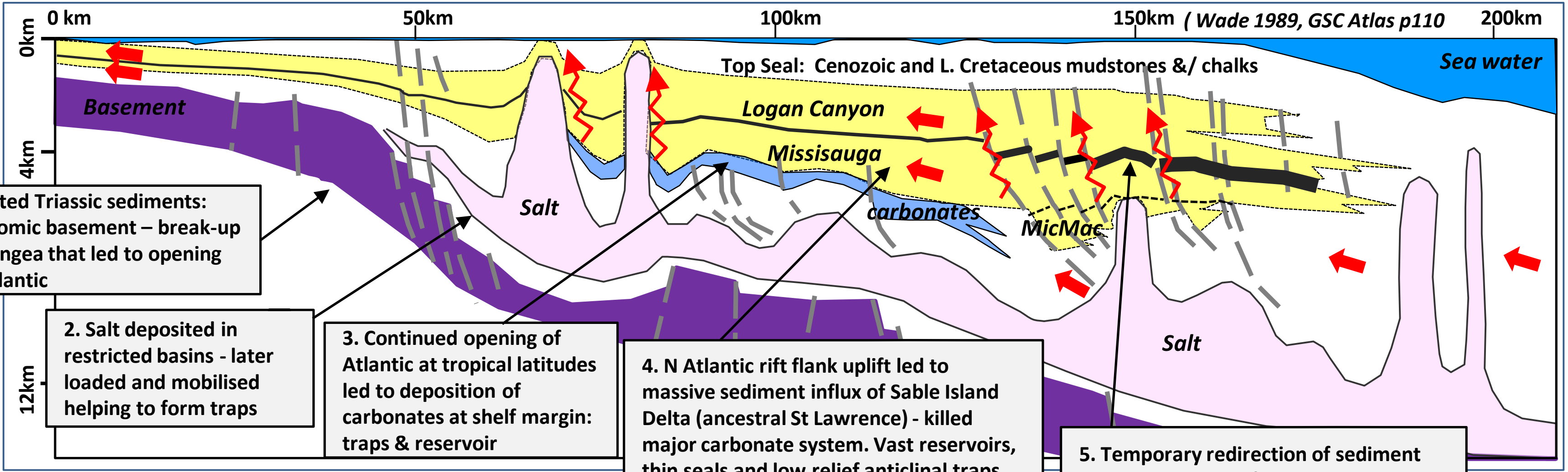

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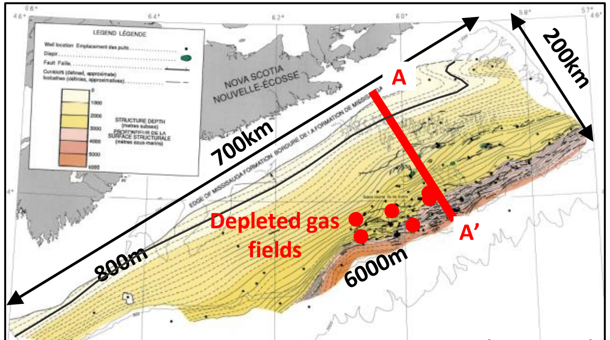

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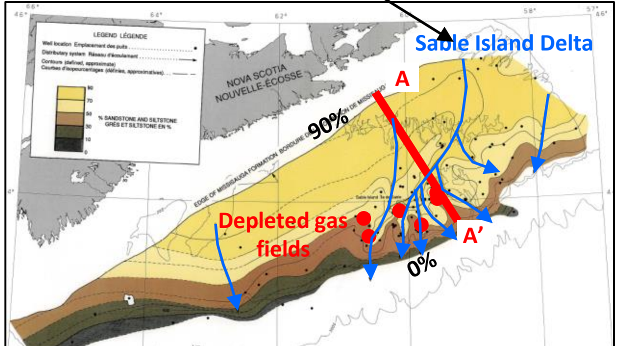

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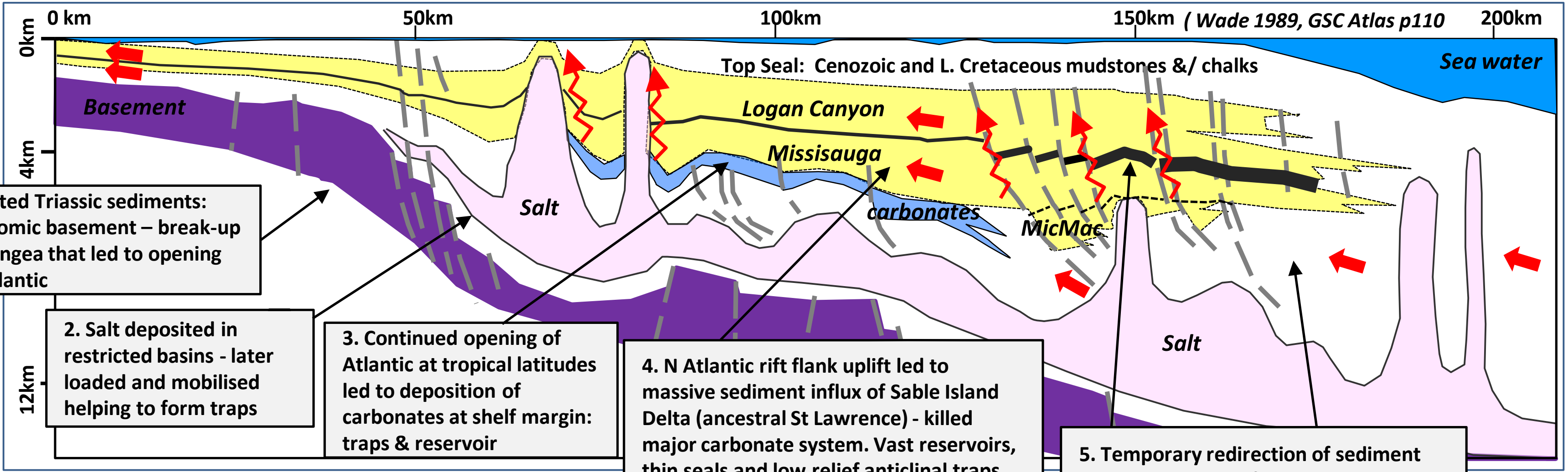

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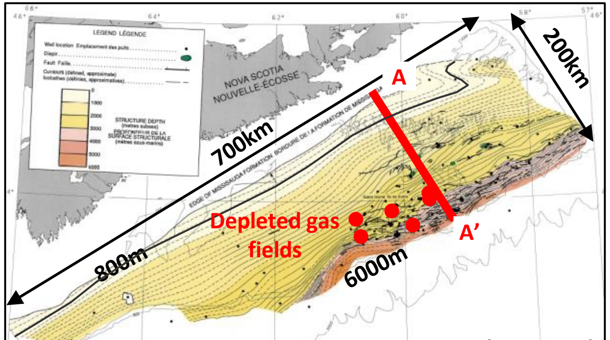

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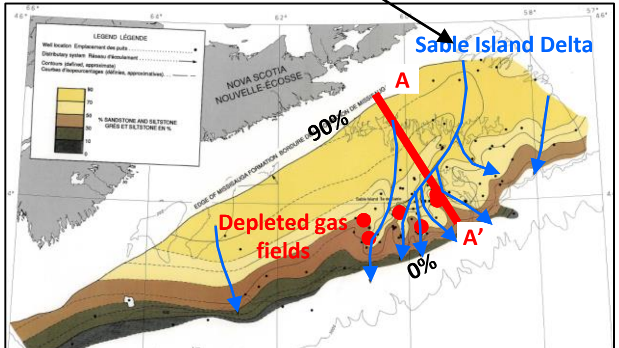

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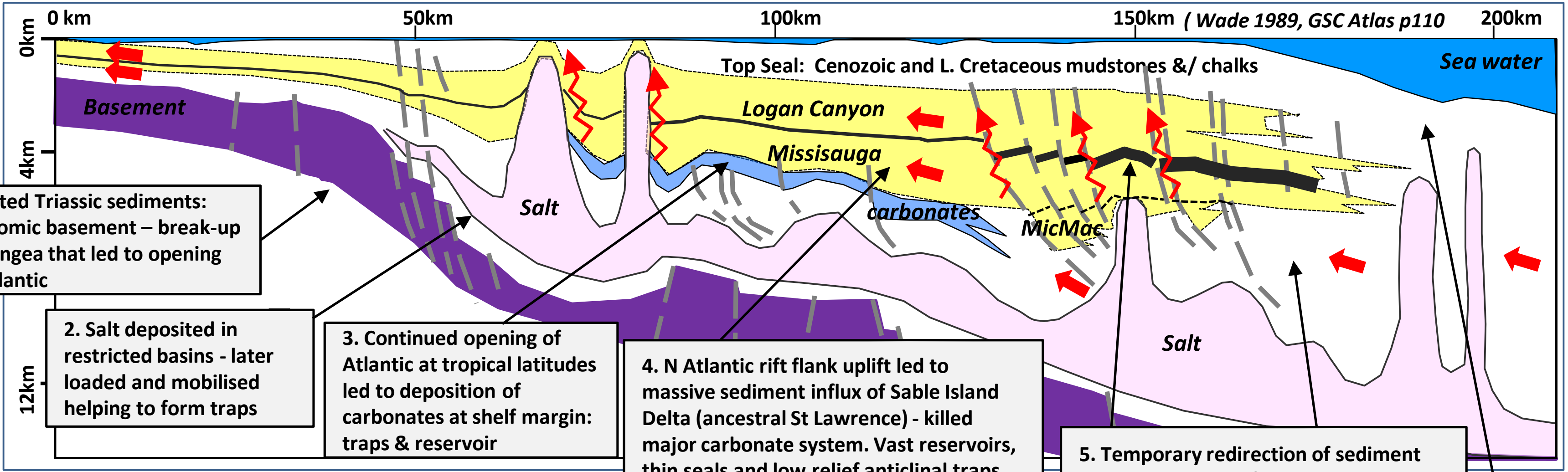

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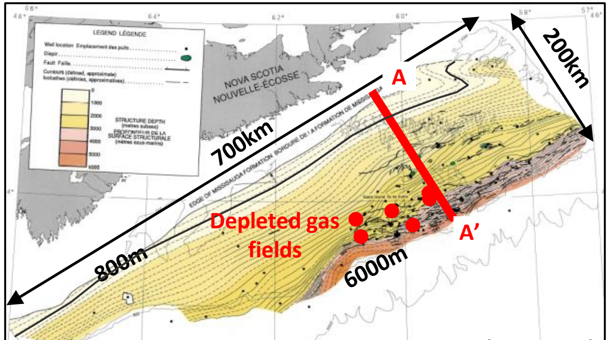
7. Deltaic source wanes in Logan Canyon giving way to deep water mudstones and marls – & prograding Cenozoic mudstones. Topseal for system. No further uplift at basin margins producing deep water fan systems similar to North Sea or Newfoundland

(GSC East Coast Basin Atlas Series: Cant, 1991)



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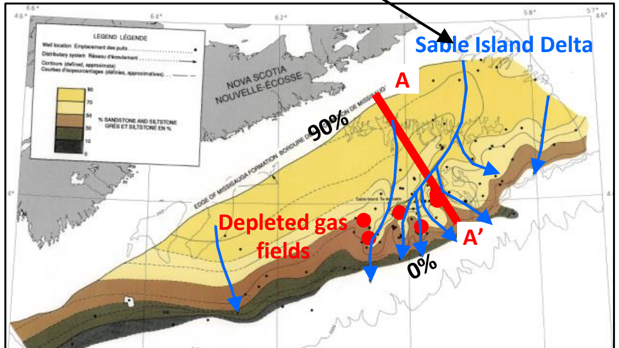
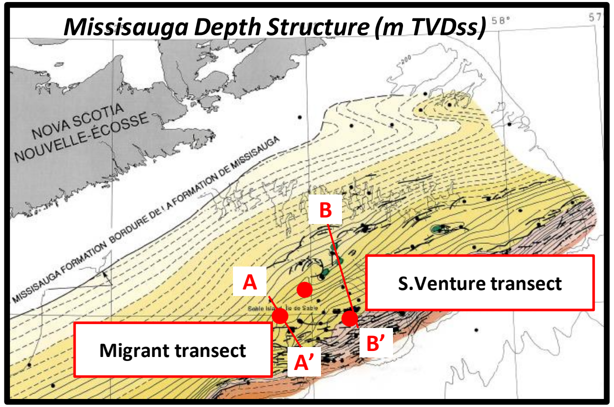


Missisauga % Sandstone & Siltstone

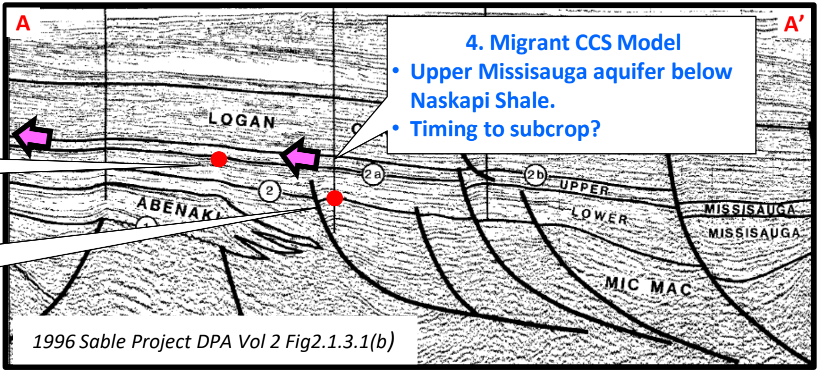
Summary of Dynamic Modeling Presented Here

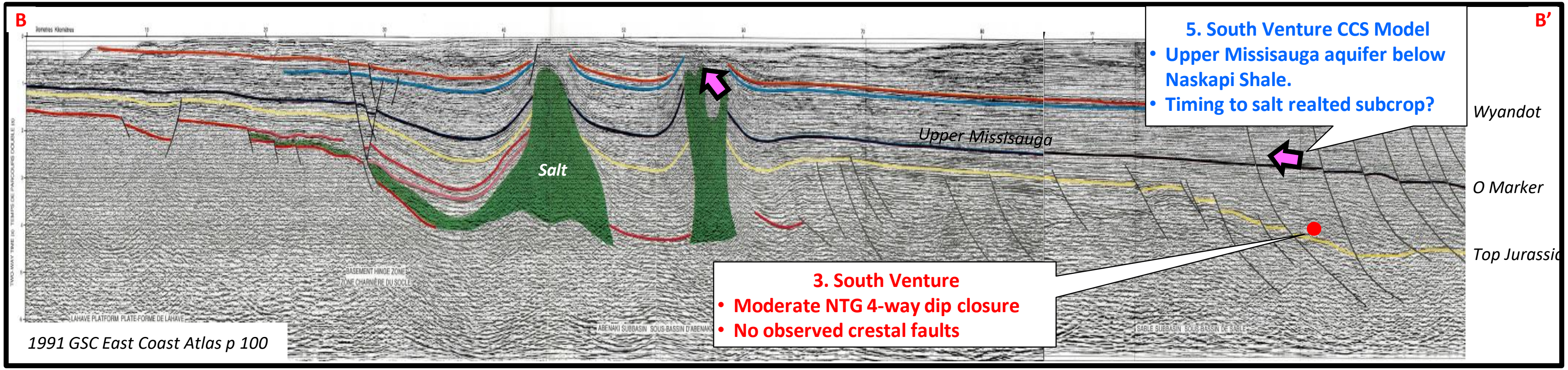
- Objective (1) to understand "fill & spill" fluid migration (leakage) in hydrocarbon traps
- Objective (2) to understand CCS migration paths and timing – worst cases (large grid cells & dissolution not modeled)



1. Penobscot (~25km NE)
- high NTG faulted structure

2. Migrant
- high NTG 4-way dip closure
- with crestal cross fault leak

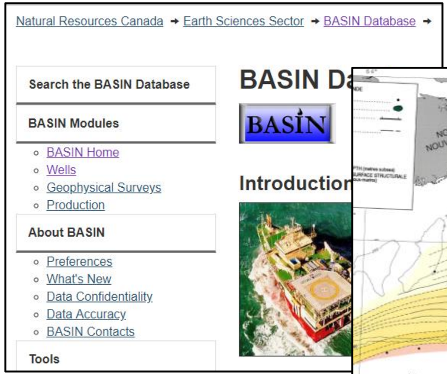




Nova Scotia Offshore Public Data Base

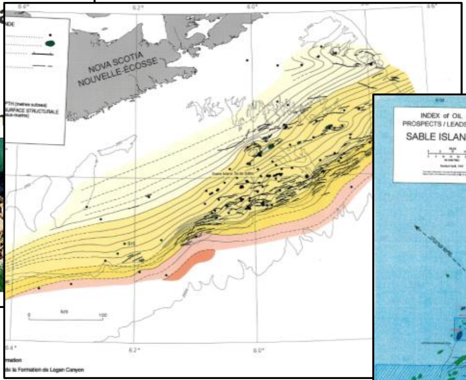
GSC 'BASIN' Database

- Downloadable Excel files of well data
- Pressure, Geochem. Temp. Maturity,
- Lithostrat, Biostrat etc.



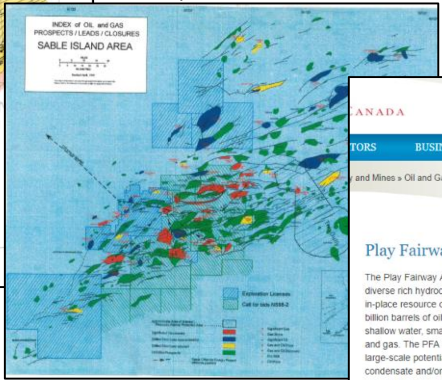
GSC 2011 East Coast Basin Atlas Series

- Multiple maps, logs and sections



NS Petroleum Directorate 1999 Map

Prospects, Leads and Closures

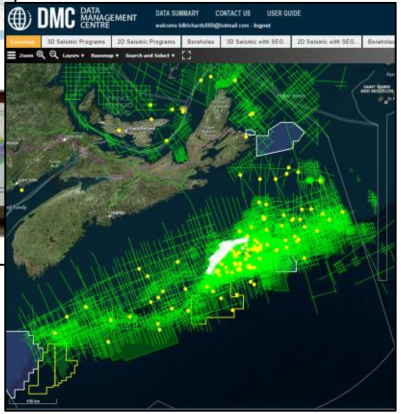


DOE / OERA / PFA

2011 & 2016 Play Fairway Analyses

CNSOPB & CNSOPB DMC

- Multiple reports and call for bids
- Point and click PDFs of:
- well data and reports
- 2D and 3D seismic data, associated maps and reports



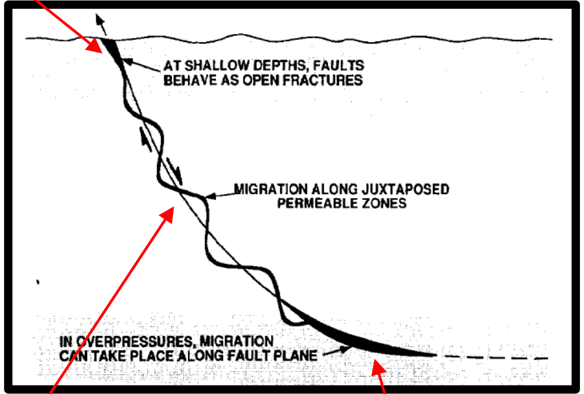
+ Development Plan Applications: Panuke-Cohasset, Sable Offshore Energy Project, Deep Panuke available online

+ Academic Papers

Trapping Mechanisms at Sable

Downey, 1994 AAPG Memoir 60

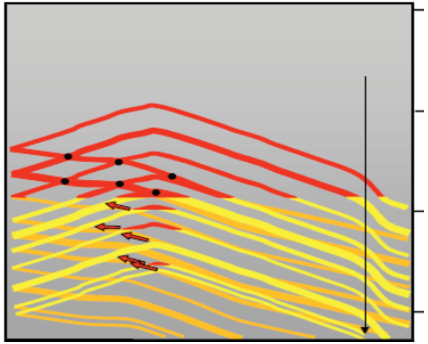
Shallow Depths
- Near vertical faults (low sigma 1) and open fractures



Intermediate Depths - Moderate NTG
- Hydrostatic pressures
- Permeable system connected to SL via cross-fault reservoir juxtapositions

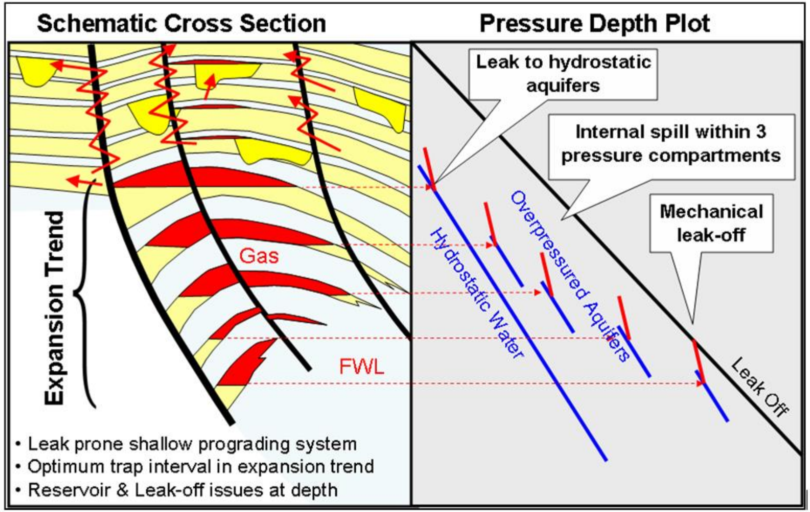
Base of prograding system - Low NTG
- High pressures due to HC generation
- Capillary leak, hydraulic fracturing
- Temporary opening of fractures / faults

James et al, 2004 AAPG v88



Faults Plane Profile
- Illustrating Cross-Fault Leakage
- “Stair-stepping”

Richards et al, 2008 Conjugate Margins Abstract, online



Trapping in Rollover Anticlines at Sable
- Deeper reservoirs at Sable commonly confined to ‘expansion trends’ controlled’ by fault (and salt) movement
- Within these, NTG ratios increase upwards (reservoirs become more proximal upwards as shelf prograded)
- As a result, reservoir connectivity increases upwards, traps become less effective upwards, and overpressure (due to recent charge) is released in steps to the hydrostatic system until the system becomes equilibrated.

IPCC 2005: Mechanisms, Properties & Storage Options

Storage Mechanisms

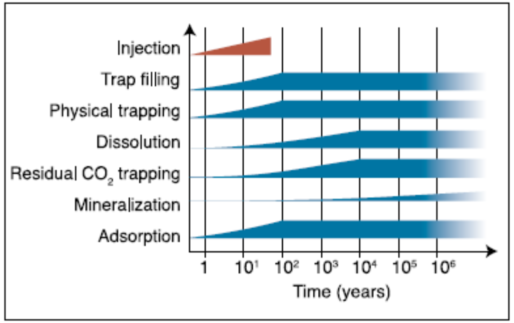
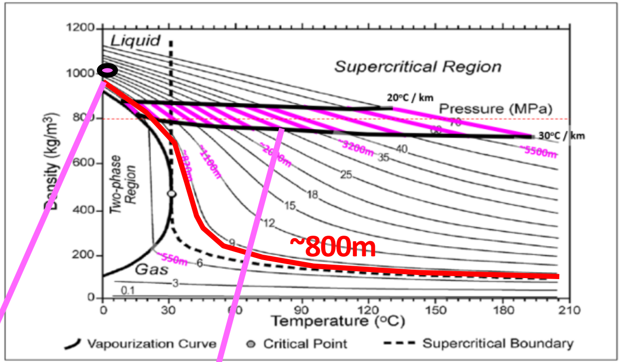


Figure 5.18 Schematic showing the time evolution of various CO_2 storage mechanisms operating in deep saline formations, during and after injection. Assessing storage capacity is complicated by the different time and spatial scales over which these processes occur.

CO2: Density versus Depth, Pressure and Temperature

Annex I: Properties of CO_2 and carbon-based fuels 387



Mpa/m		Degrees C / km		
0.01093		20	30	25
Mpa	Depth			
3	274	5	8	7
6	549	11	16	14
9	823	16	25	21
12	1098	22	33	27
15	1372	27	41	34
18	1647	33	49	41
21.5	1967	39	59	49
25	2287	46	69	57
30	2745	55	82	69
35	3202	64	96	80
40	3660	73	110	91
50	4574	91	137	114
60	5489	110	165	137
70	6404	128	192	160

Figure AI.2 Variation of CO_2 density as a function of temperature and pressure (Bachu, 2003).

Ocean Storage

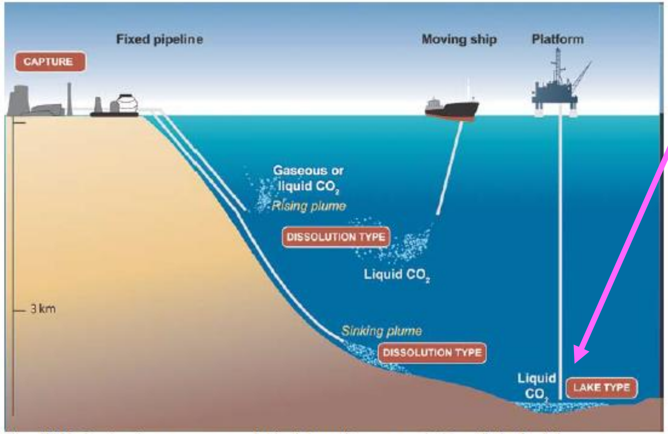
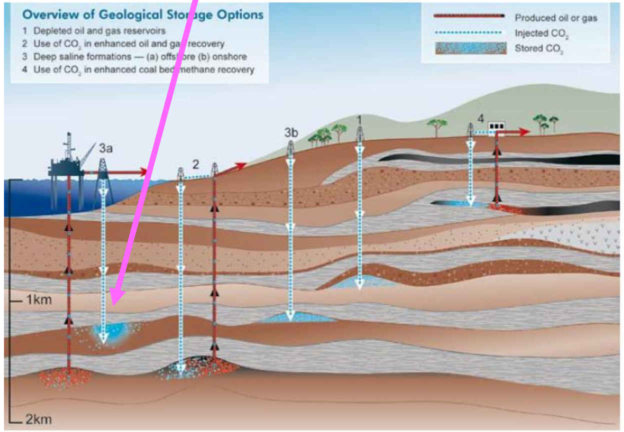


Figure SPM.5. Overview of ocean storage concepts. In "dissolution type" ocean storage, the CO_2 rapidly dissolves in the ocean water, whereas in "lake type" ocean storage, the CO_2 is initially a liquid on the sea floor (Courtesy CO2CRC).

Geologic Storage



igure SPM.4. Overview of geological storage options (based on Figure 5.3) (Courtesy CO2CRC).

CO2 Trap and Seal – Residual Trapping (Krevor, 2015)

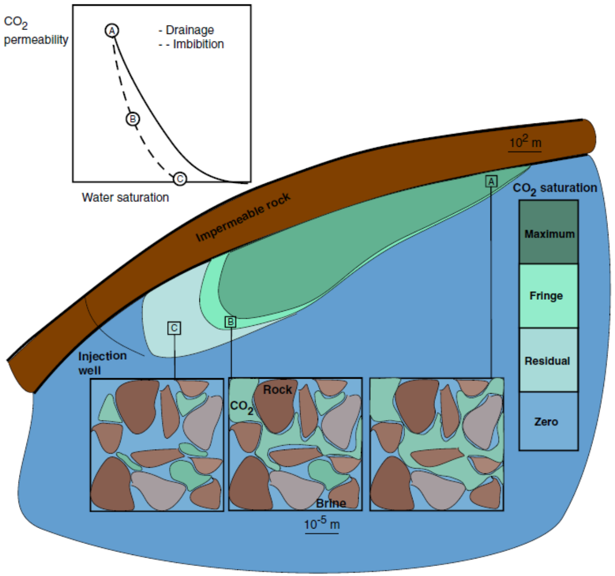


Fig. 1. A sketch of key processes governed by capillary trapping after CO_2 injection has ceased at a storage site. Plume migration is limited by the trapping as large fractions of the plume are immobilised. Capillary trapping is secure over long timescales and avoids buoyant stress on overlying cap rock layers. Trapping is also key to parameterising hysteresis in relative permeability functions – more trapping leads to greater disconnection of fluid ganglia as CO_2 saturation in the pore space decreases (movement from A towards C in the figure) and thus a larger decrease in permeability as a function of saturation.

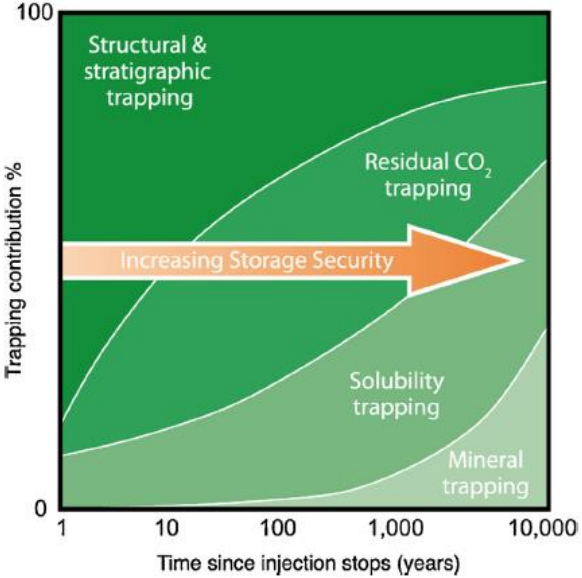
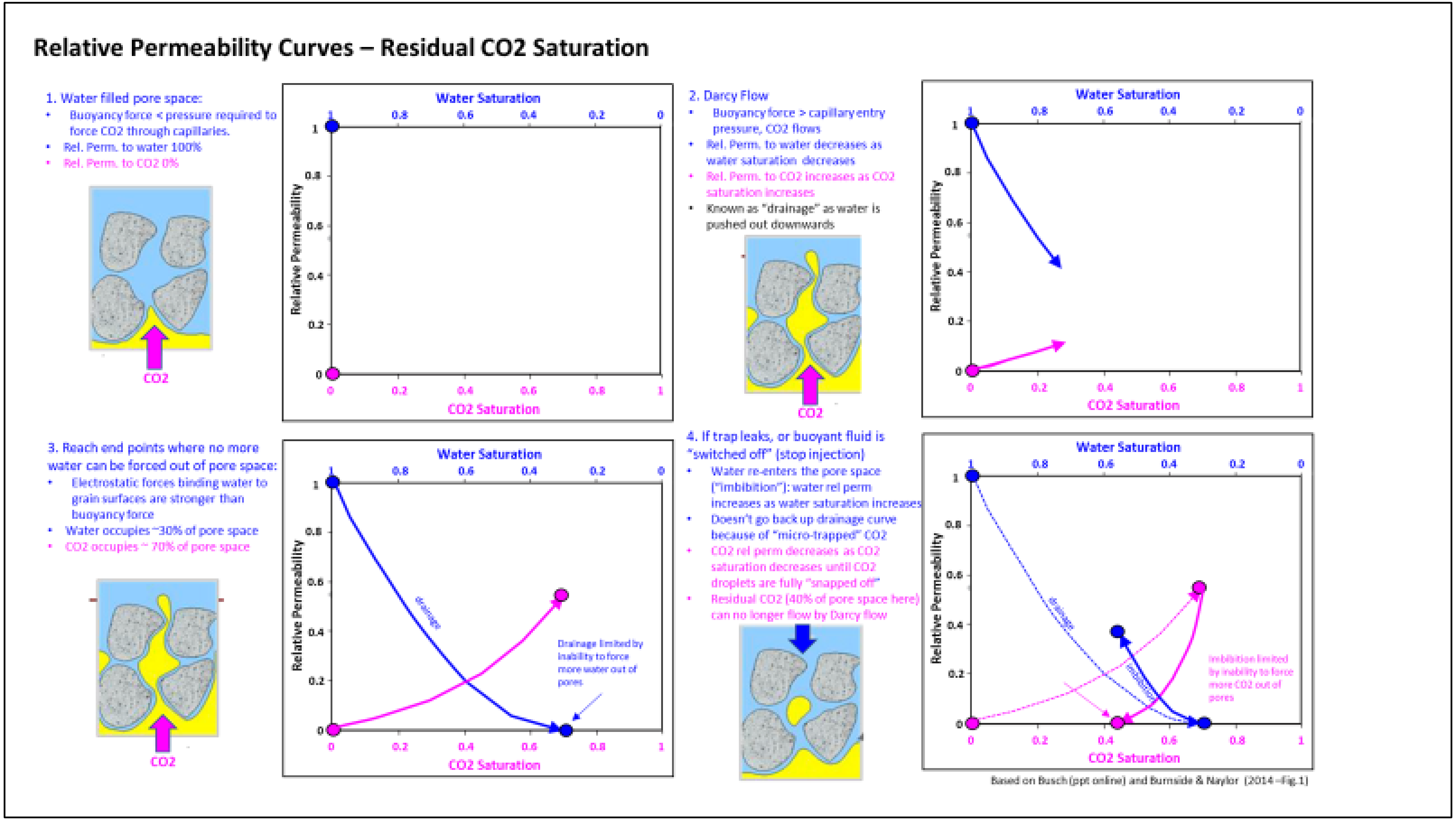
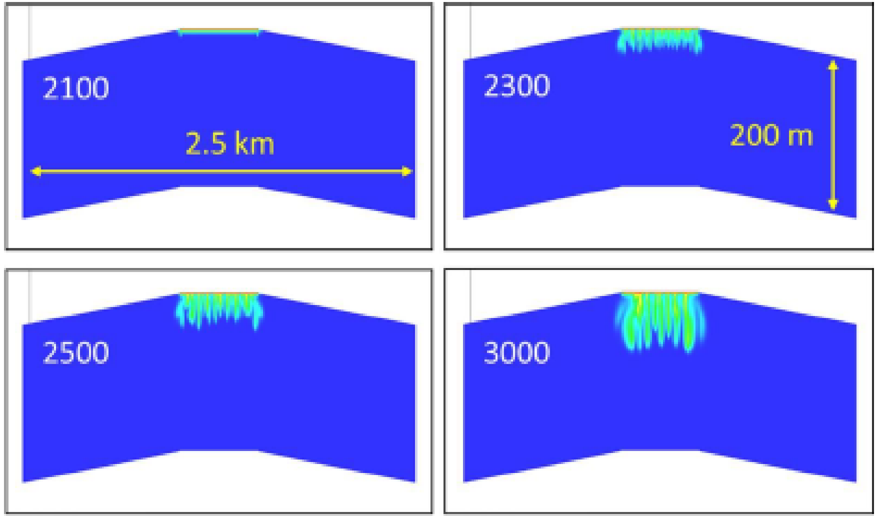


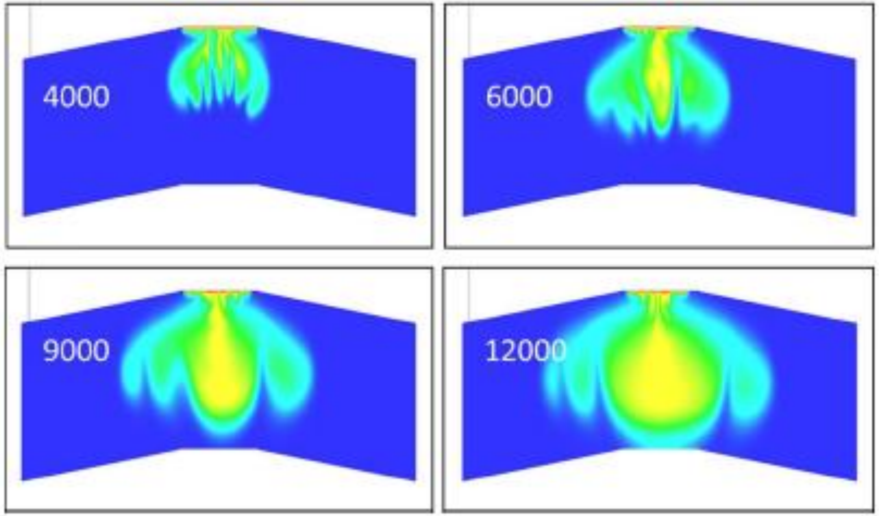
Fig. 2. A schematic of the relative importance of various trapping mechanisms over time, from Benson et al. (2005, 2012). Residual trapping is significant both in the amount of trapping capacity it provides as well as for the speed over which residual trapping takes place, simultaneously with water influx into the migrating plume.

CO2 Trap and Seal – Residual Trapping



CO2 Trap and Seal – Solution (Furnival, 2015)



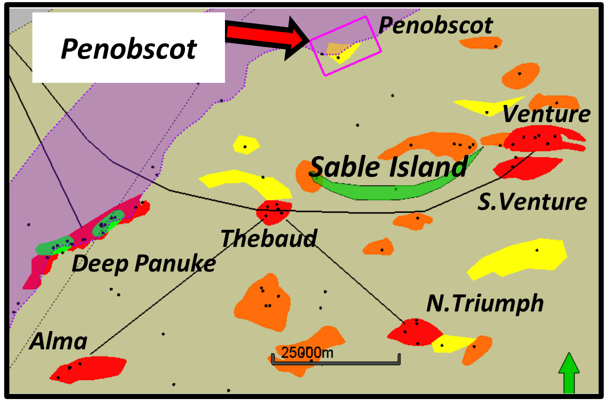


Static and Dynamic Modeling_1
“Leaky” Structure at
Penobscot

Injection of CH4

Static and Dynamic Modeling_1 “Leaky” Structure at Penobscot

- **Penobscot L-30 drilled by Petro Canada & Shell 1976:**
  - ➢ 7 thin hydrocarbon zones mapped, supported by (logs & RFTs)
  - ➢ Valanginian – Hauterivian Middle Missisauga fluvio-deltaic reservoirs
- **Penobscot B-41 drilled by Petro Canada & Shell 1976**
  - ➢ Wet
- **Why is L-30 HC bearing and B-41 wet?**
- **What are the implications for North Penobscot & NE Penobscot Prospects?**
- **Is this a possible CCS site?**



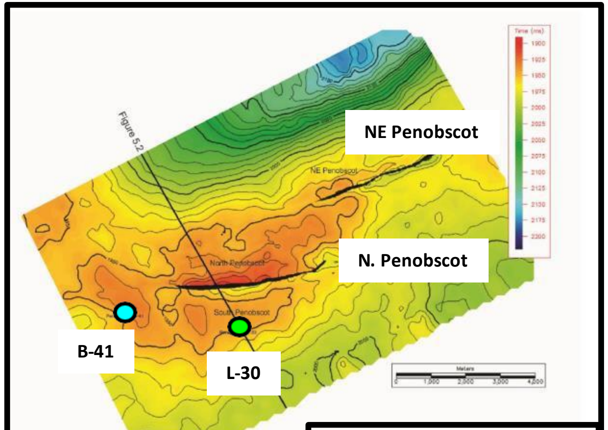
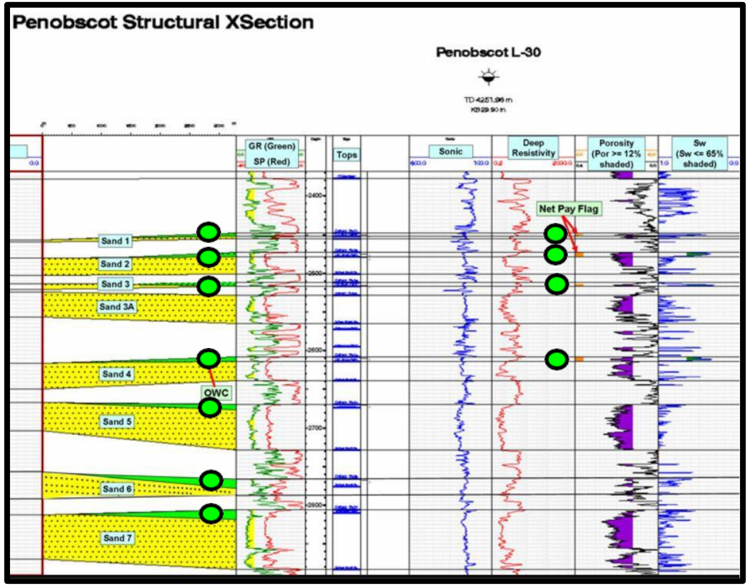
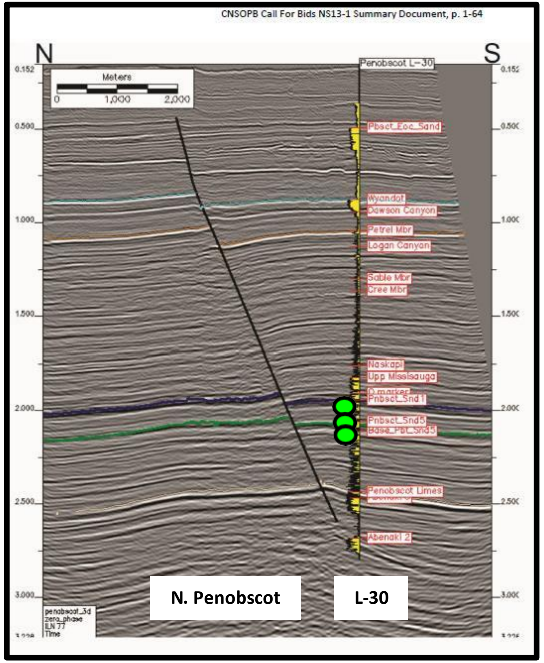


Figure 5.2 Penobscot Pay Sand Time Structure Map

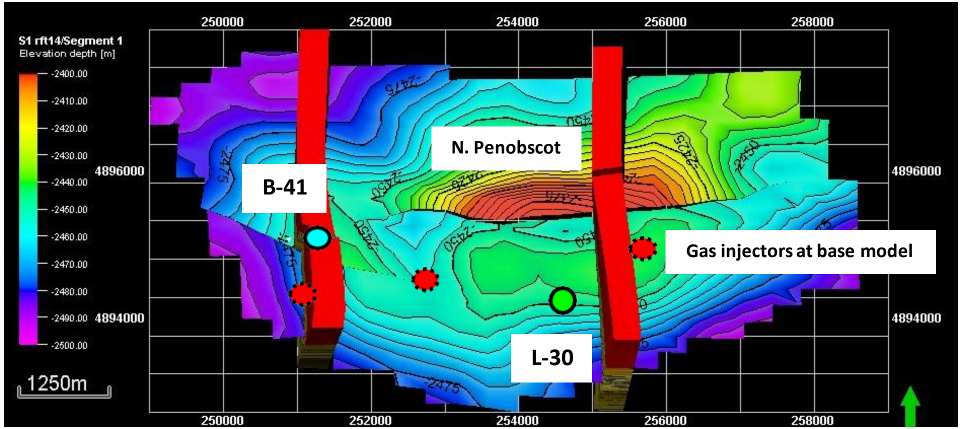


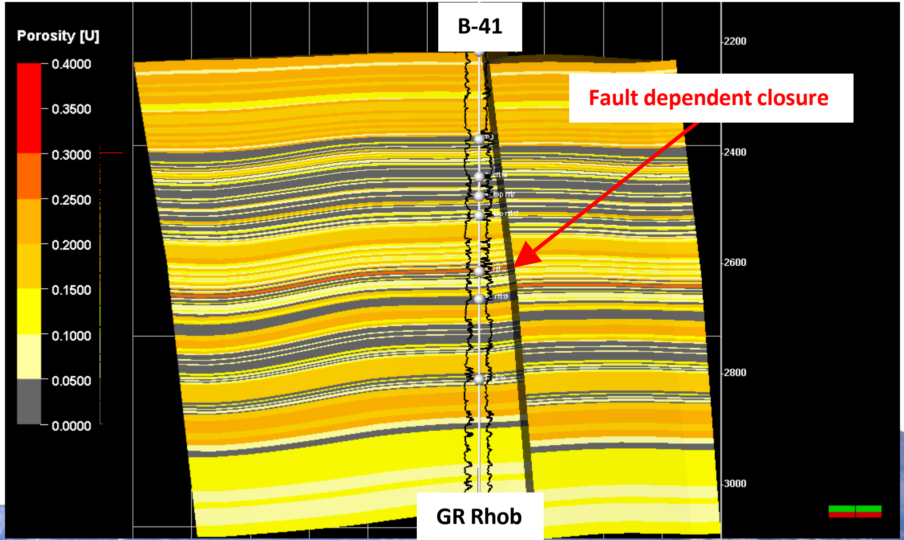


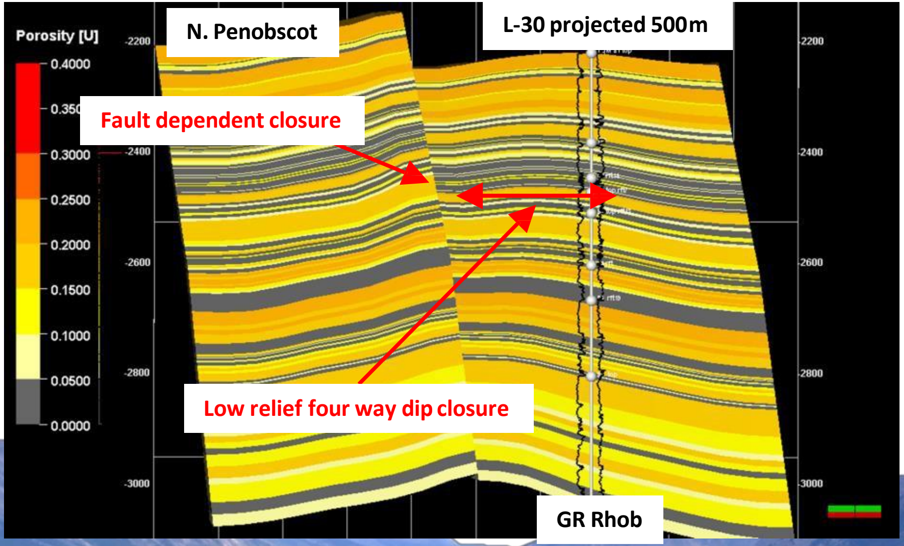
CNSOPB Call For Bids NS13-1 Summary Document, p. 1-64

- **Detailed depth mapping shows:**
  - B-41 trap is fault dependent
  - L-30 is at the edge of a low relief 4-way dip closure

- **Implications**
  - In high NTG fluvio-deltaic section cross-fault leak is prevalent in fault dependent traps
  - Fault dependent hydrocarbon columns in undrilled structures will likely be short, sporadic and hard to predict
  - Undrilled structures are likely 'leaky' and are poor candidates for CCS

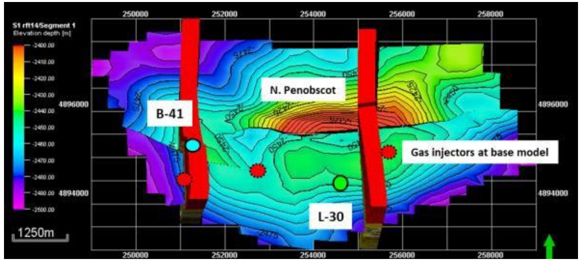


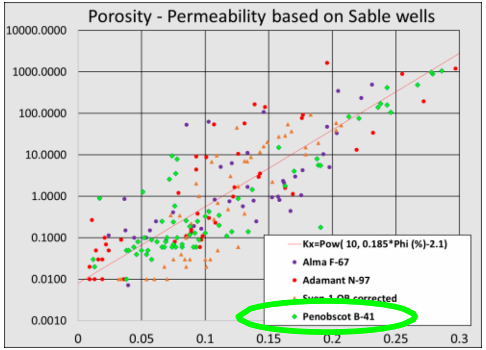


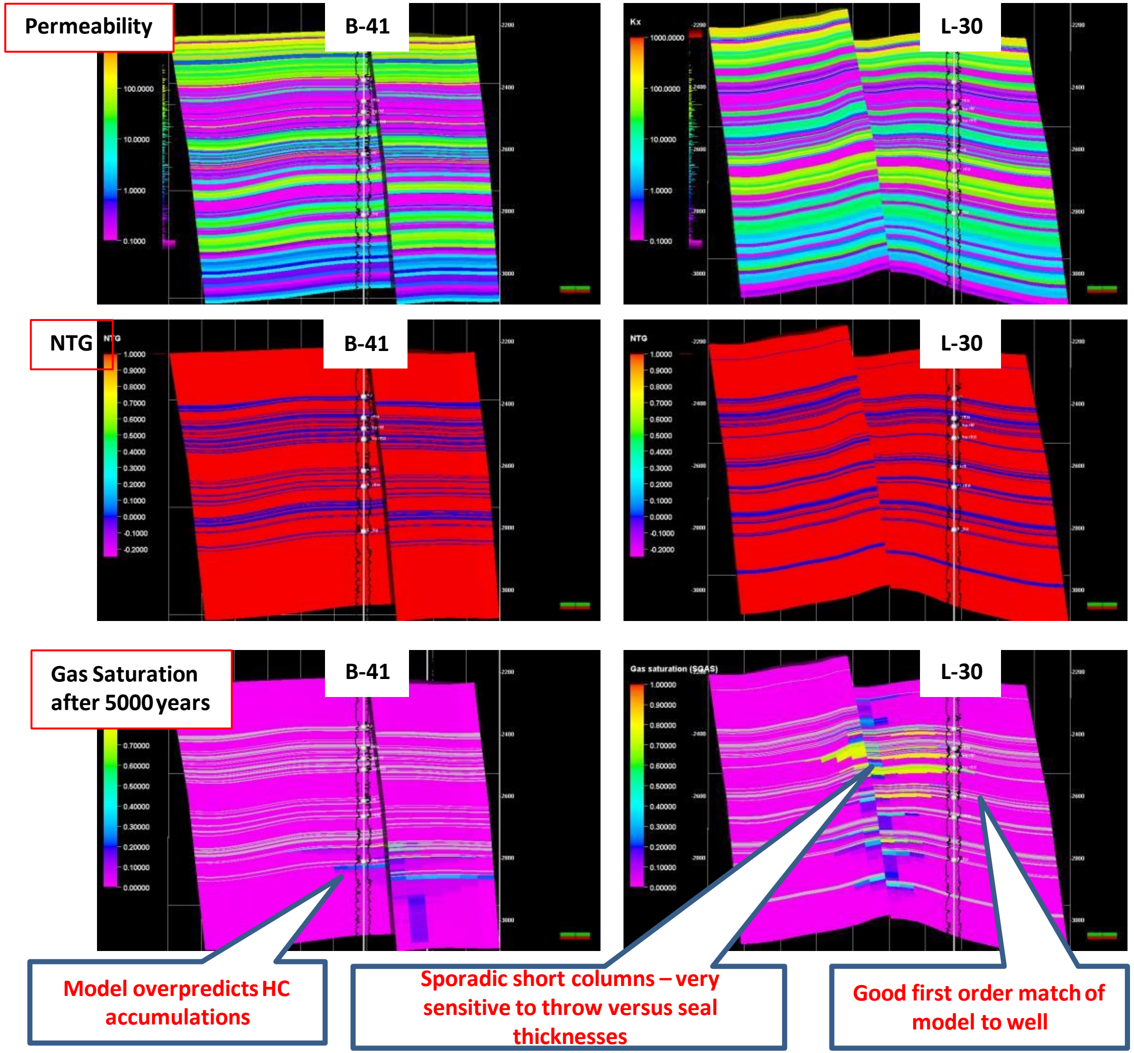


- **Tested these ideas by injecting gas:**
  - at high pressure (600 bars)
  - for 50 years in 3 wells below Sand 7
  - then ran model up to 9999 years.

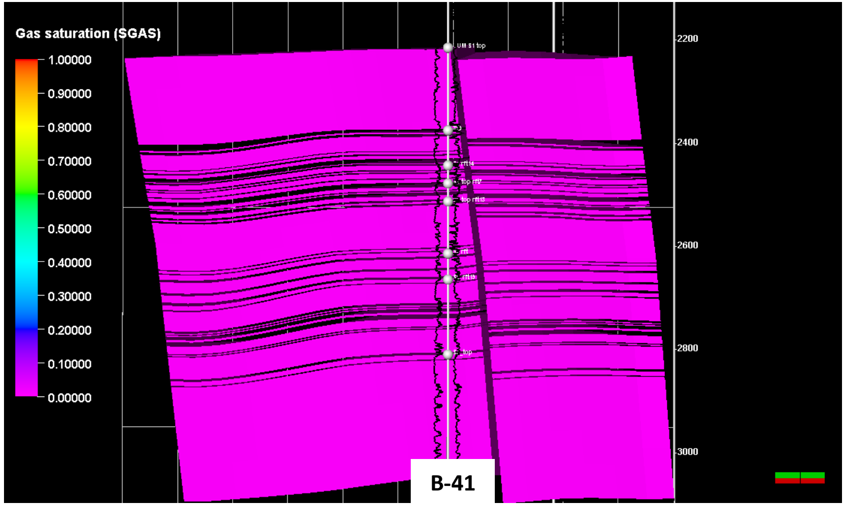
- **Used L-30 & B-41 ‘stratigraphies’**
  - ‘closest point’ algorithm maximises topseal effectiveness and potential to trap hydrocarbons

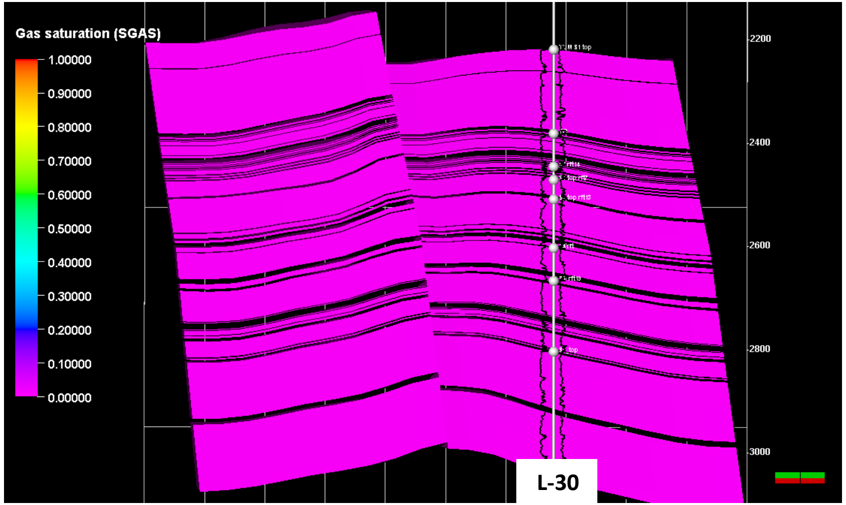


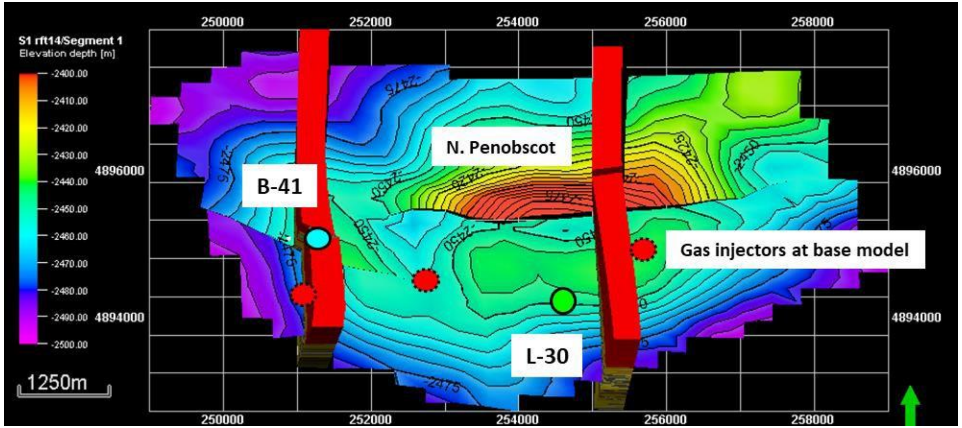




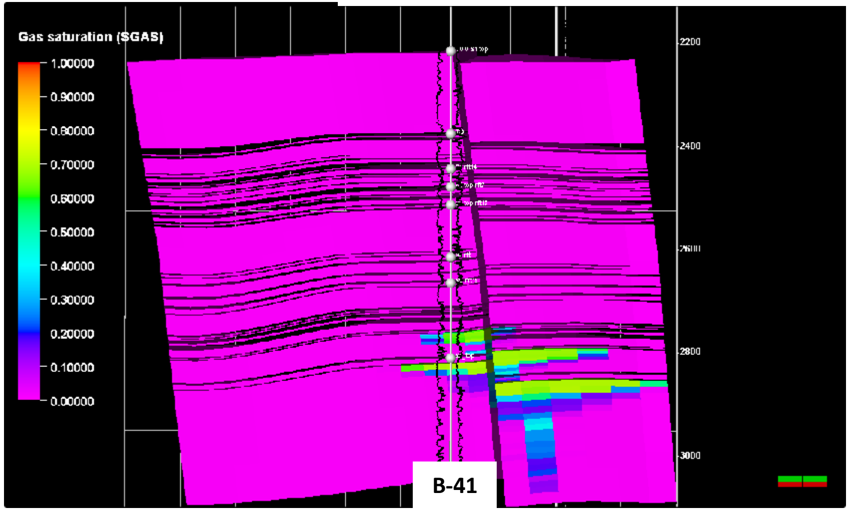
2019: 0 years – start of model

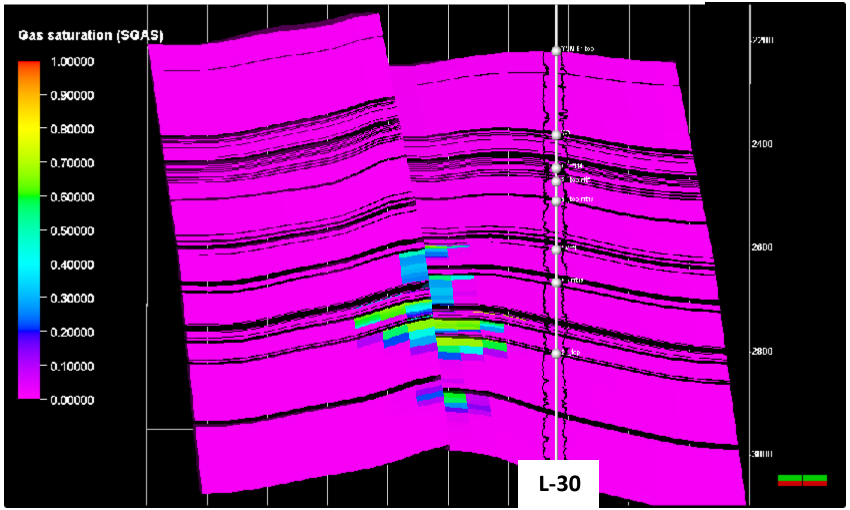


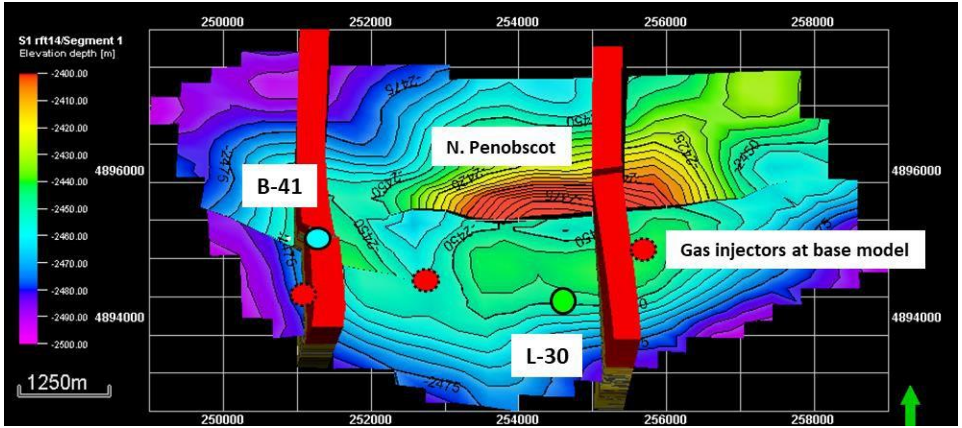




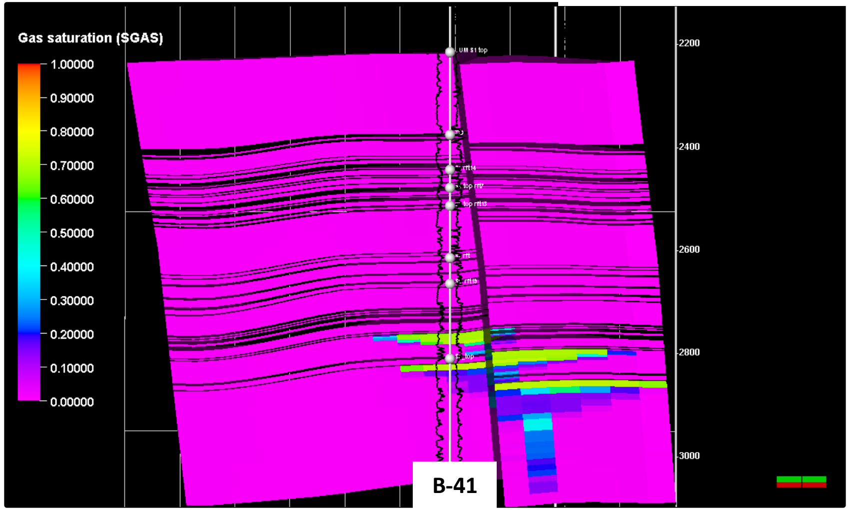
2069: 50 years – end of injection period

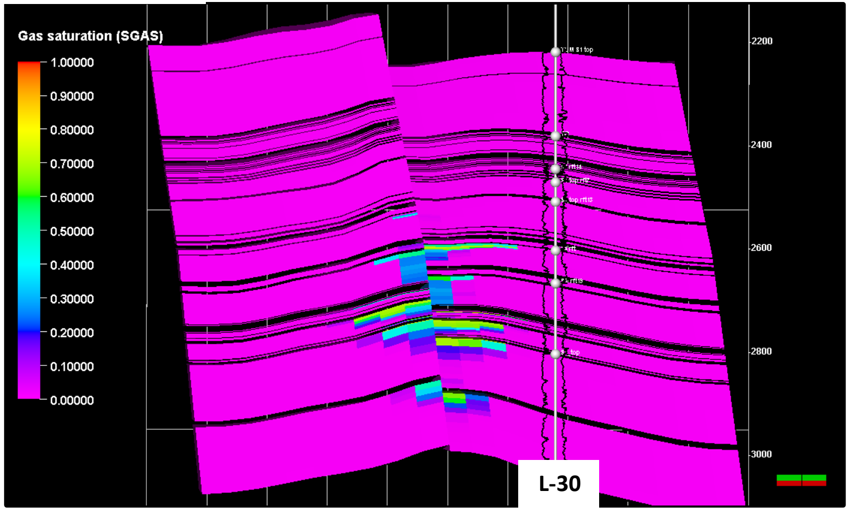


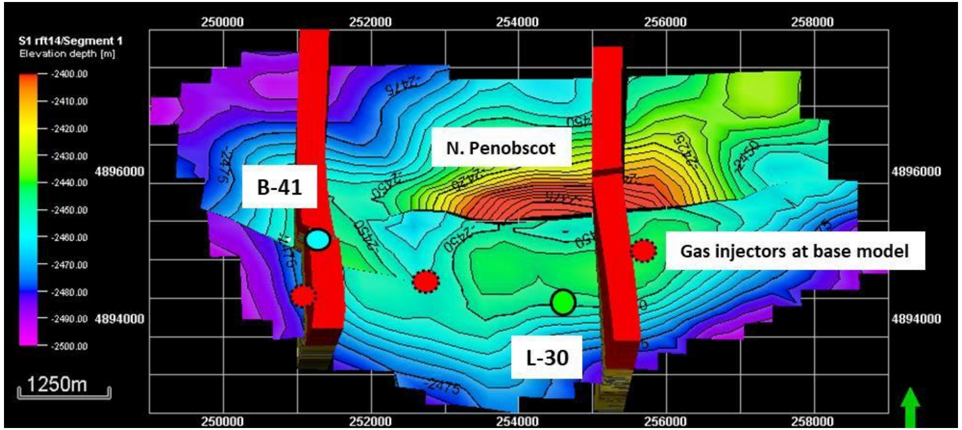




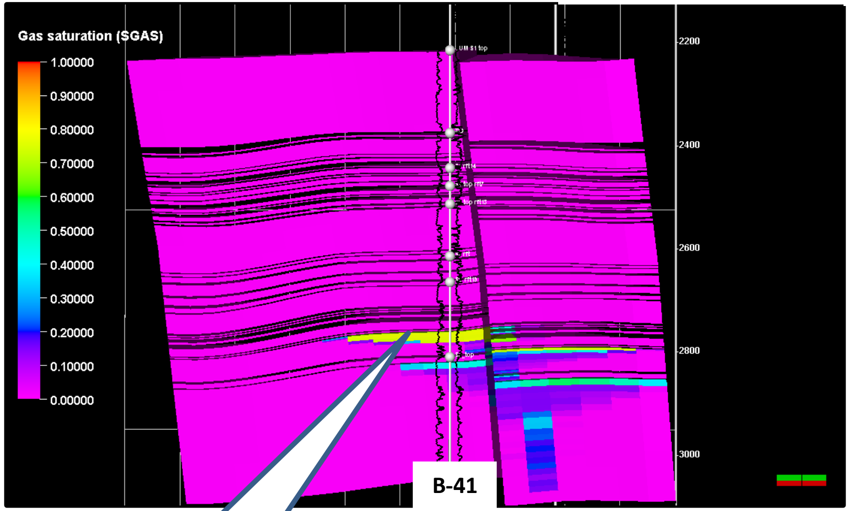
2119: 100 years

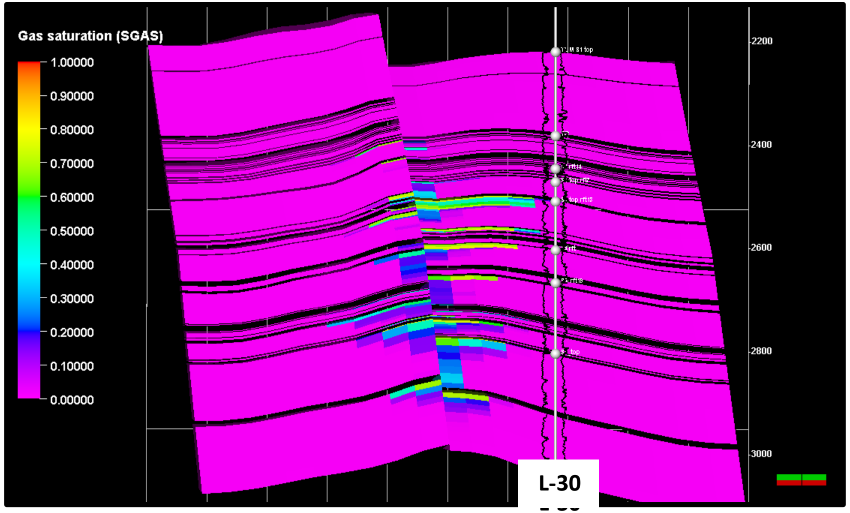




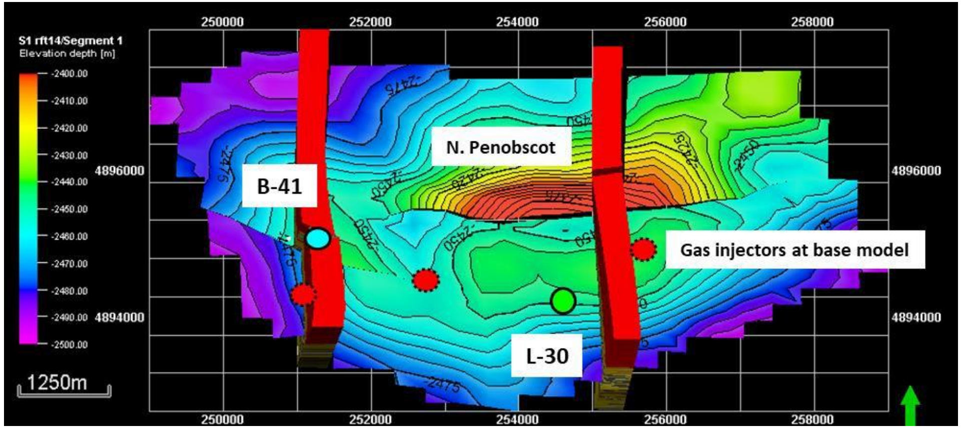


2519: 500 years

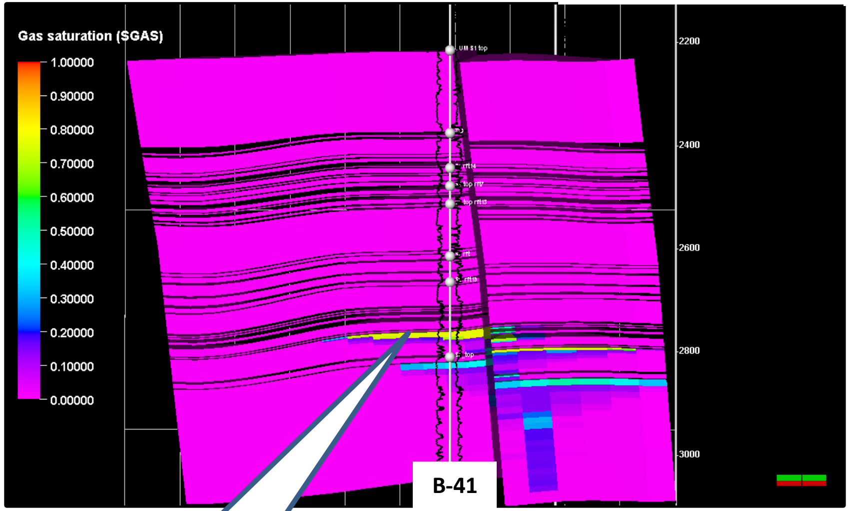


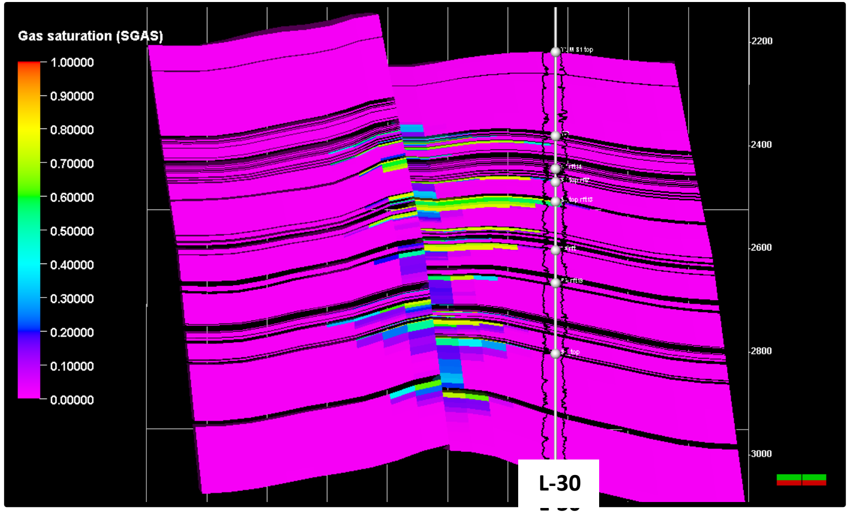


B-41 accumulation at maximum

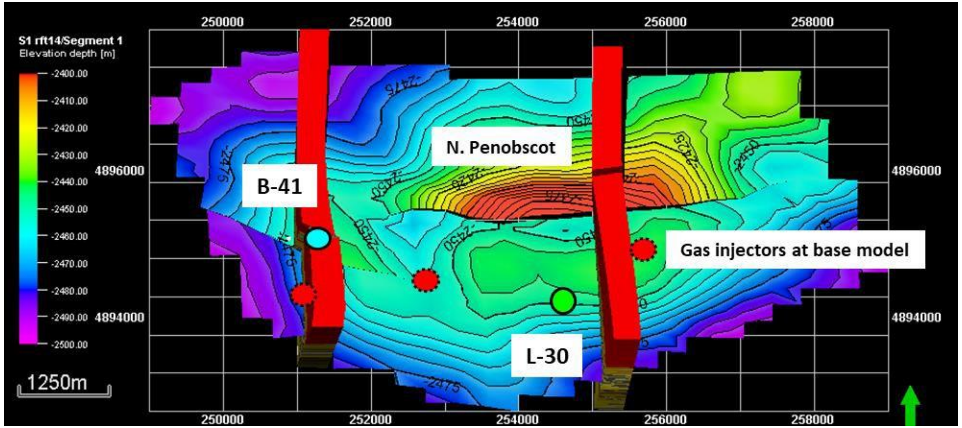


3019: 1000 years

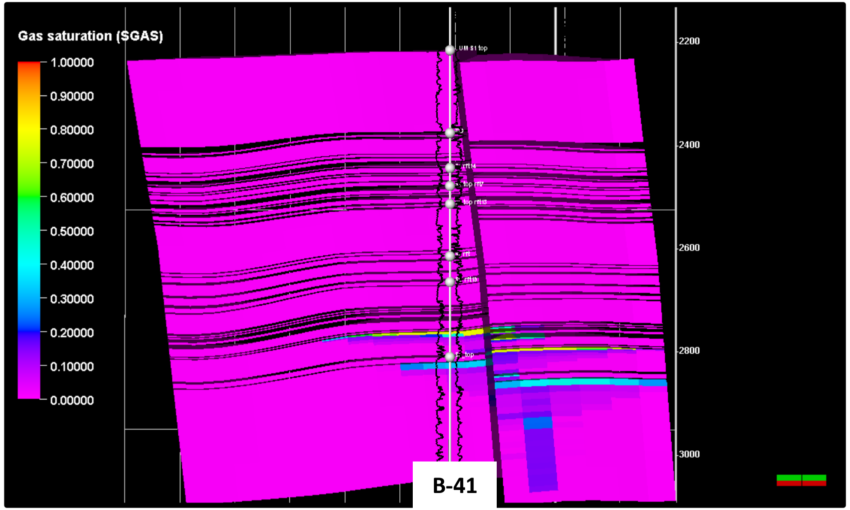


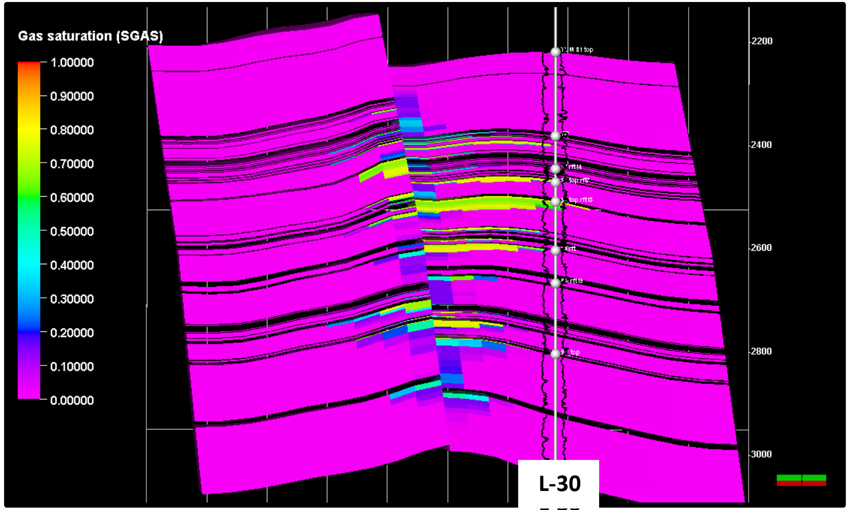


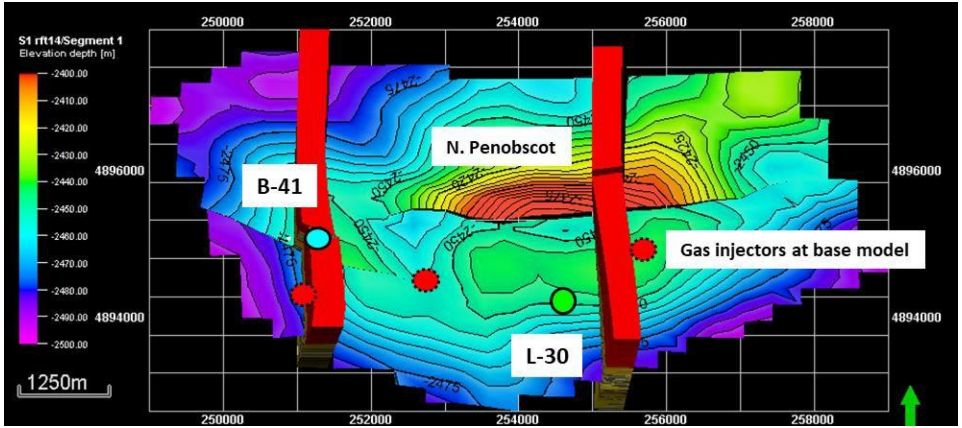
B-41 accumulation diminishing



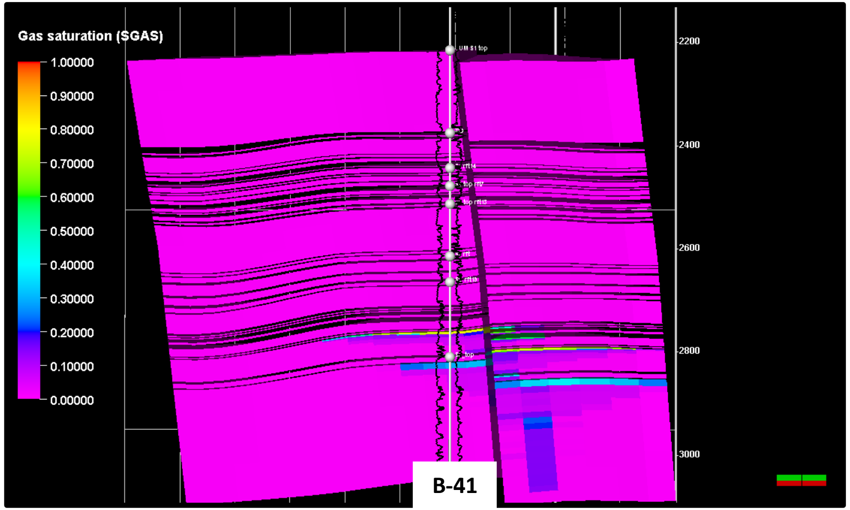
4019: 2000 years

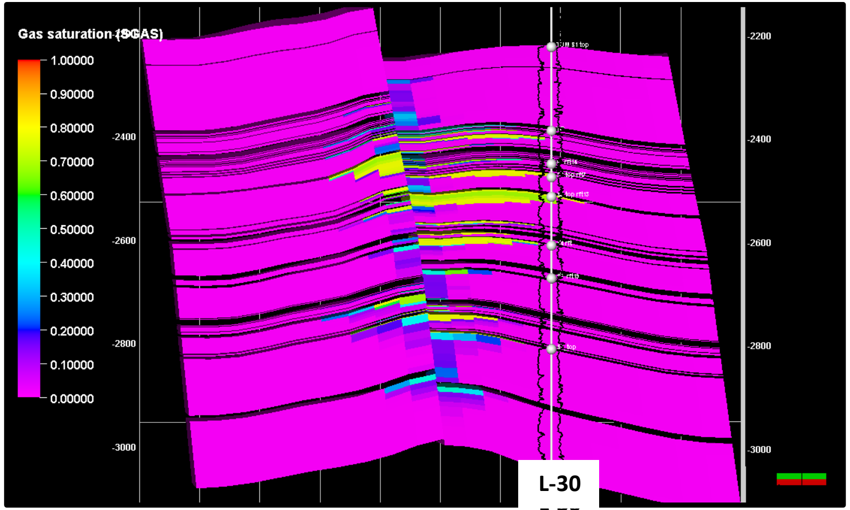


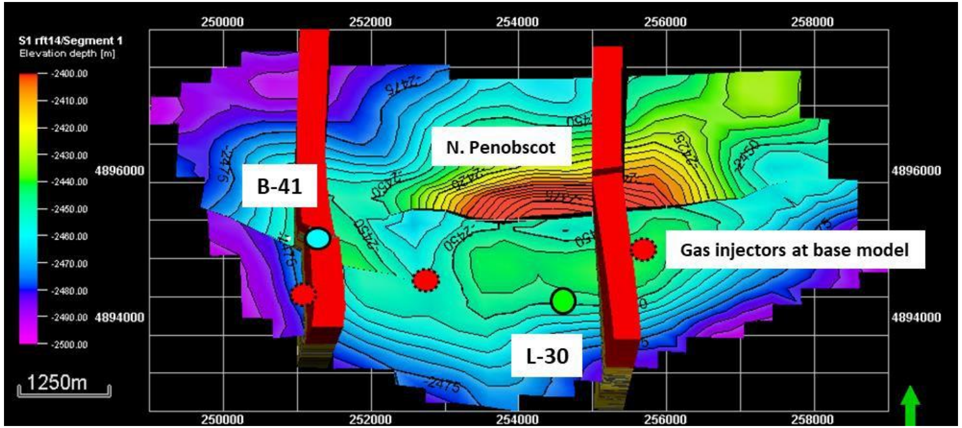




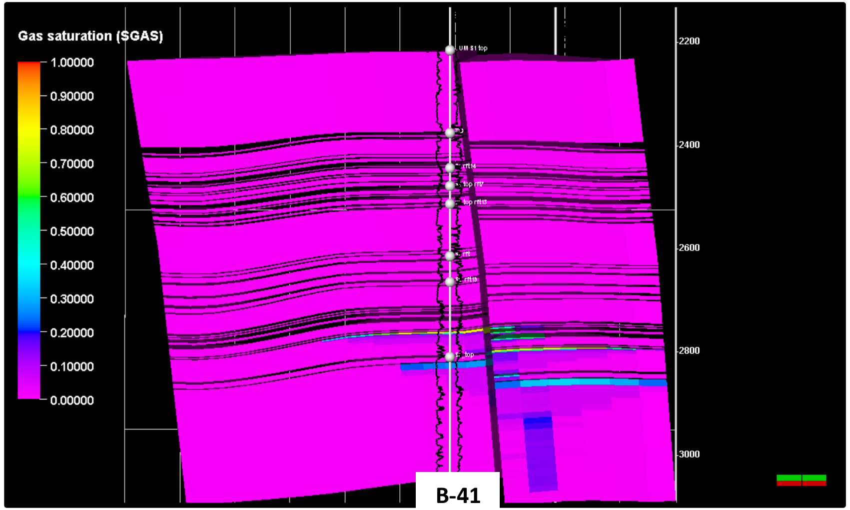
5019: 3000 years

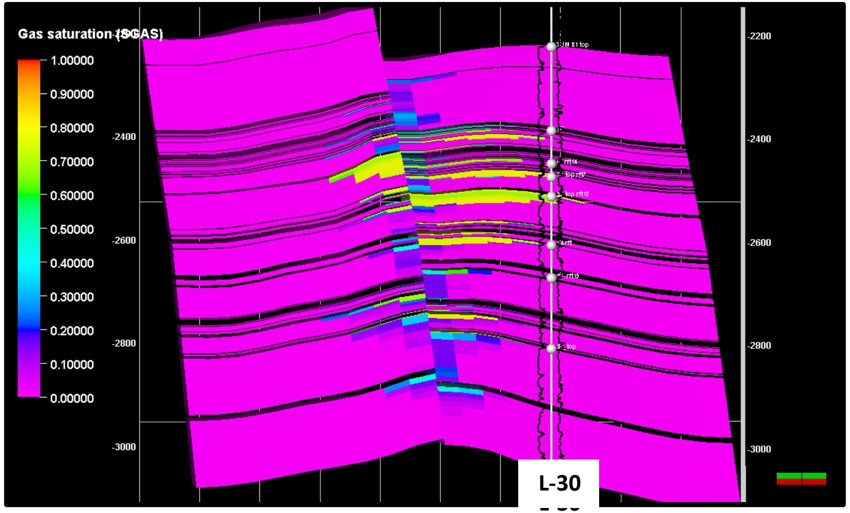


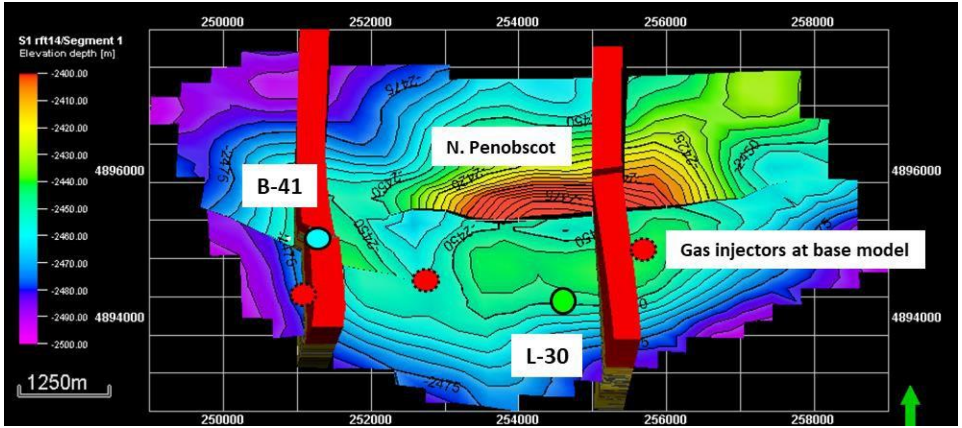




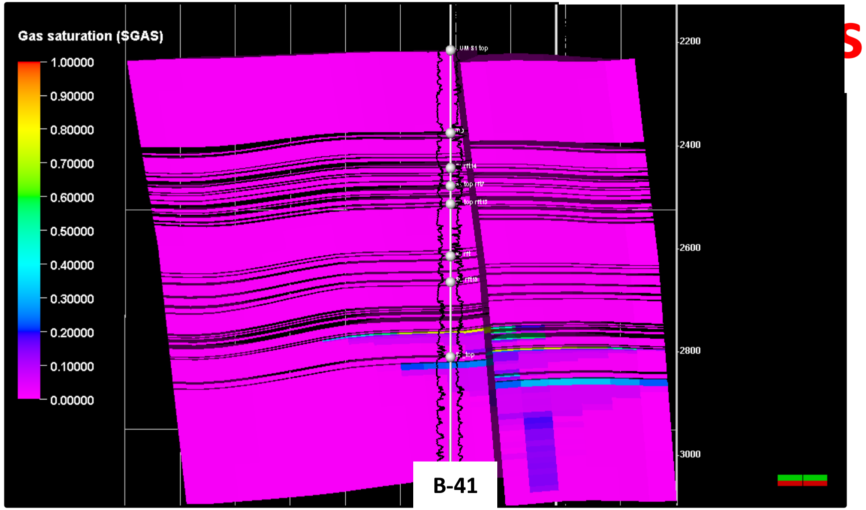
6019: 4000 years

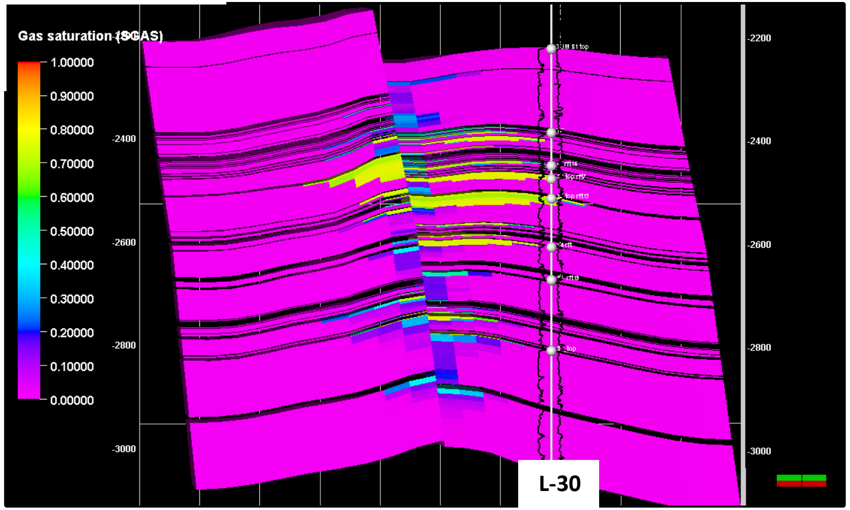


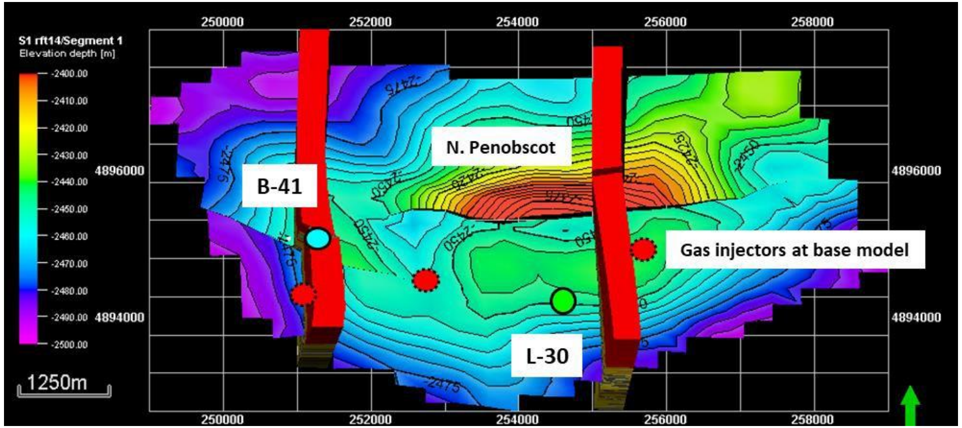




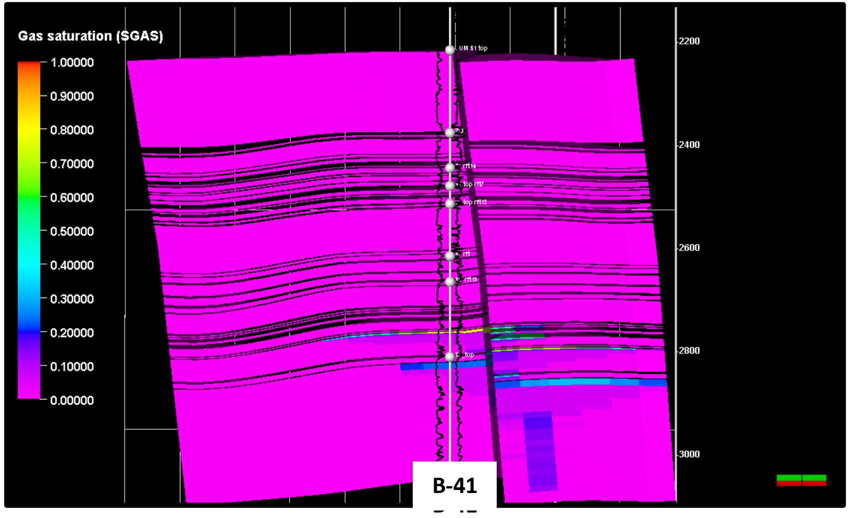
7019: 5000years

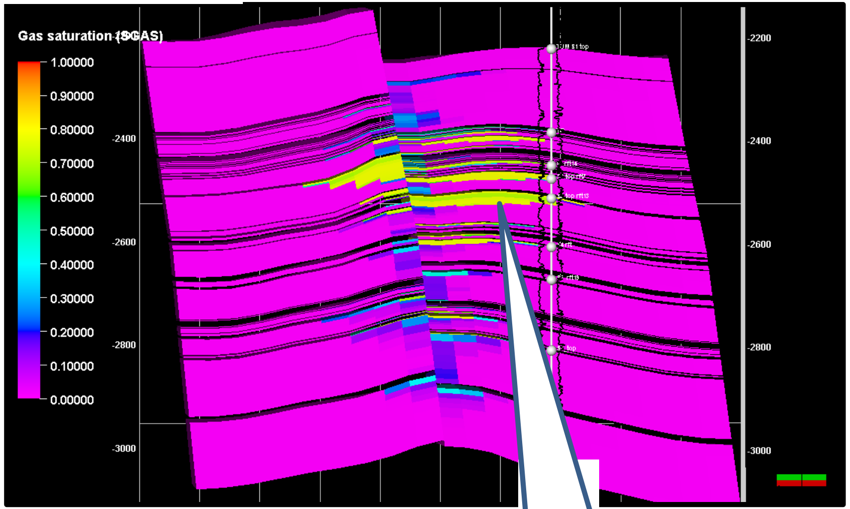


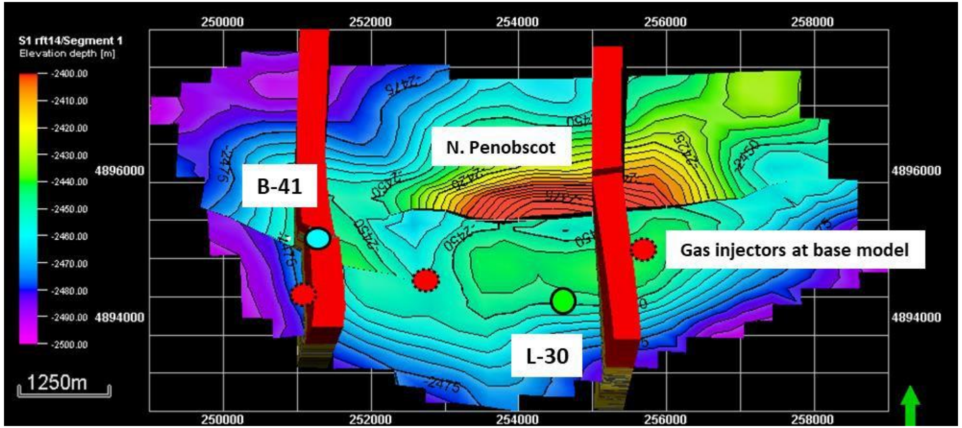




8019: 6000 years

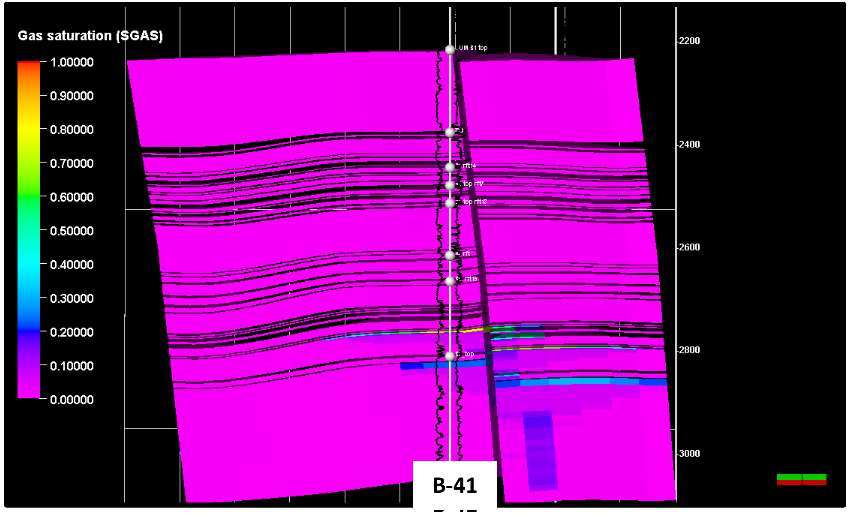


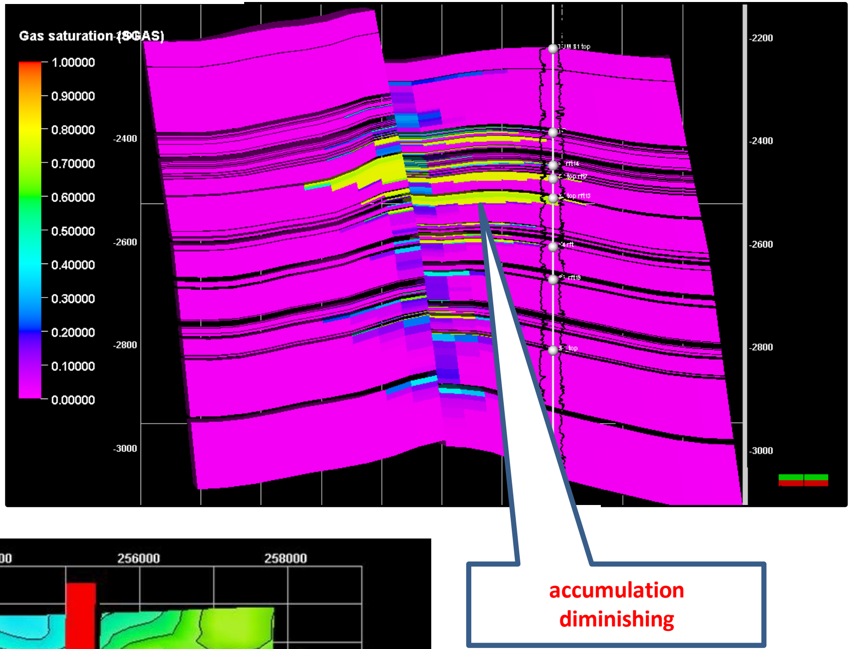


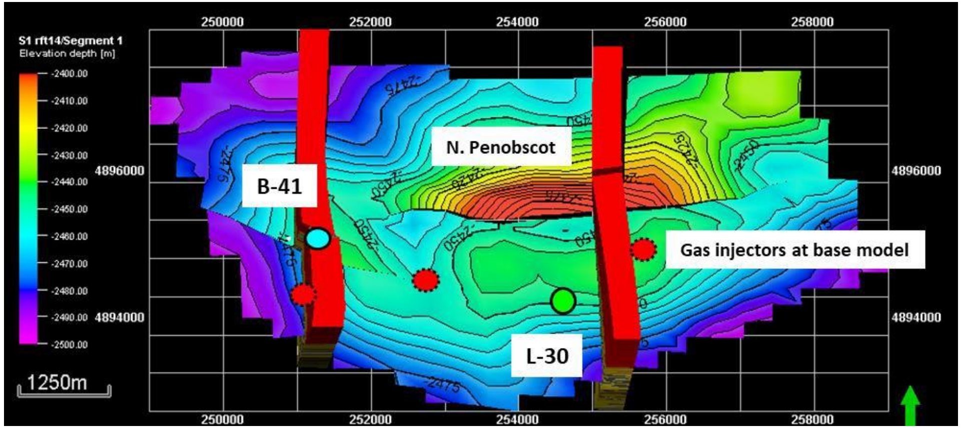


accumulation at maximum

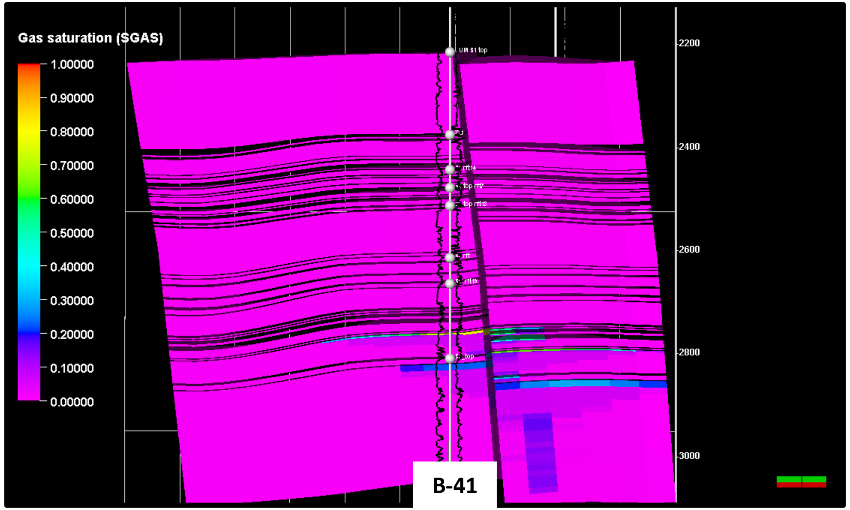
9019: 7000 years

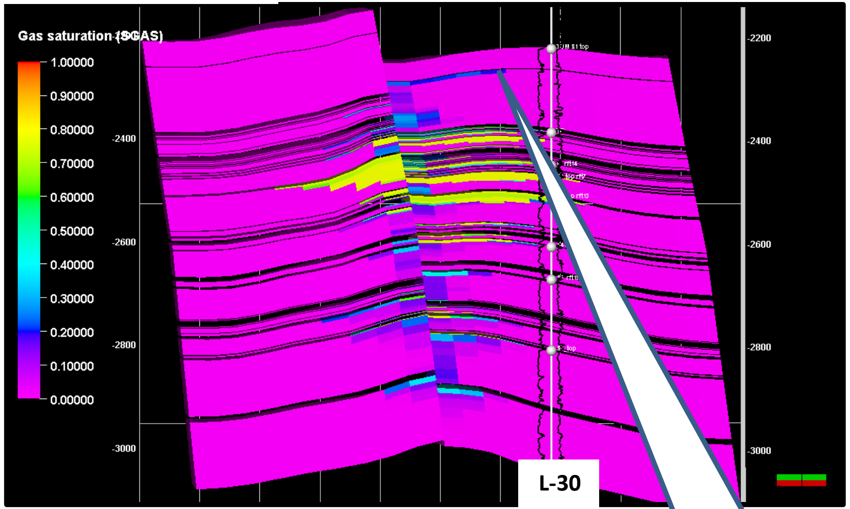


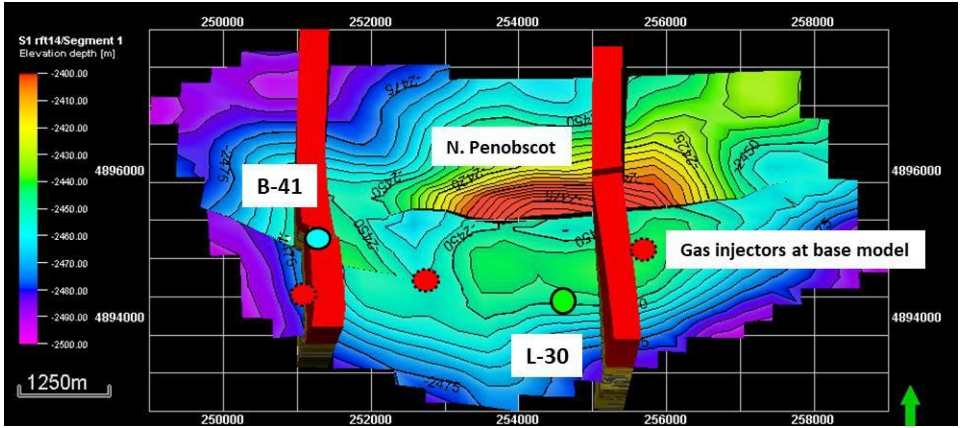




9999: ~7880 years







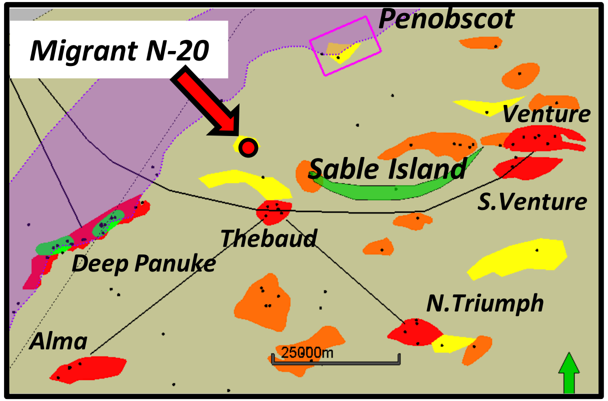
- L-30 still equilibrating at limit of simulation
- Simulation continued in separate model with shallower injection wells and younger stratigraphy

Static and Dynamic Modeling_2
"Leaky" Structure at
Migrant

Injection of CH_4

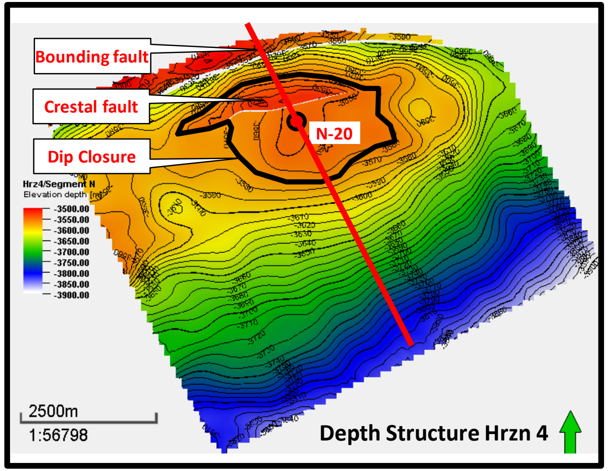
Static and Dynamic Modeling_2 “Leaky” Structure at Migrant

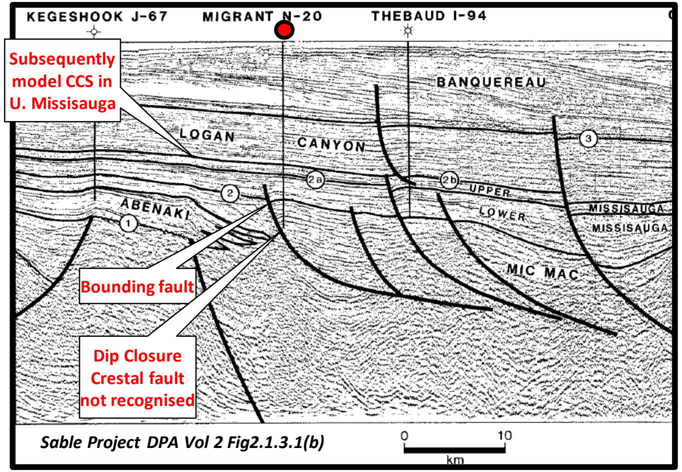
Migrant N-20: Mobil TetCo and PetroCanada (1978)

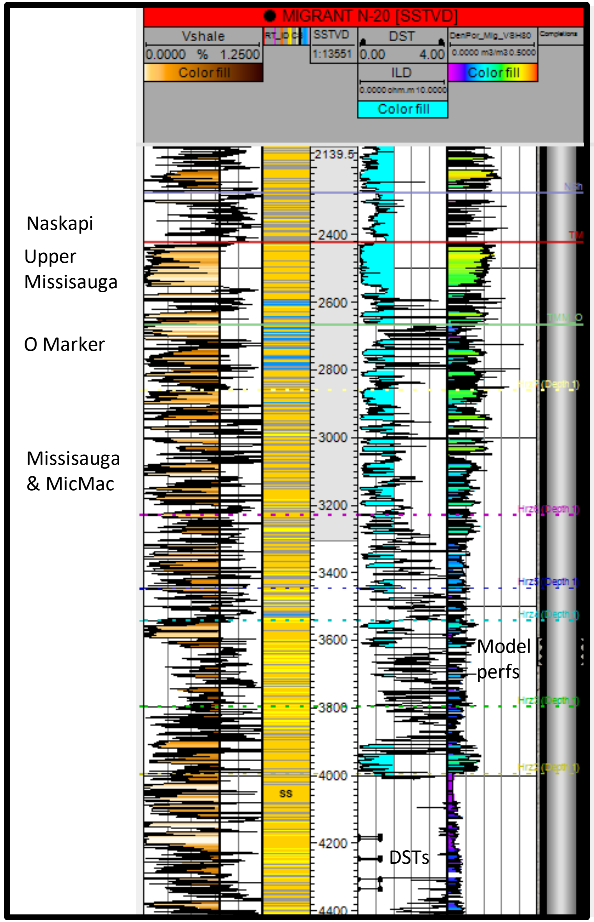


- 4-way dip closure – with ‘minor’ crestal faulting
- High Net to Gross section
- Residual gas in hydro- & over-pressured zones
- Short gas DST from fractured deep tight sand

- Dynamic modeling demonstrates cross-fault leak (throws > shale thicknesses at minor crestal fault
- Overlying monocline modeled here for CCS

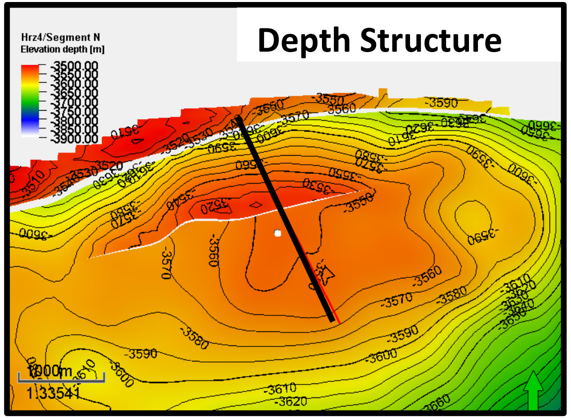


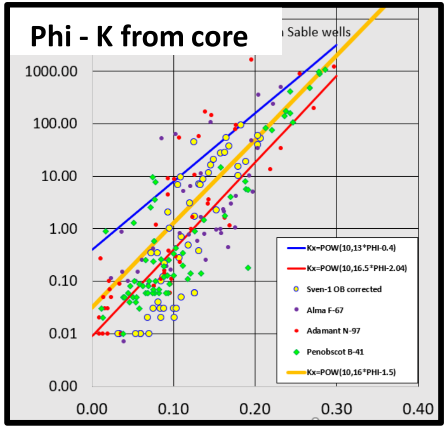


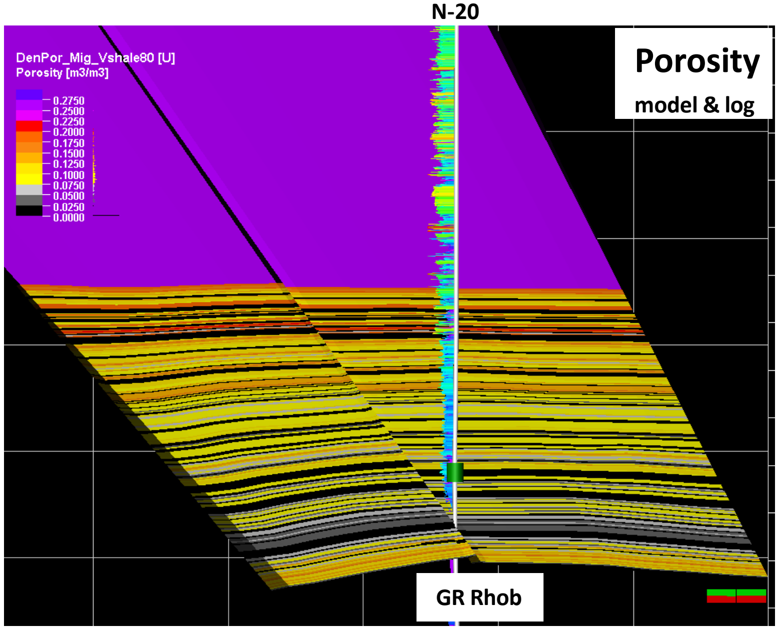


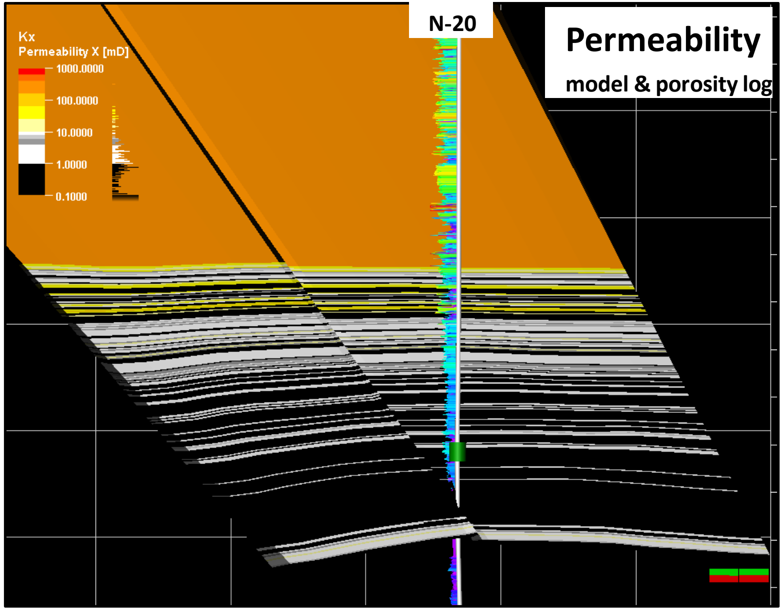
Migrant Static Model

- Log Density with Vshale cut off
- ML Phi-K relationship from core analyses
- Injected CH4 into perfs near base hydro-pressured zones
- Model extends to top of structural closure

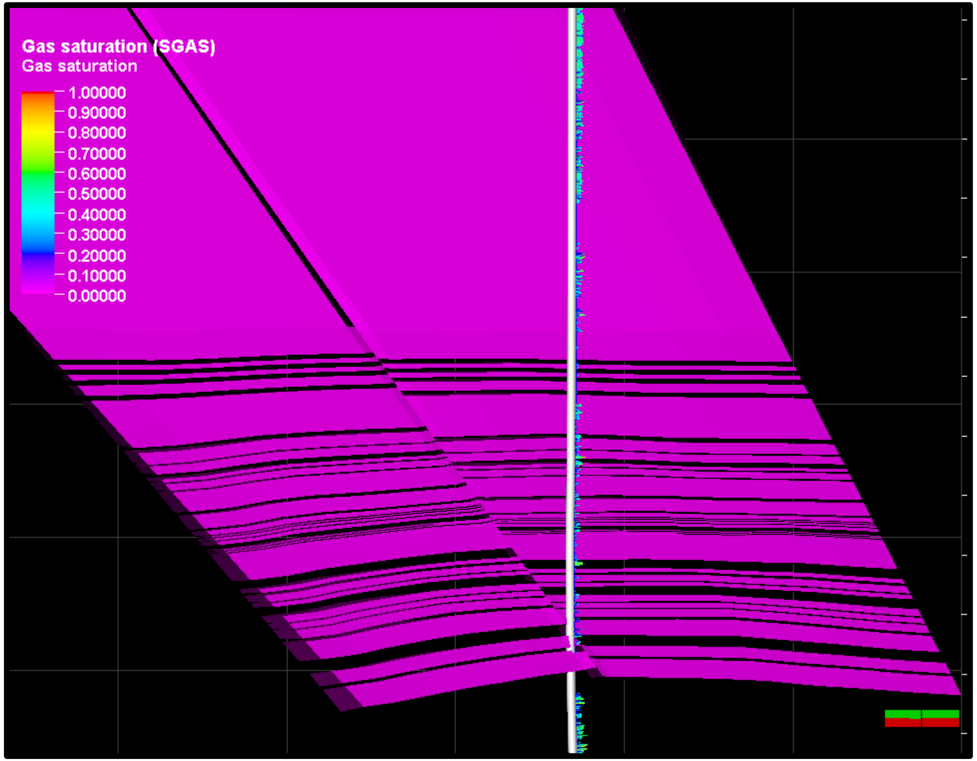


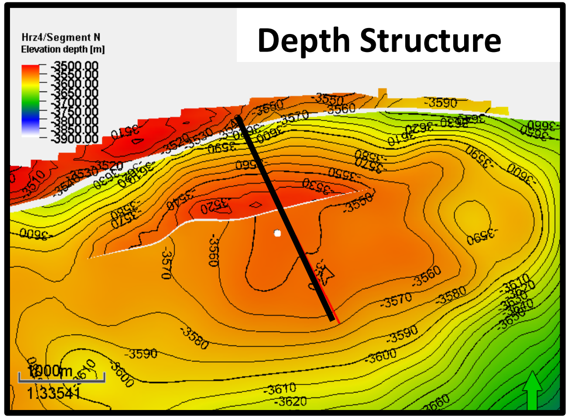




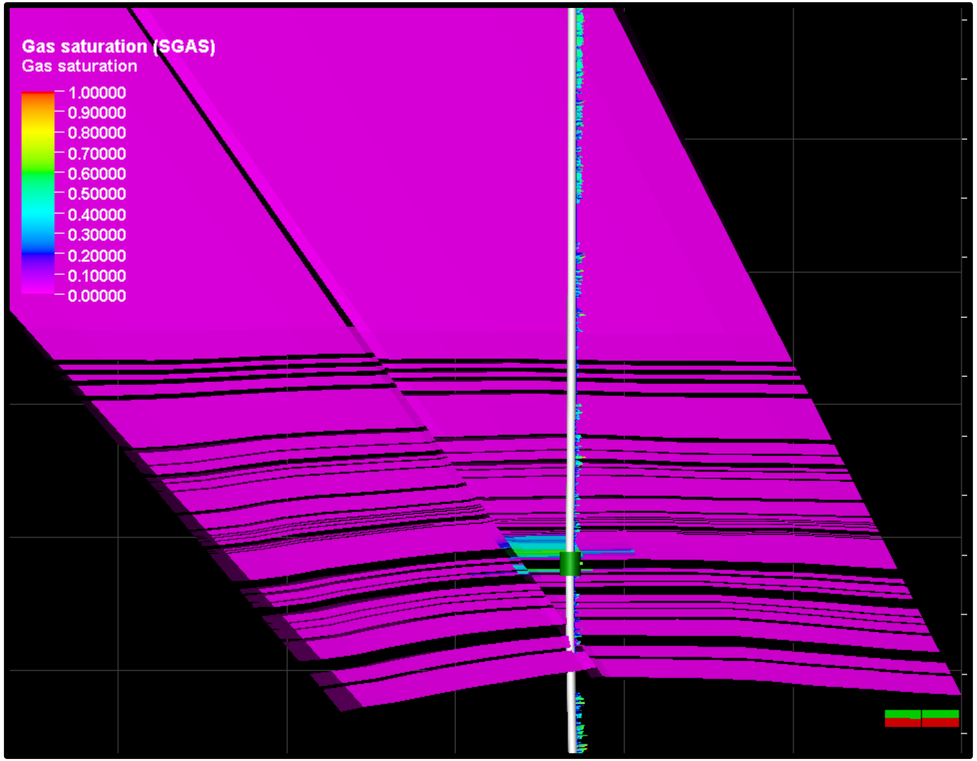


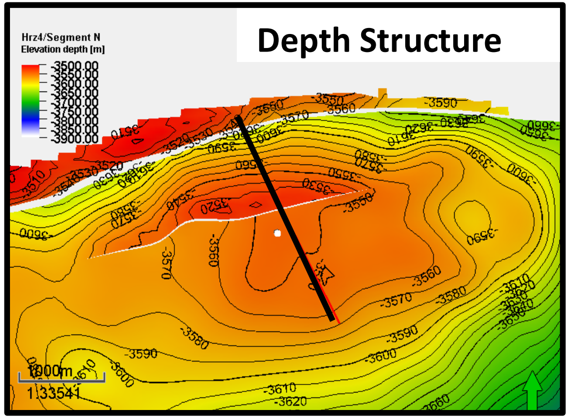
2000: 0 years – start of model



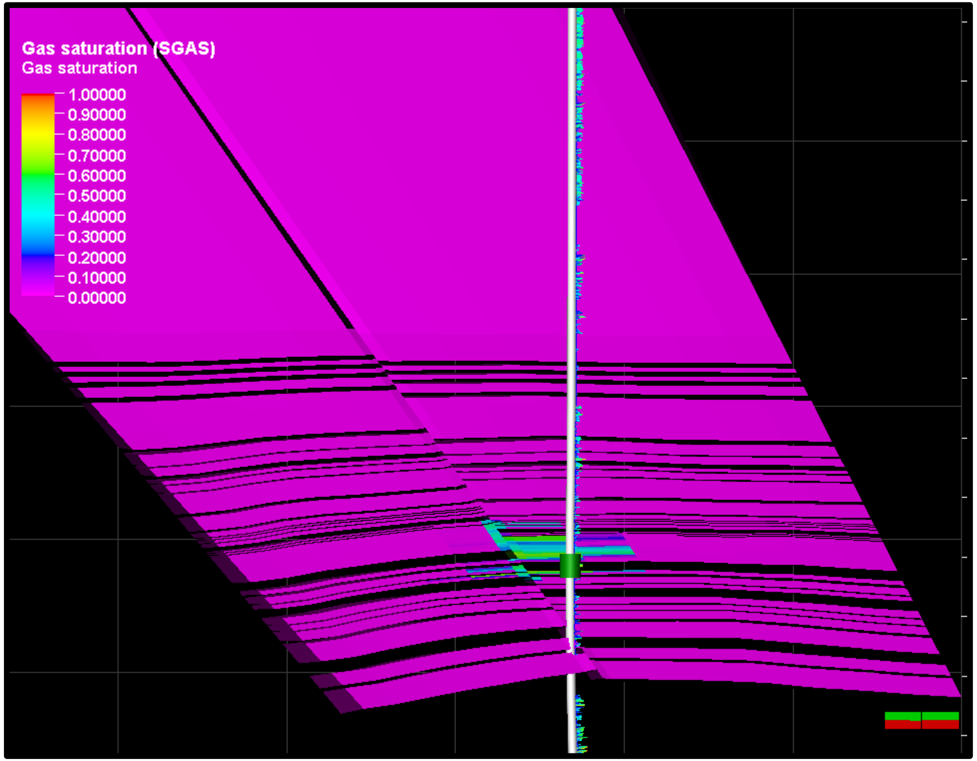


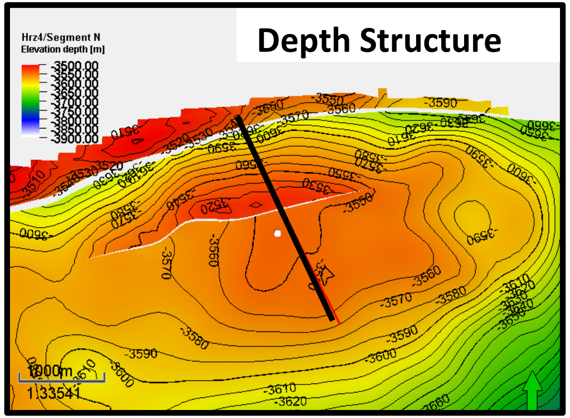
2050: 50 years – of injection



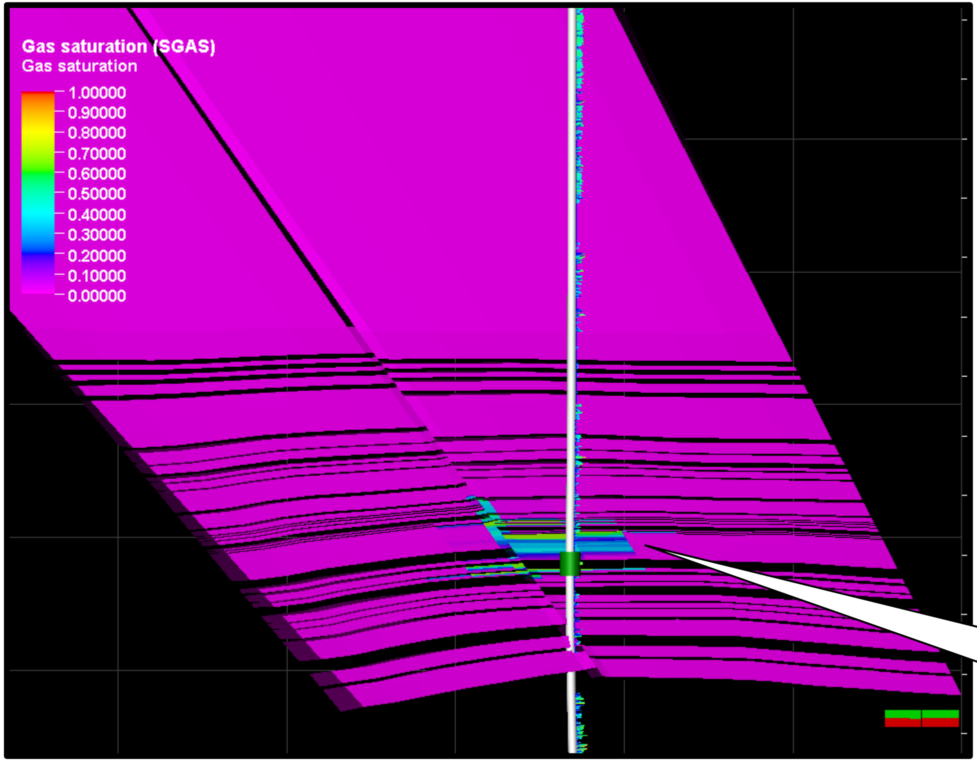


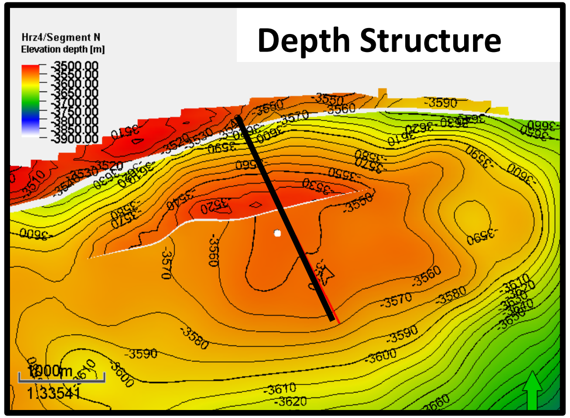
2100: 100 years – end injection





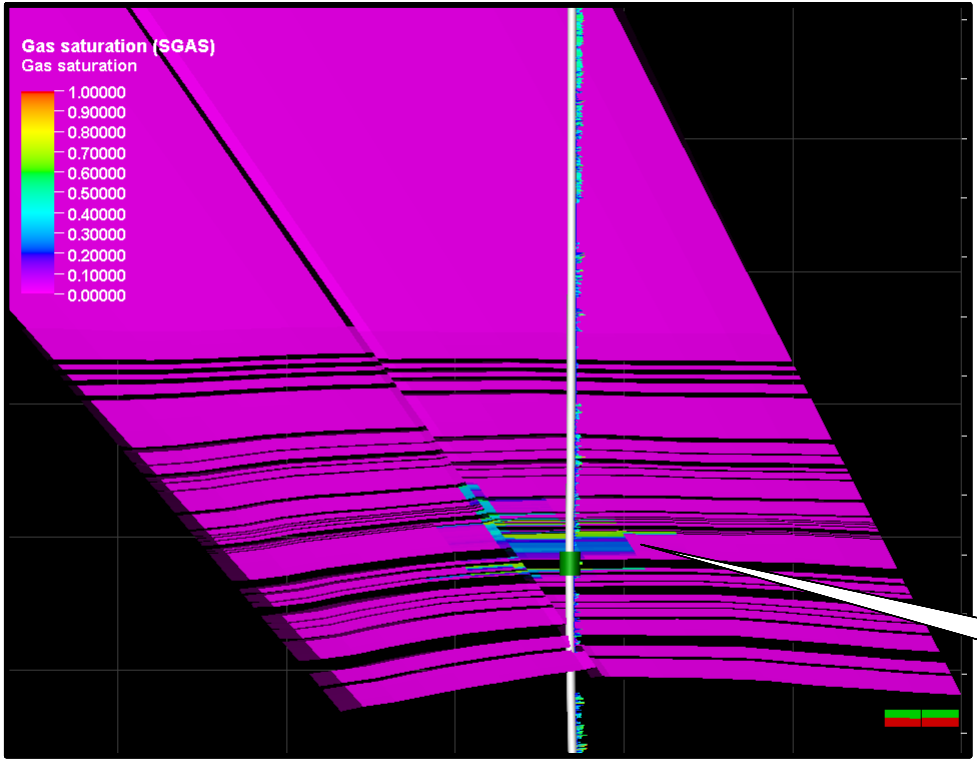
2200: 100 years injection – 100 years equilibration

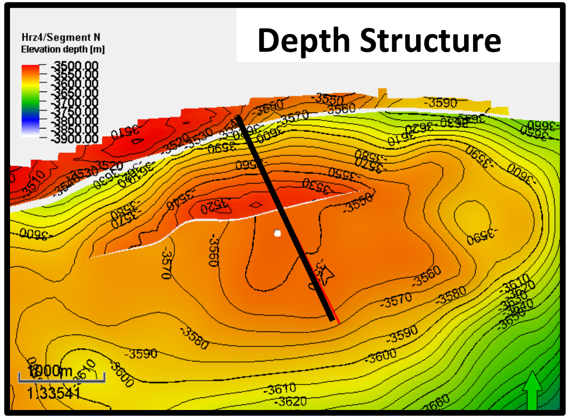




Gas near perfs dissipates upwards, but retains some residual saturation.

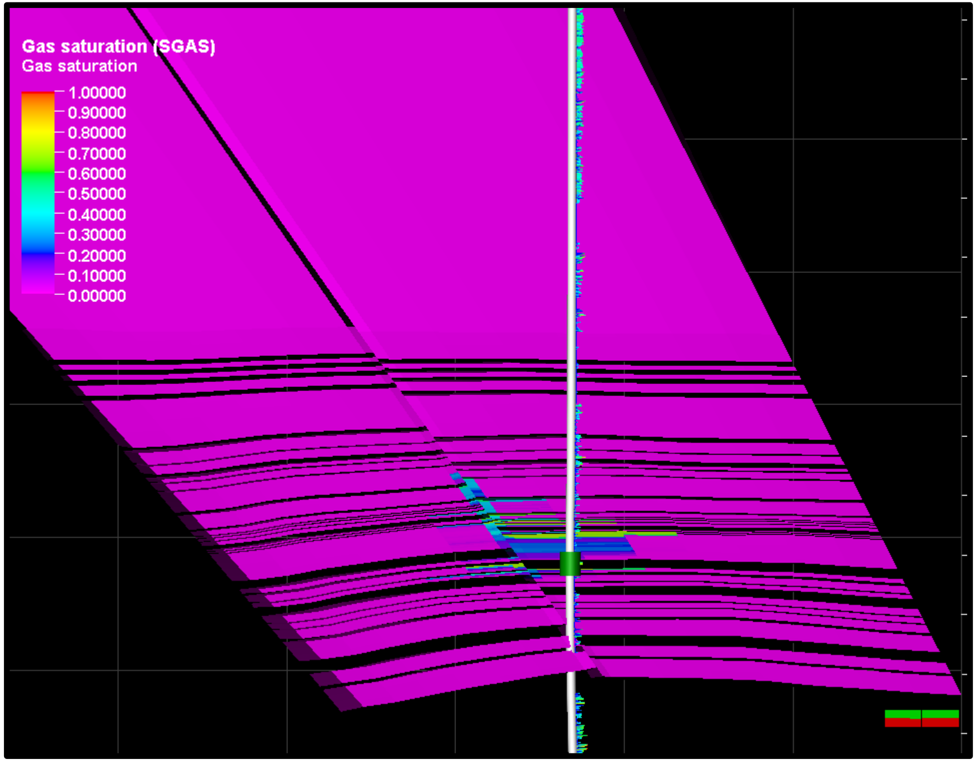
2300: 100 years injection – 200 years equilibration

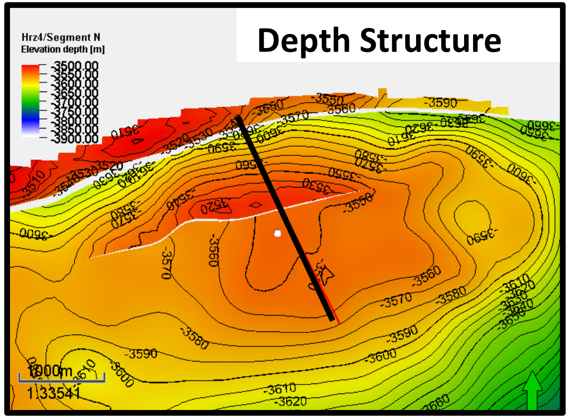




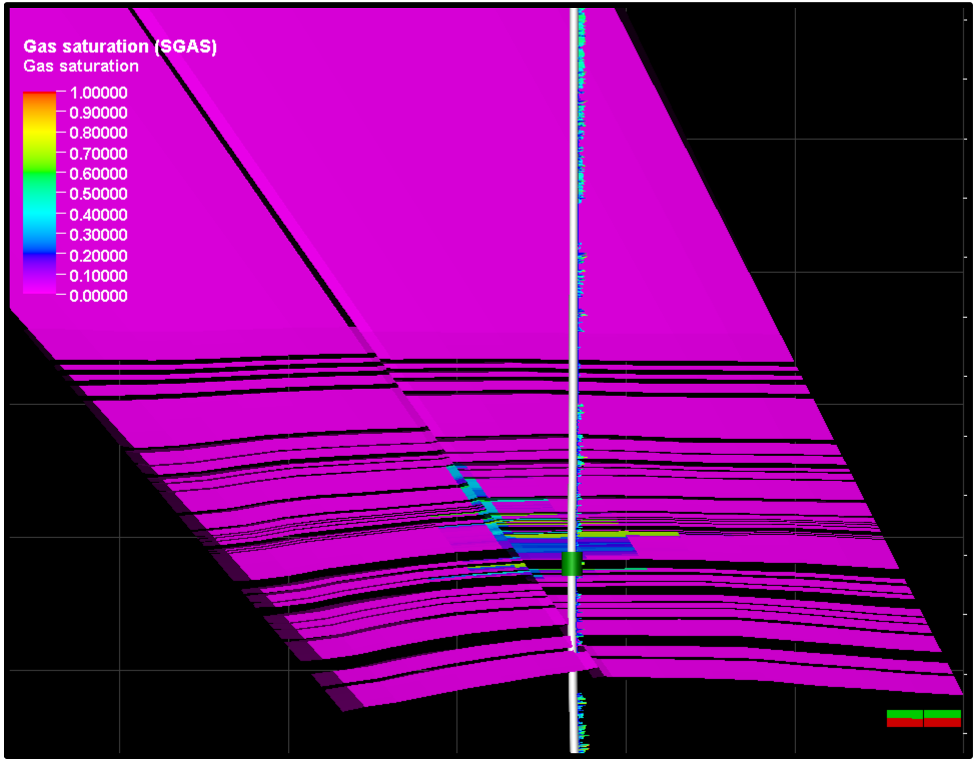
Forms a very thin column within small closure

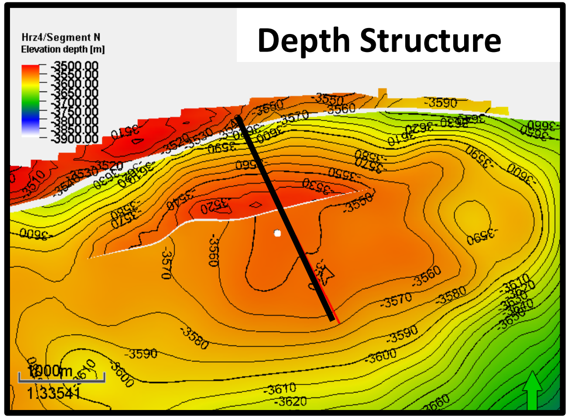
2400: 100 years injection – 300 years equilibration



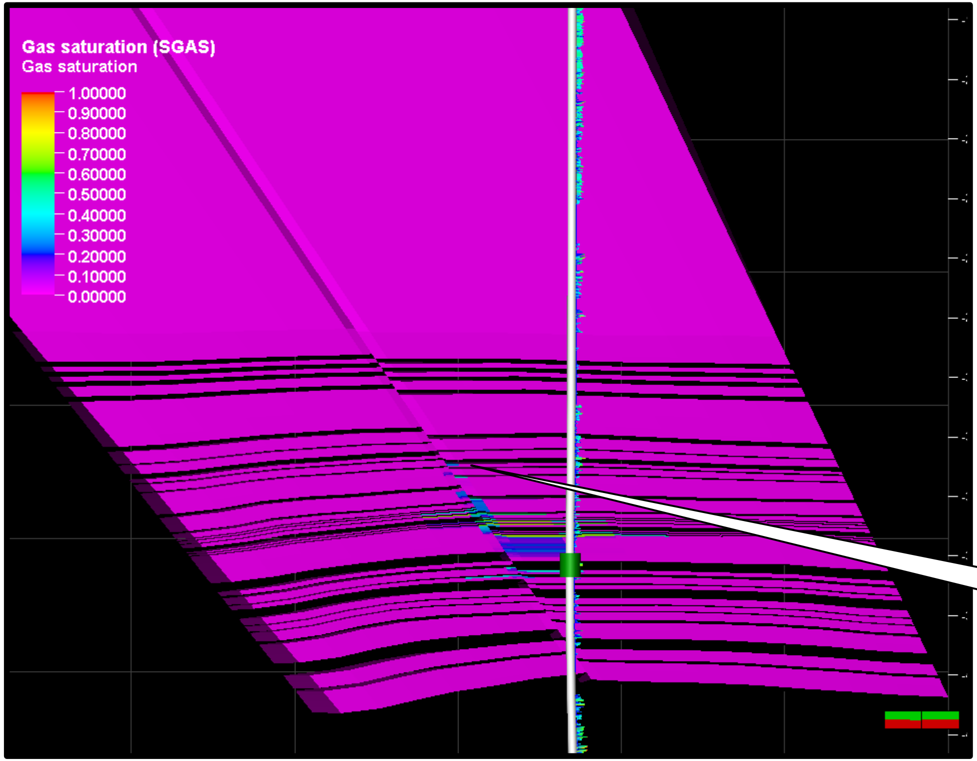


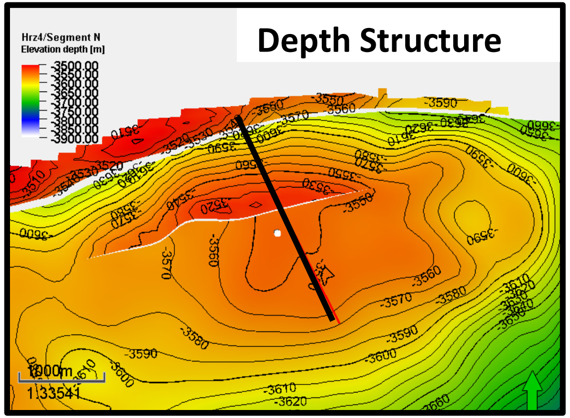
2500: 100 years injection – 400 years equilibration





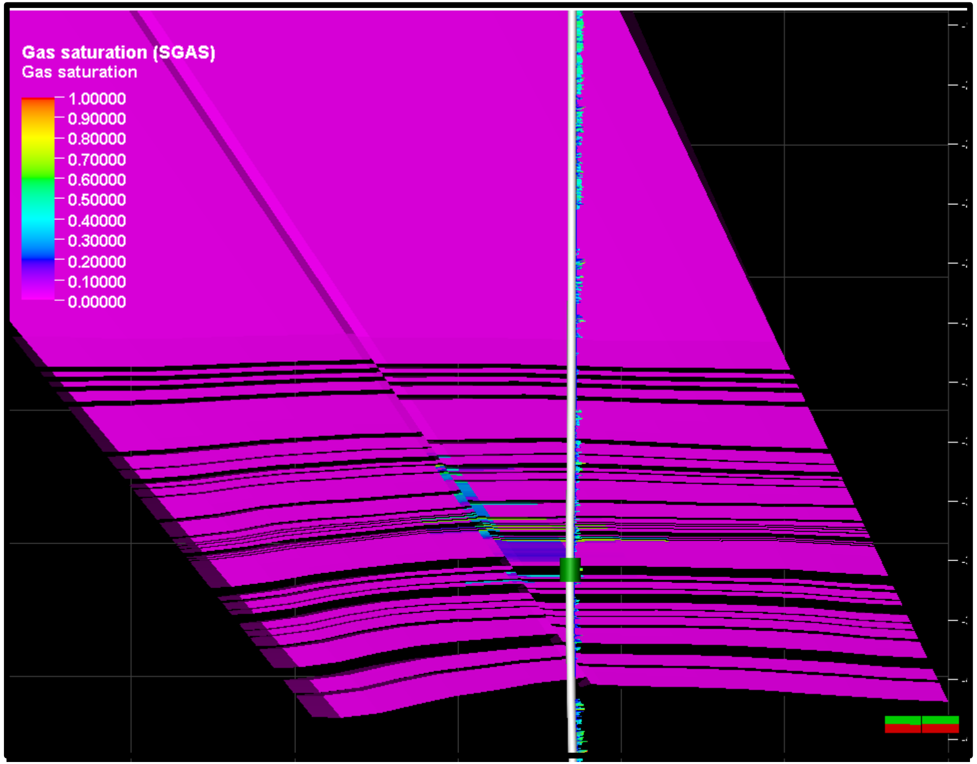
2600: 100 years injection – 500 years equilibration

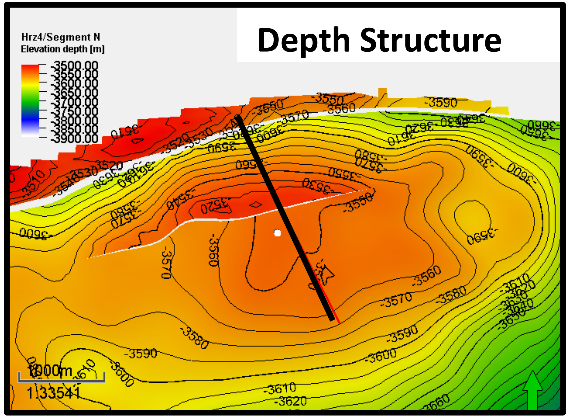




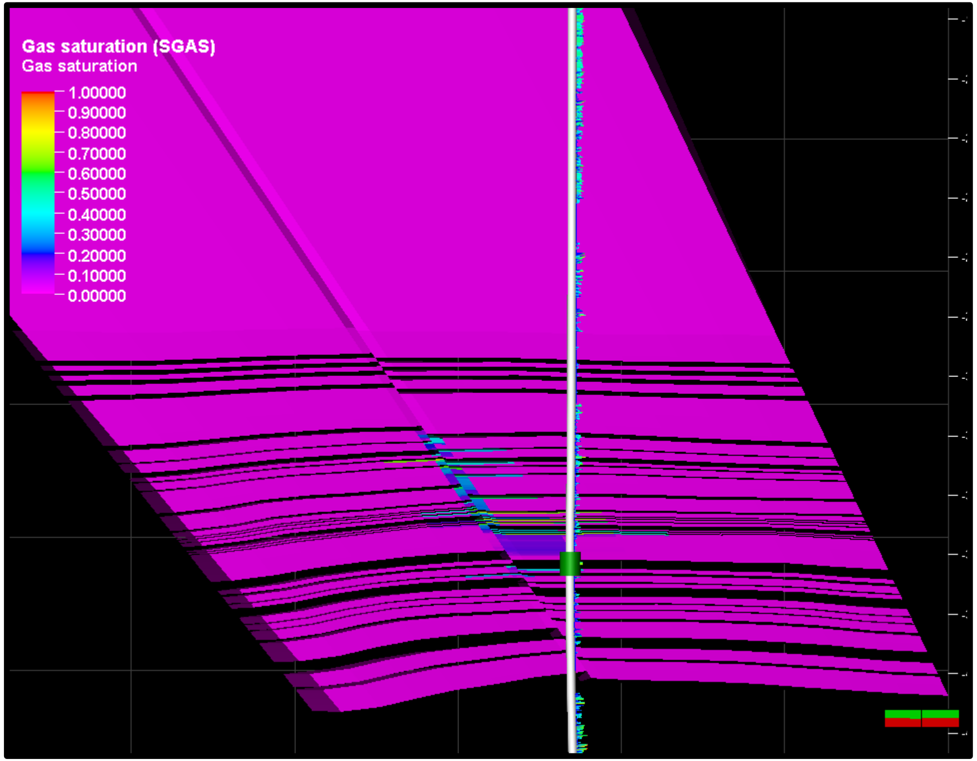
Continuing upward leakage (section has stepped over one cell to NE)

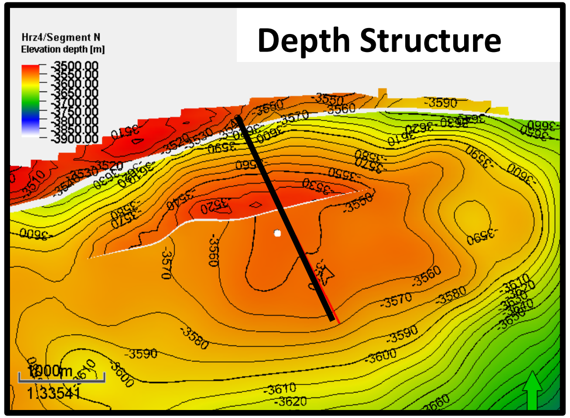
3100: 100 years injection – 1000 years equilibration



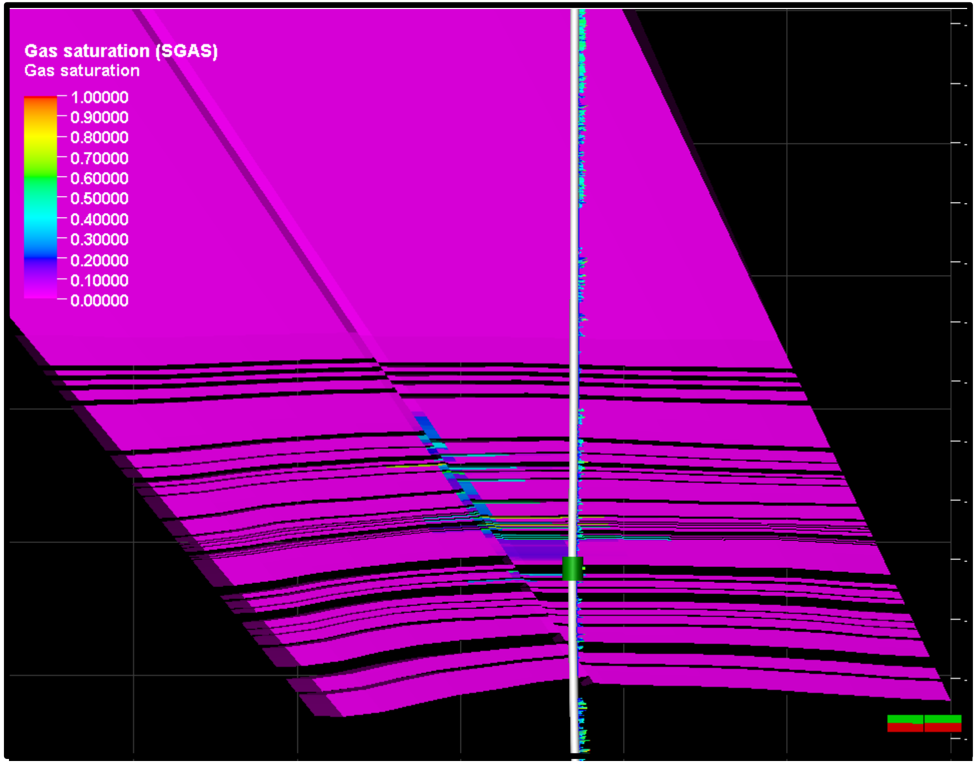


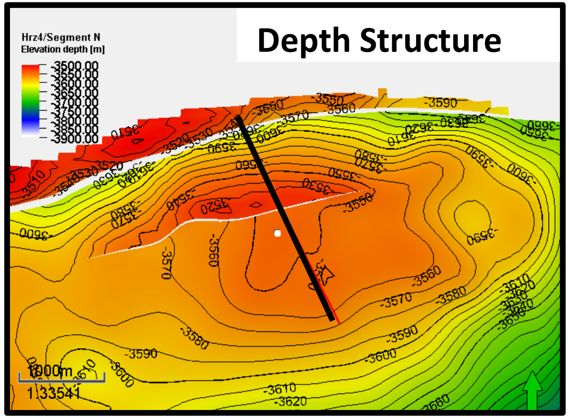
4100: 100 years injection – 2000 years equilibration



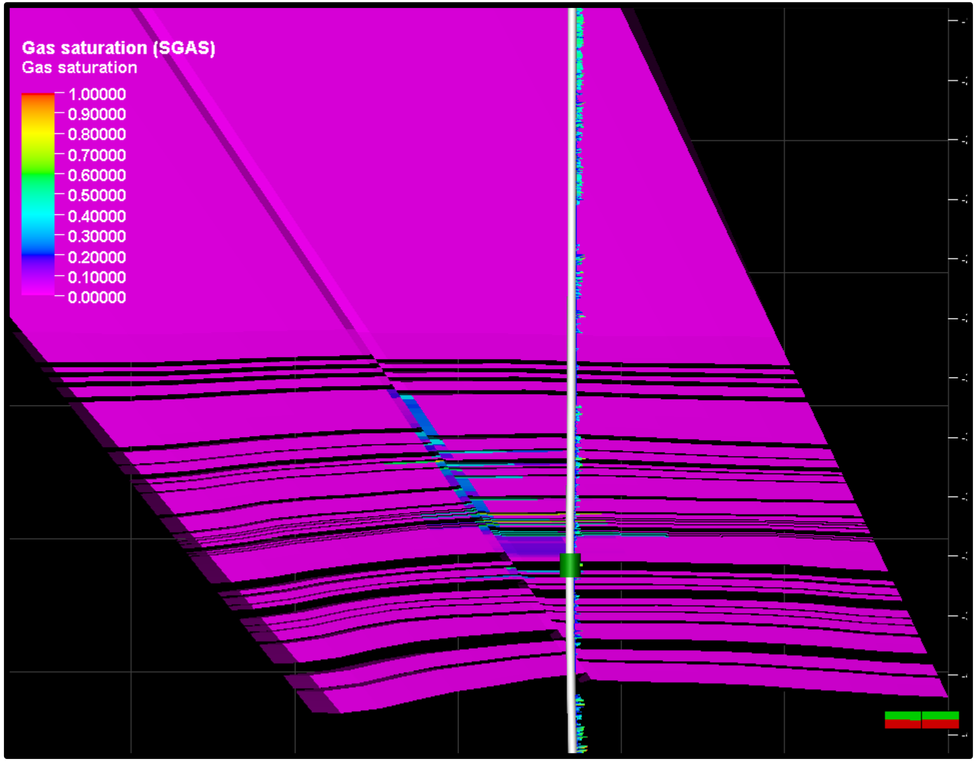


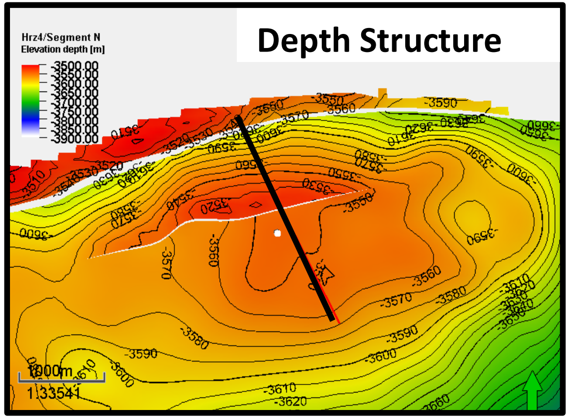
5100: 100 years injection – 3000 years equilibration



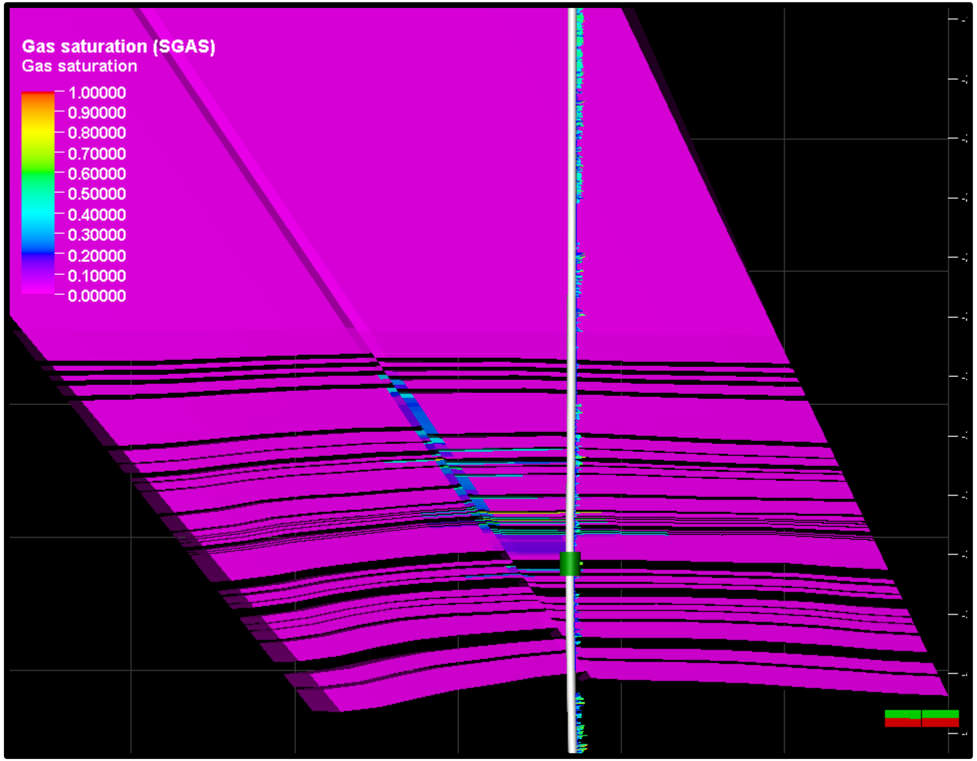


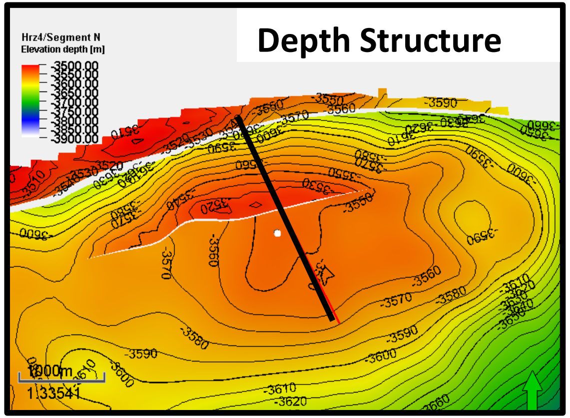
6100: 100 years injection – 4000 years equilibration



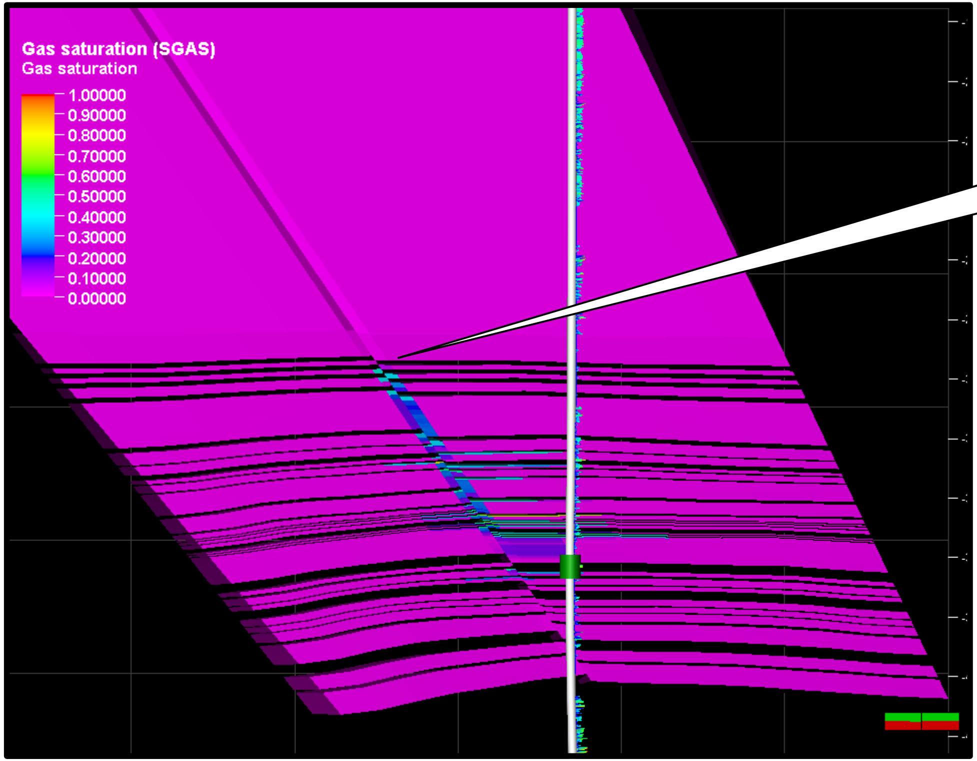


7100: 100 years injection – 5000 years equilibration

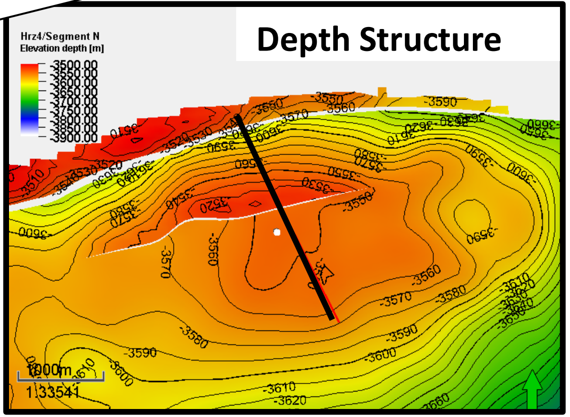




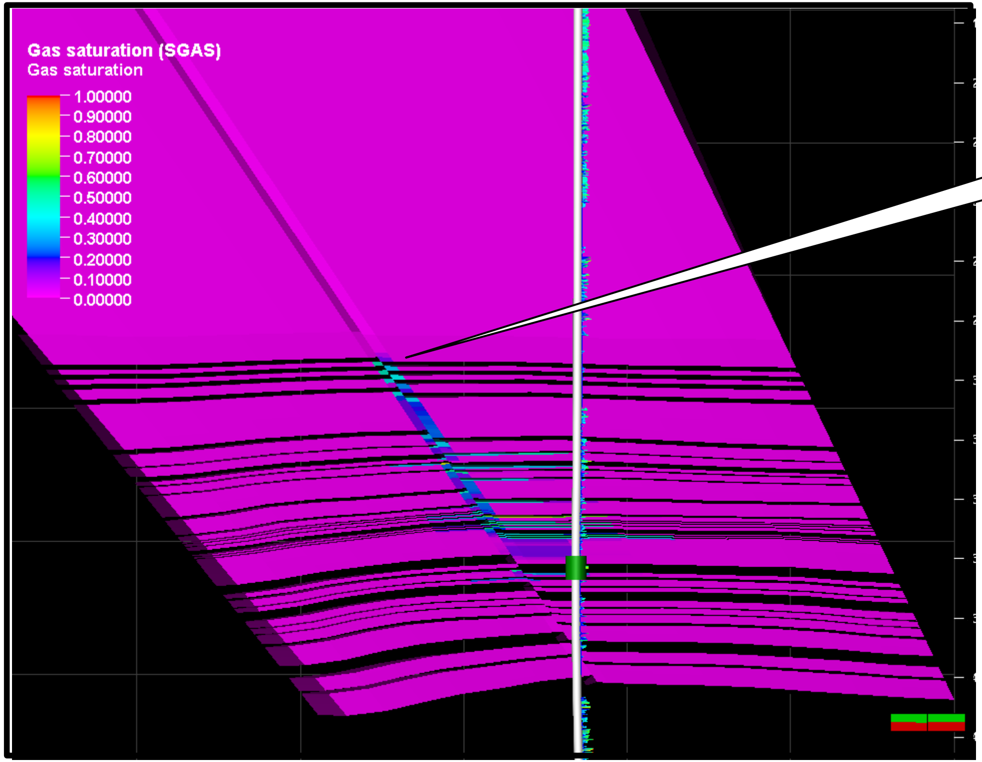
8100: 100 years injection – 6000 years equilibration



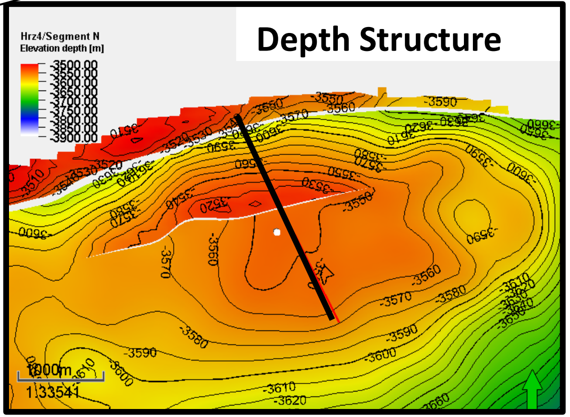
Leaking to Upper Missisauga



9999: 100 years injection – 7899 years equilibration



Leaking to Upper Missisauga
Time limit of software

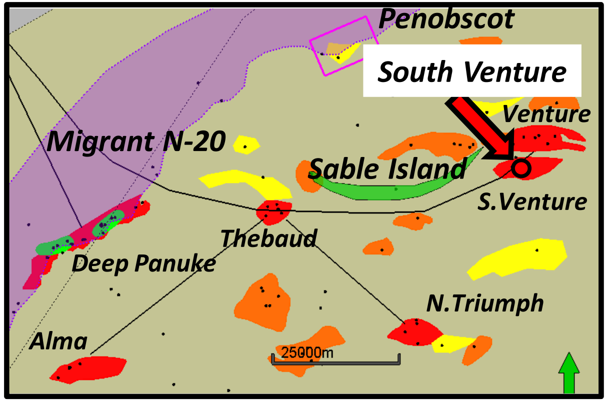


Static and Dynamic Modeling_3
High Integrity (High Adequacy) Trap
South Venture

Injection of CH_4

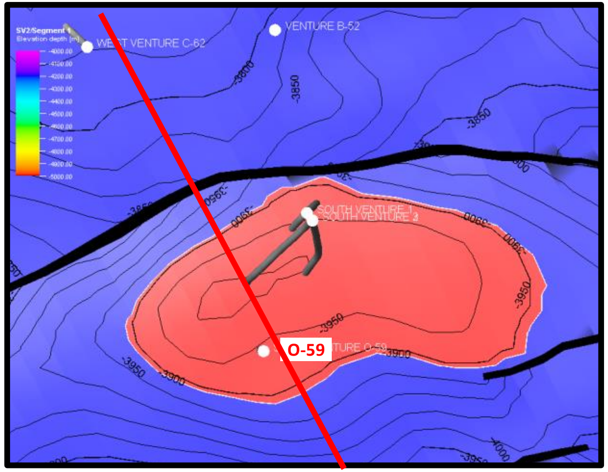
Static and Dynamic Modeling_3 High Integrity Structure at S.Venture

South Venture 0_59: Mobil et al 1982. Plus 3 development wells produced 315 BCF gas (history matched in this study)

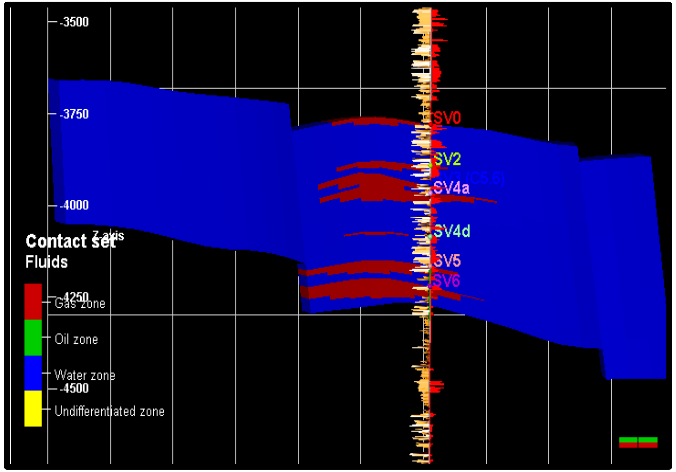


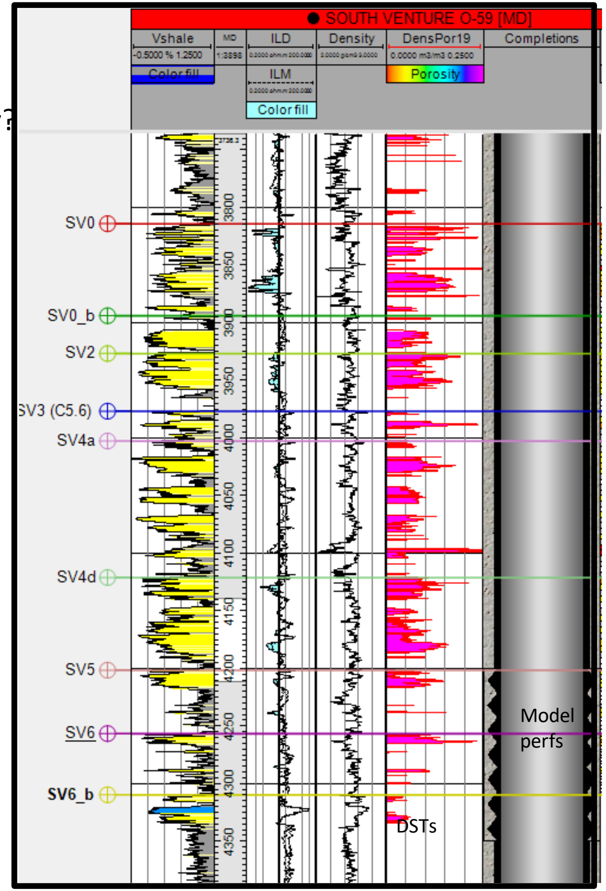
- 4-way dip closure – with 7 commercial gas pools
- No observable crestal faulting
- GWCs controlled by flank faults & stratigraphically?

- Dynamic modeling demonstrates cross-fault leak (throws > shale thicknesses at minor crestal fault
- Overlying monocline modeled here for CCS



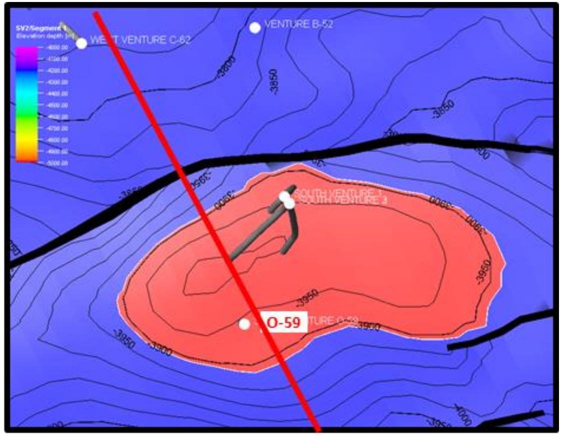
Depth Structure Sand SV3



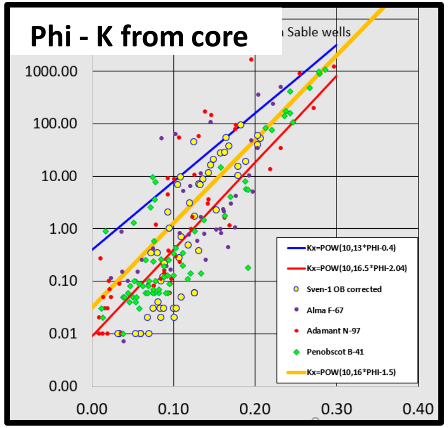


South Venture Static Model

- Log Density with Vshale cut off
- ML Phi-K relationship from core analyses
- Injected CH4 into perfs near base hydro-pressured zones
- Model extends to top of structural closure

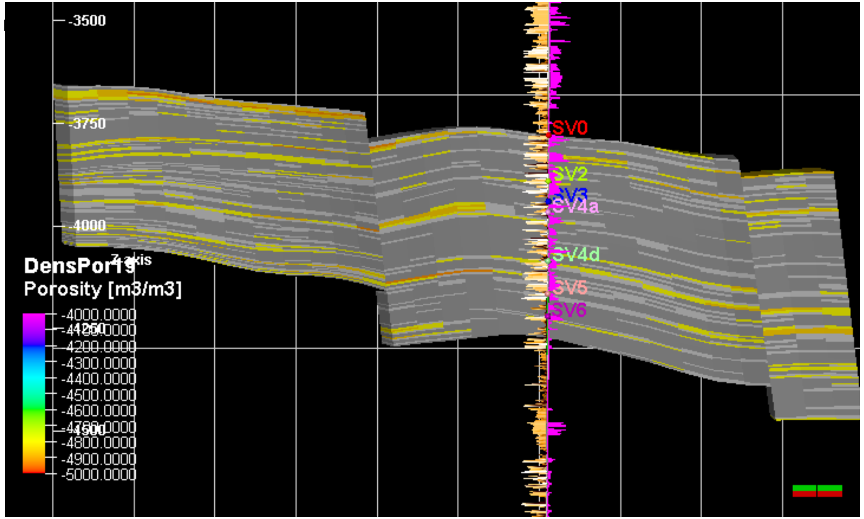


Depth Structure Sand SV3



Porosity

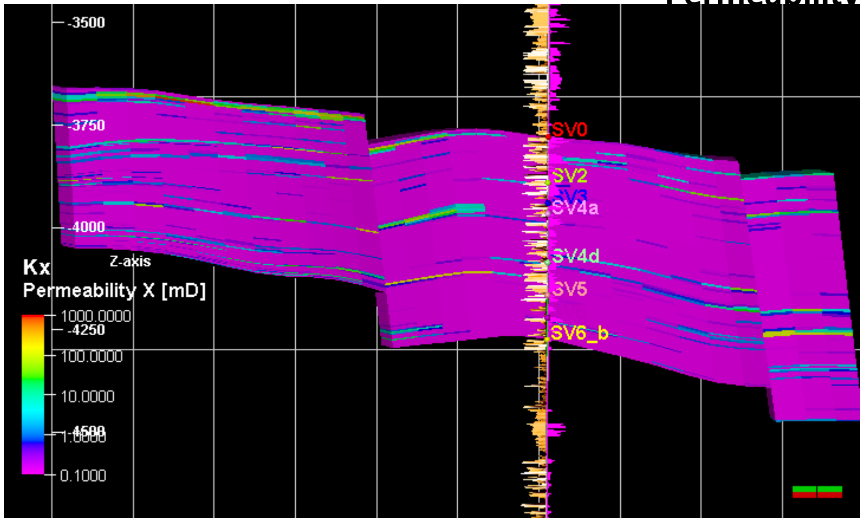
O-59



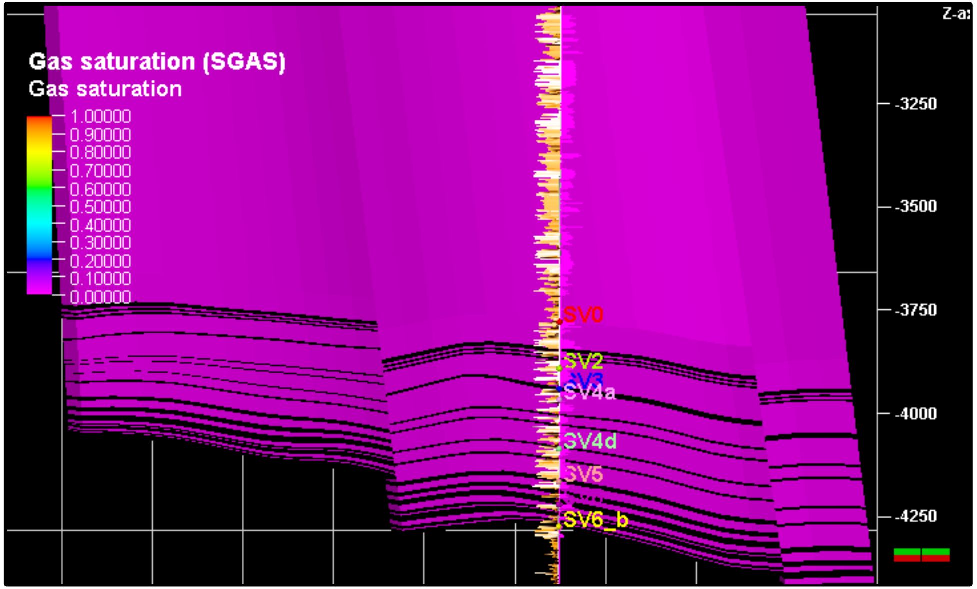
Vshale Porosity

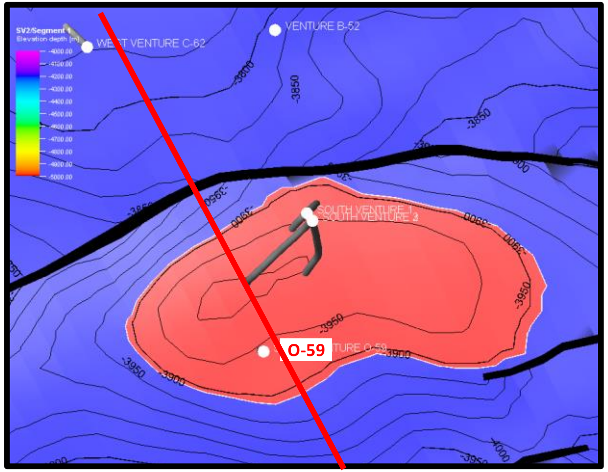
O-59

Permeability



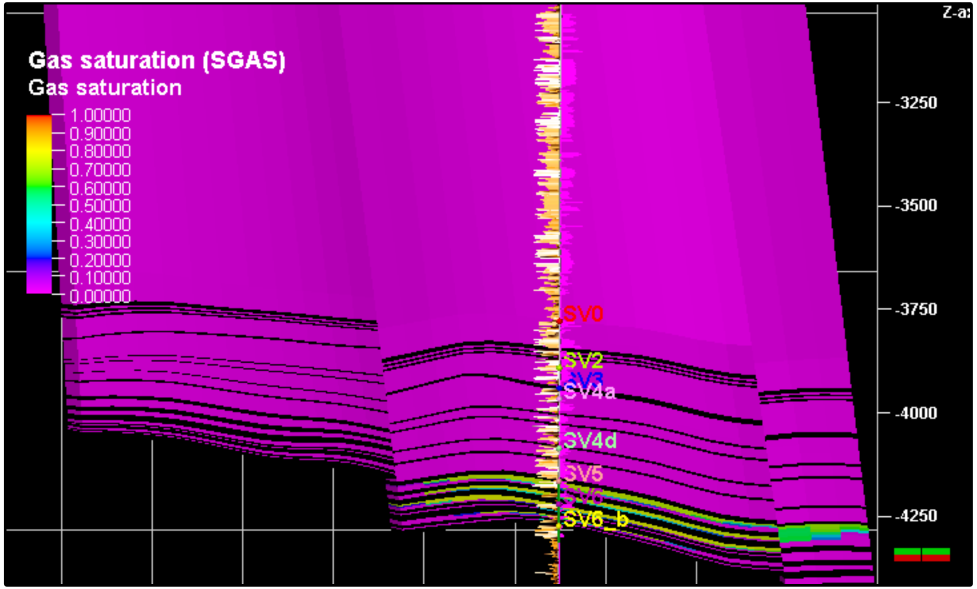
2000: 0 years – start of model

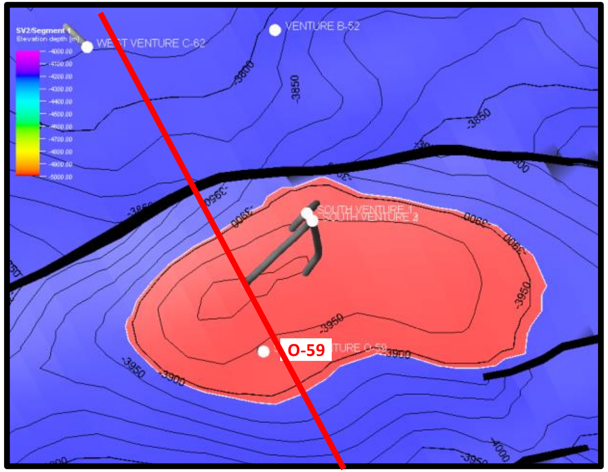




Depth Structure Sand SV3

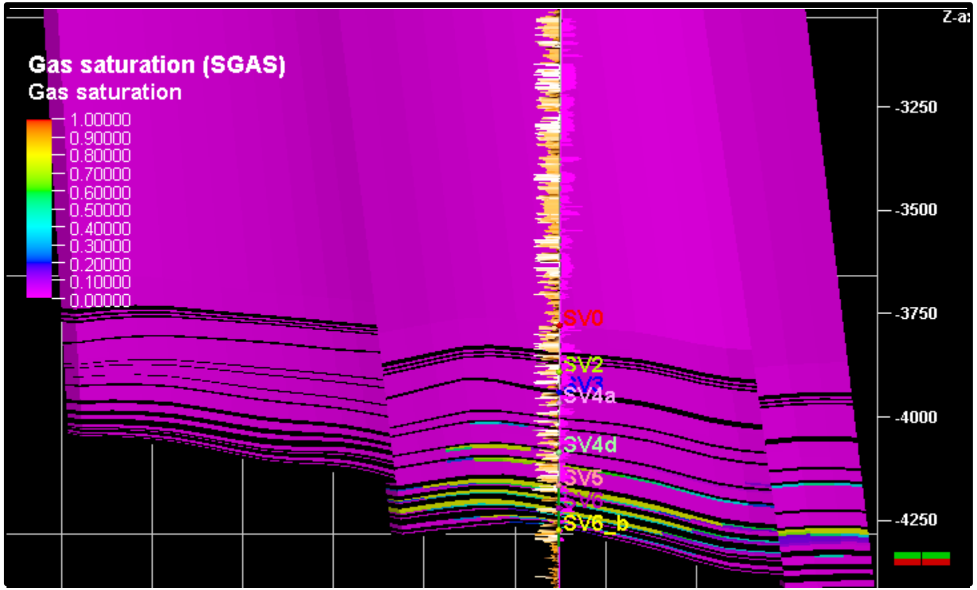
2100: 100 years – end injection

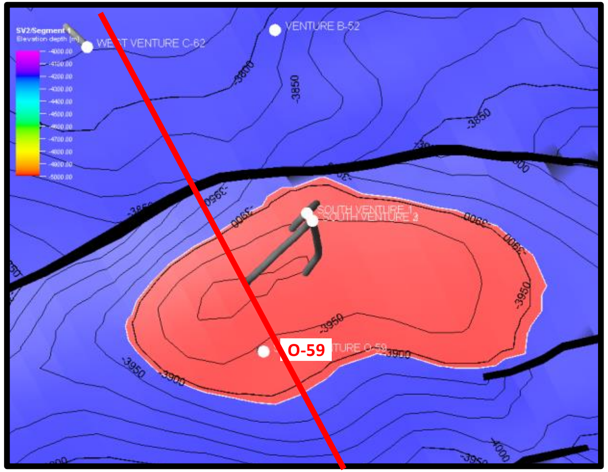




Depth Structure Sand SV3

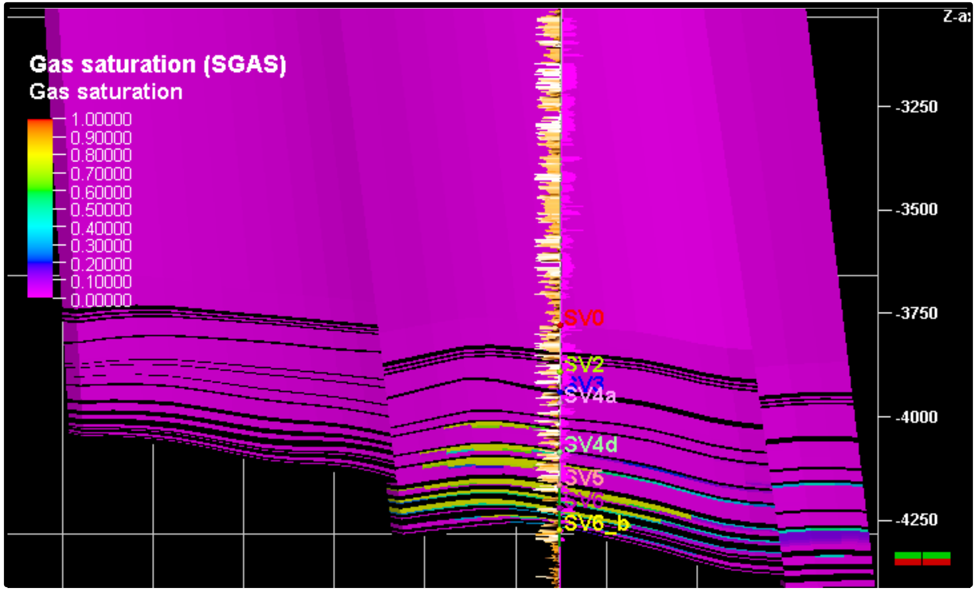
2600: 100 years injection – 500 years equilibration

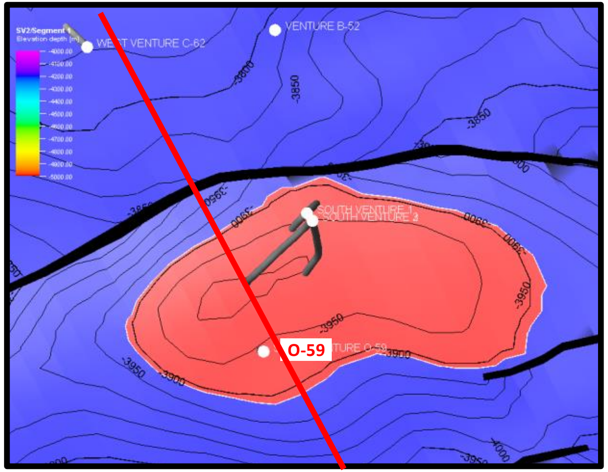




Depth Structure Sand SV3

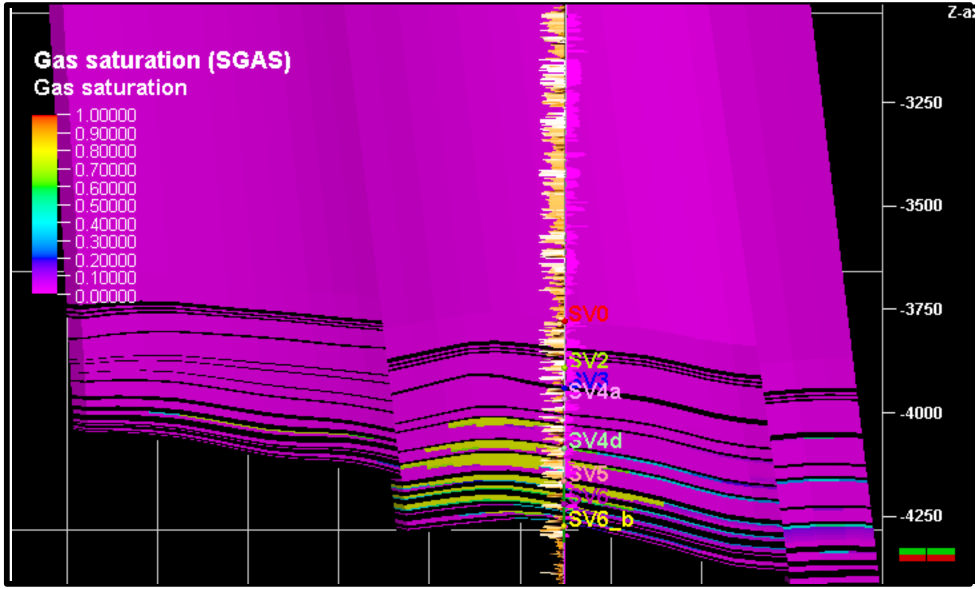
3100: 100 years injection – 1000 years equilibration

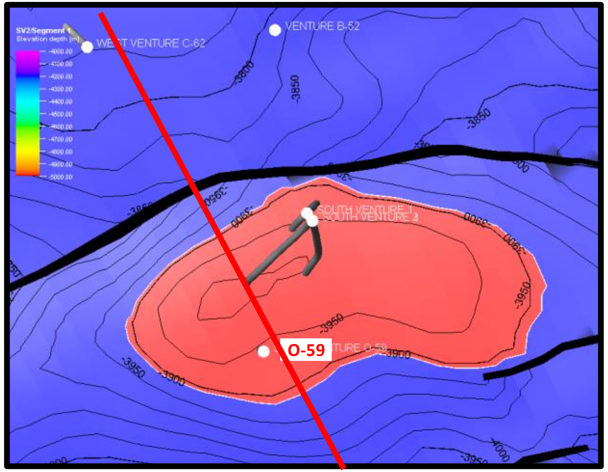




Depth Structure Sand SV3

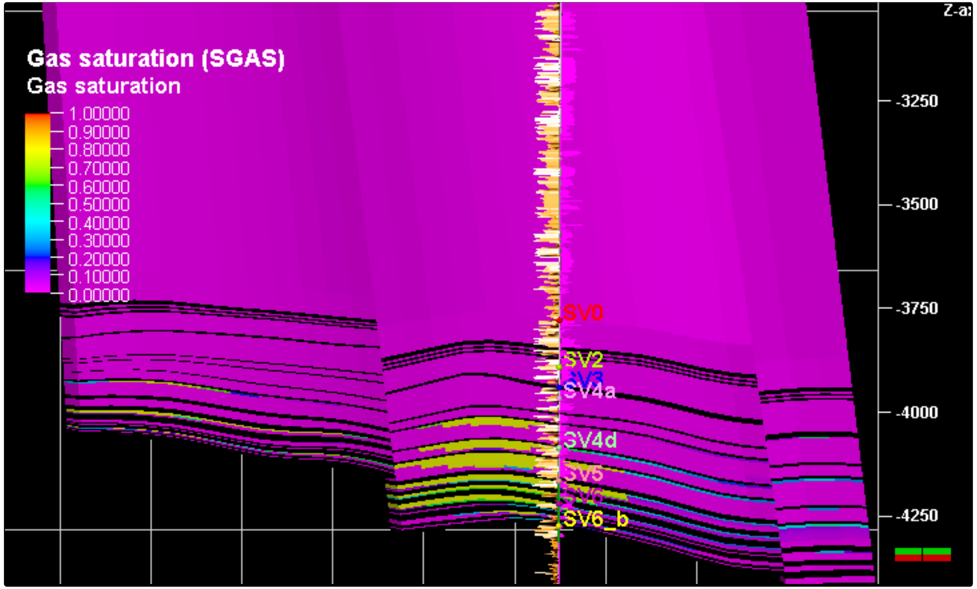
4100: 100 years injection – 2000 years equilibration

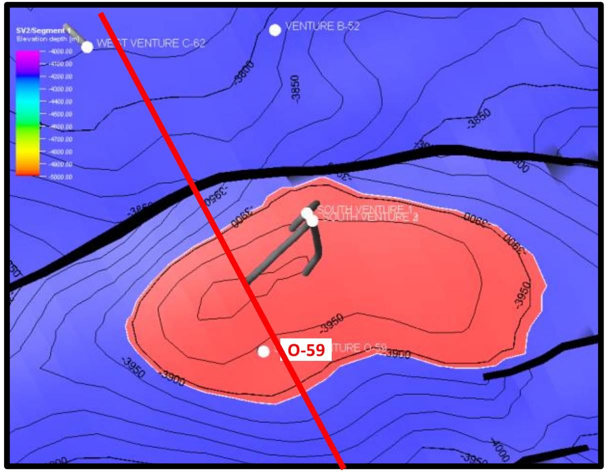




Depth Structure Sand SV3

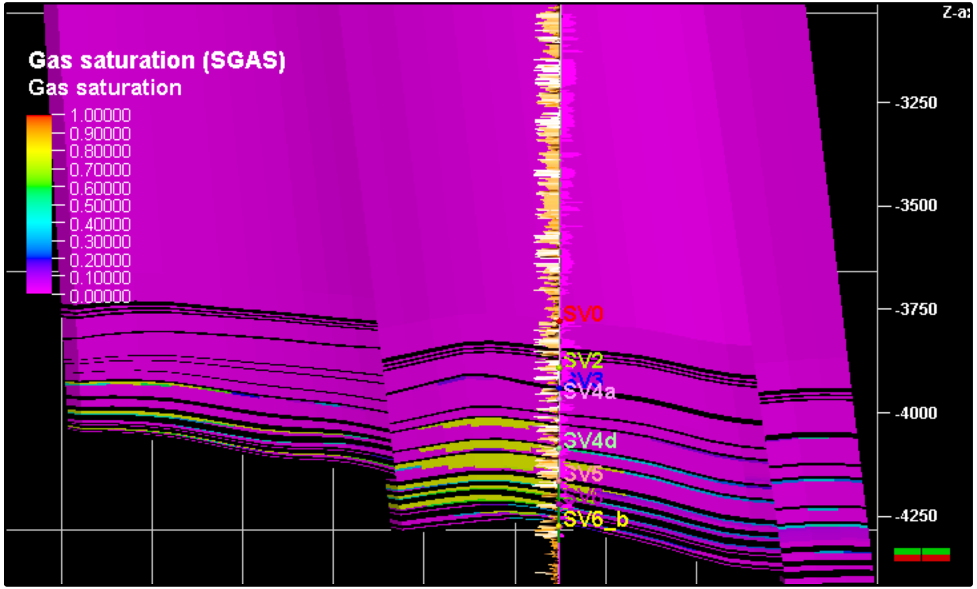
5100: 100 years injection – 3000 years equilibration

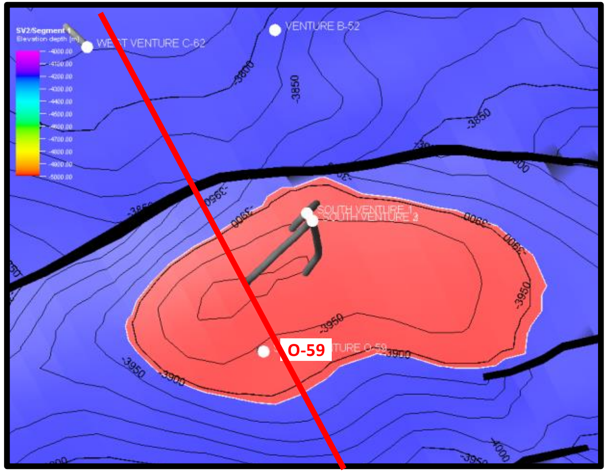




Depth Structure Sand SV3

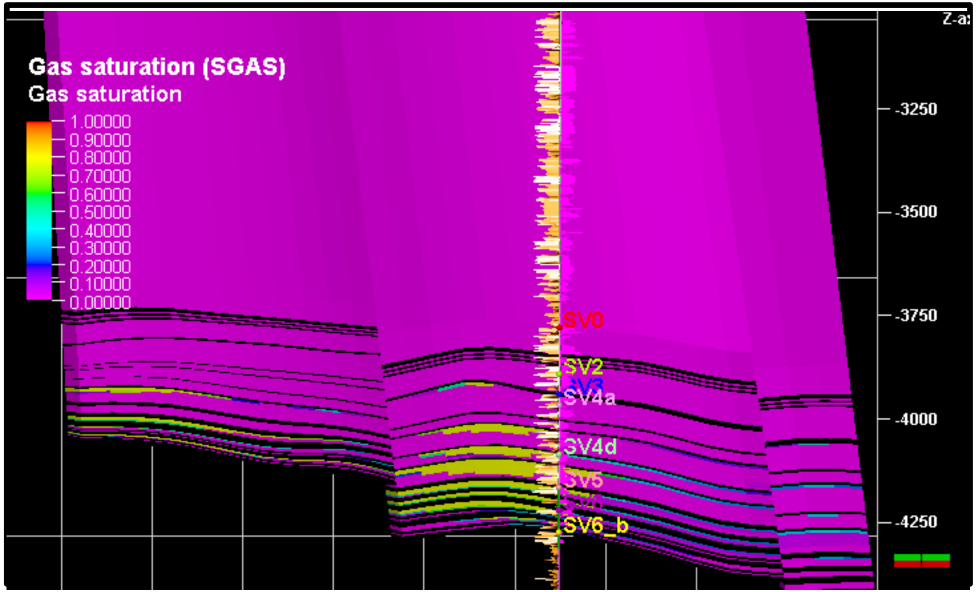
6100: 100 years injection – 4000 years equilibration

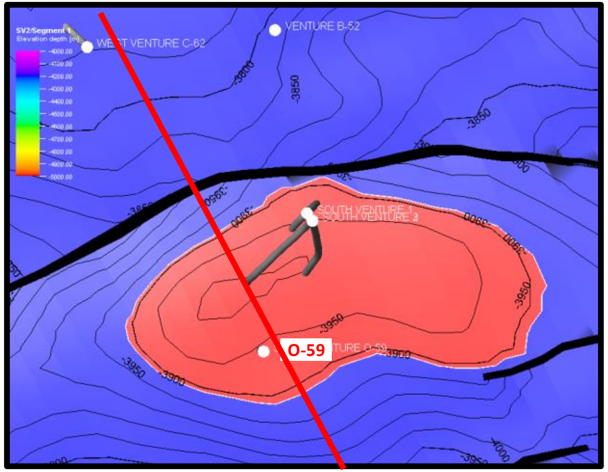




Depth Structure Sand SV3

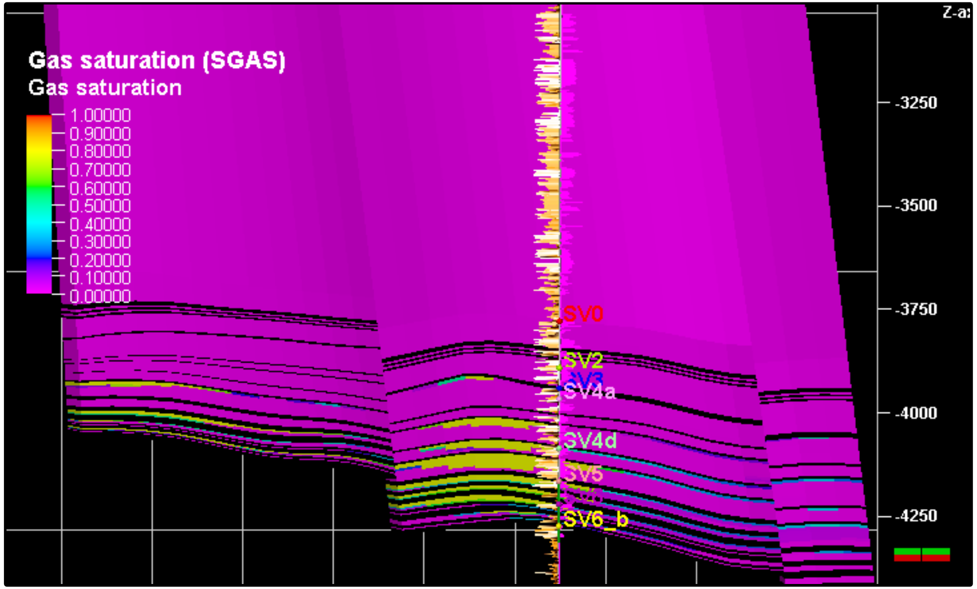
7100: 100 years injection – 5000 years equilibration

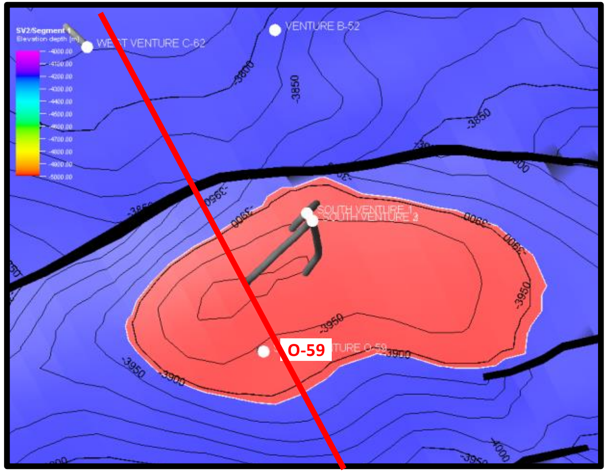




Depth Structure Sand SV3

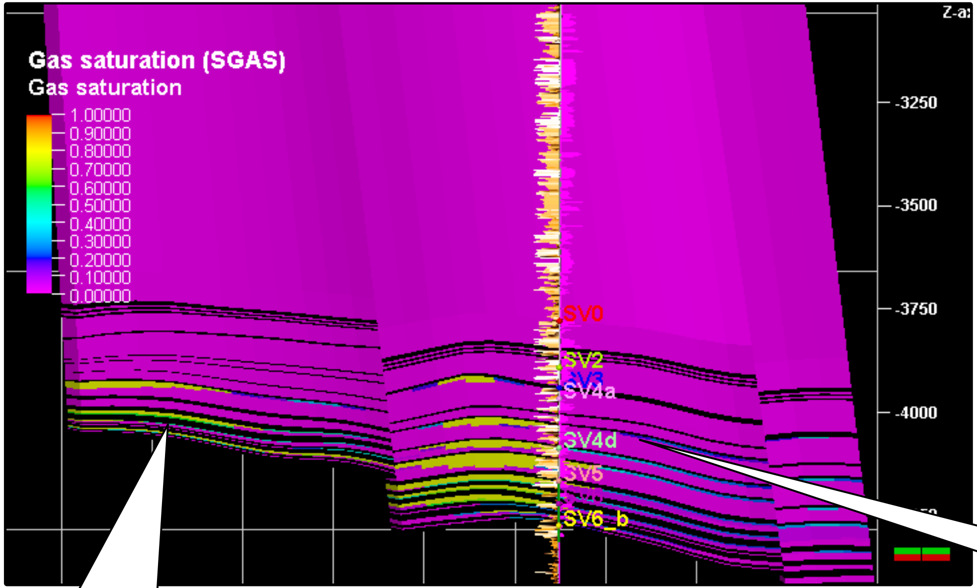
8100: 100 years injection – 6000 years equilibration

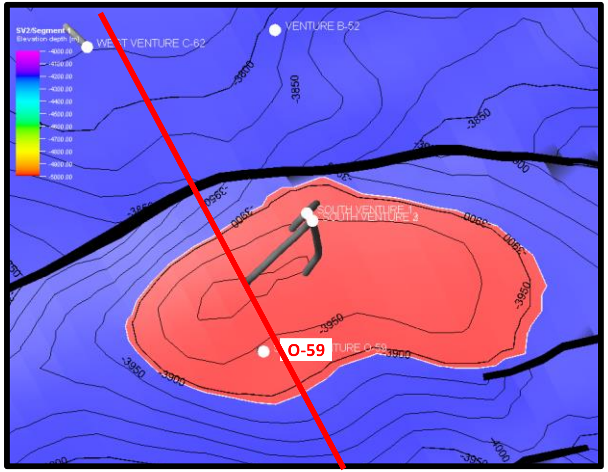




Depth Structure Sand SV3

9990: 100 years injection – 7890 years equilibration





Depth Structure Sand SV3

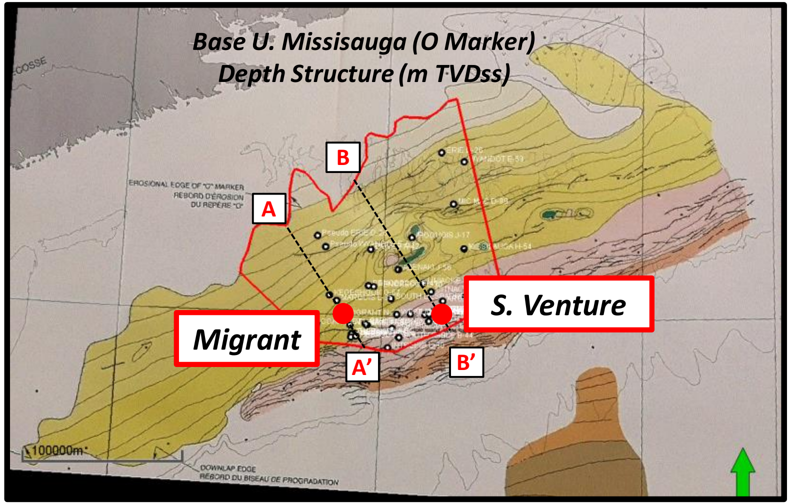
Trapped by model boundary – actually no closure

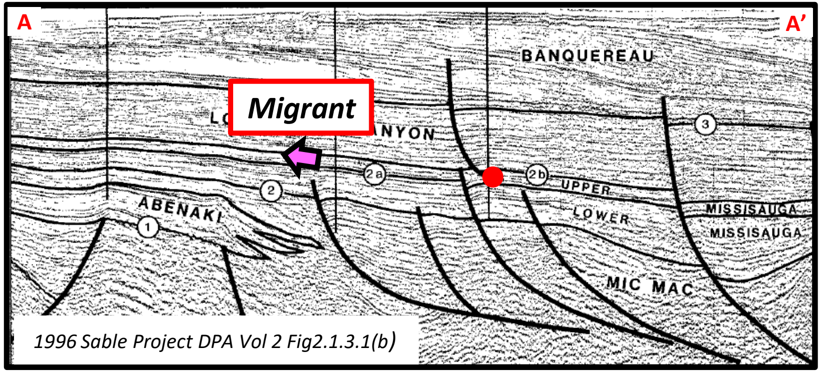
Each of 4 way dip closures fills to saddle spill or cross- fault leak at flank faults
Time limit of software before filling SV3 to SV0

Static and Dynamic Modeling_4 & 5
Regional Upper Missisauga model below Naskapi Shale
Deep (unconfined) Saline Aquifers above South Venture and Migrant
Injection of CO2

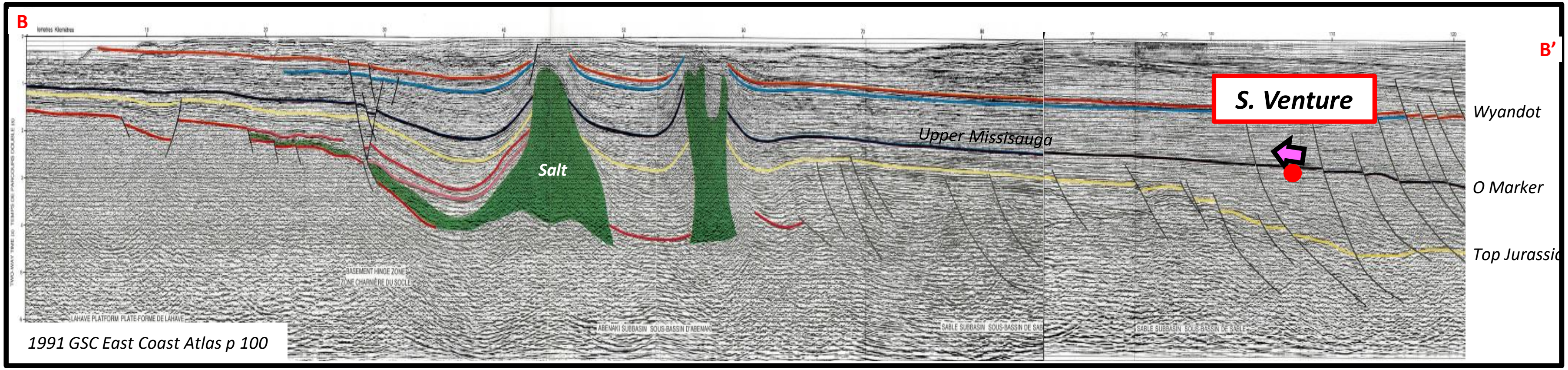
Regional CCS Model

- Structure based on GSC Missisauga maps
- Properties calculated from DivestCo wireline data & core lab data
- Injecting CO_2 above structural traps





1996 Sable Project DPA Vol 2 Fig2.1.3.1(b)

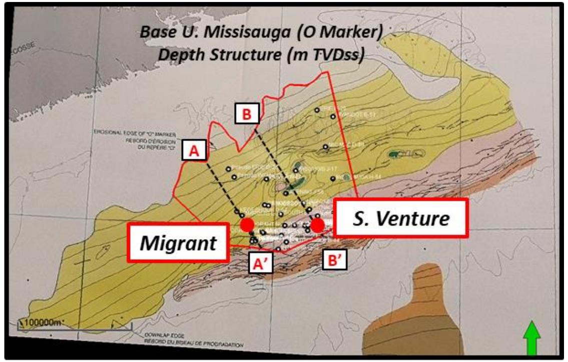


1991 GSC East Coast Atlas p 100

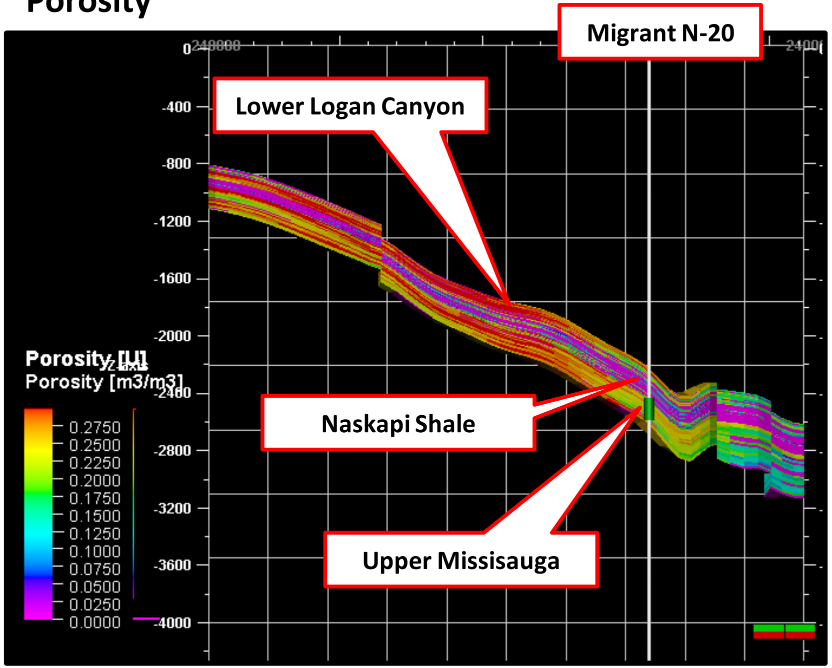
Regional Upper Missisauga Model

Migrant Cross-Section

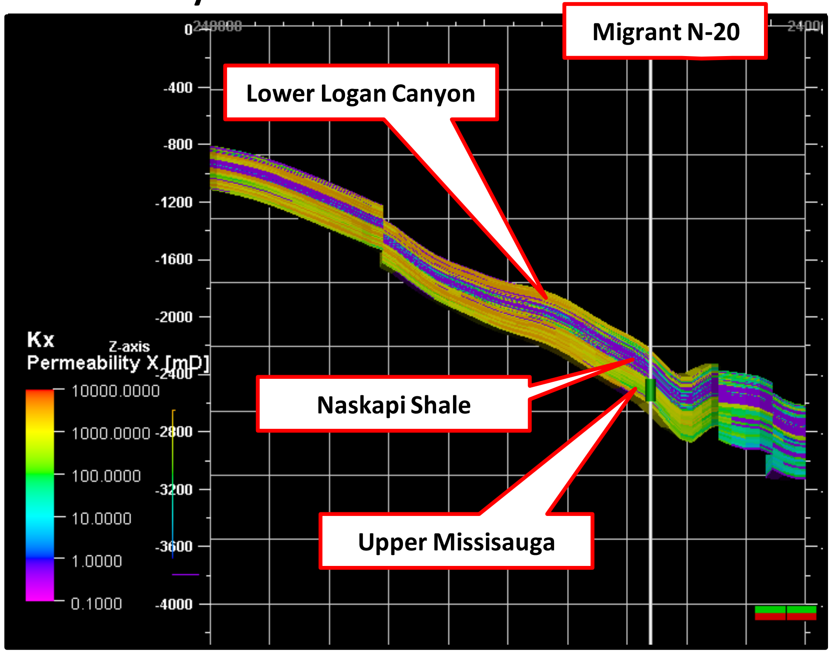
- Perf'd in Upper Missisauga below Naskapi Shale



Porosity



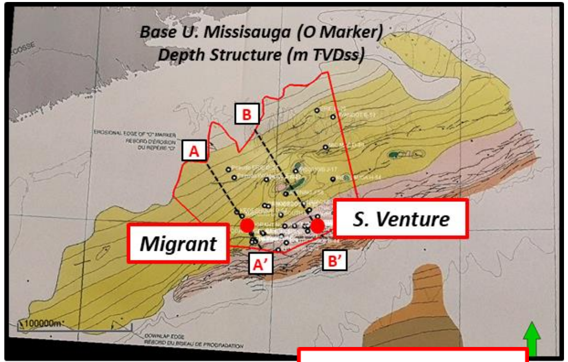
Permeability



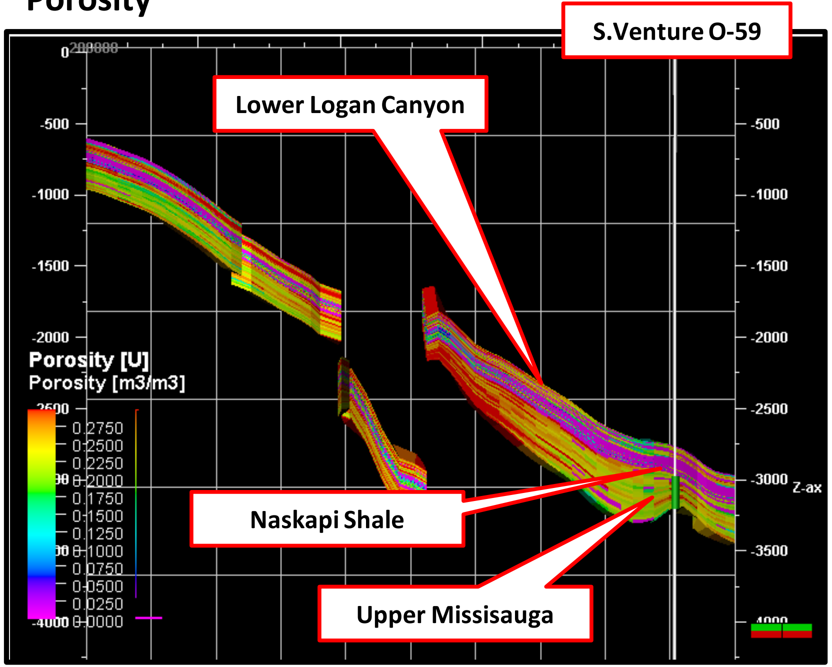
Regional Upper Missisauga Model

South Venture Cross-Section

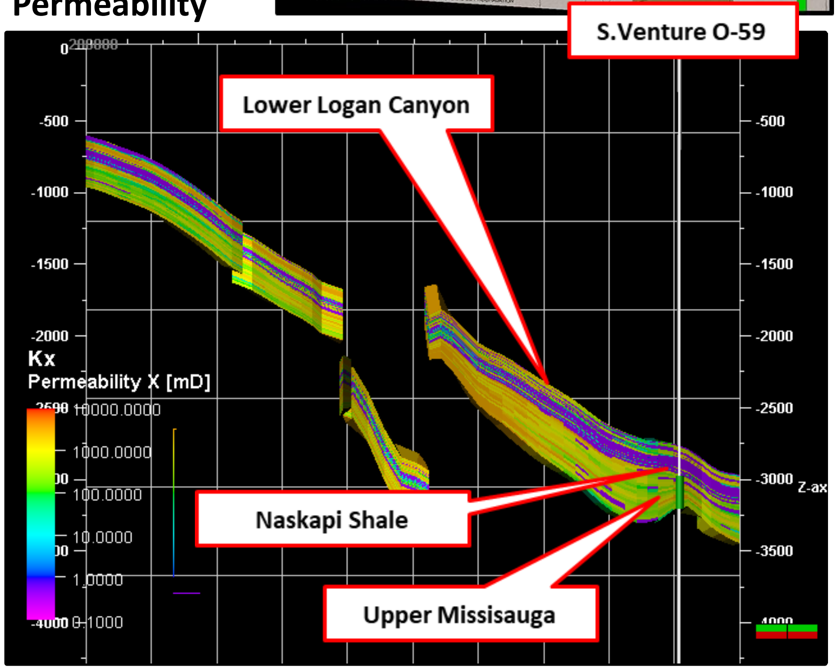
- Perf'd in Upper Missisauga below Naskapi Shale



Porosity



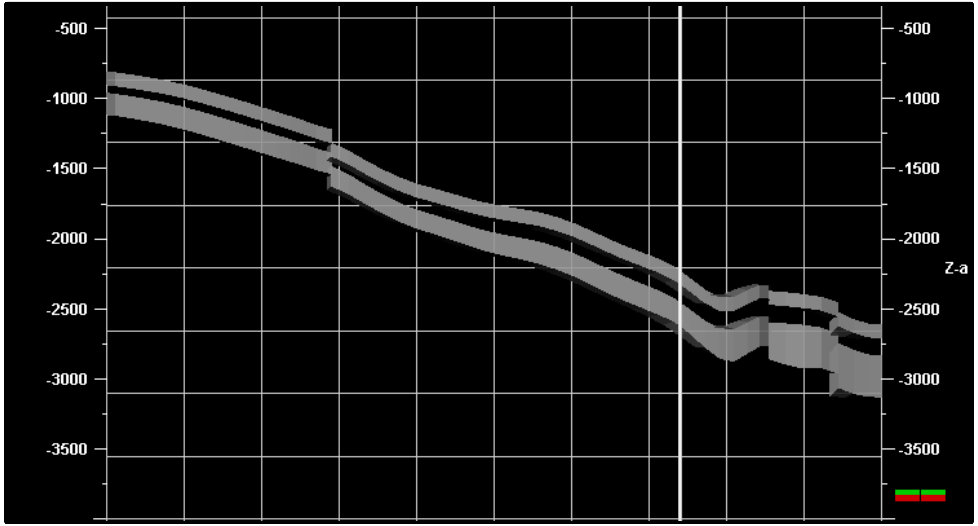
Permeability



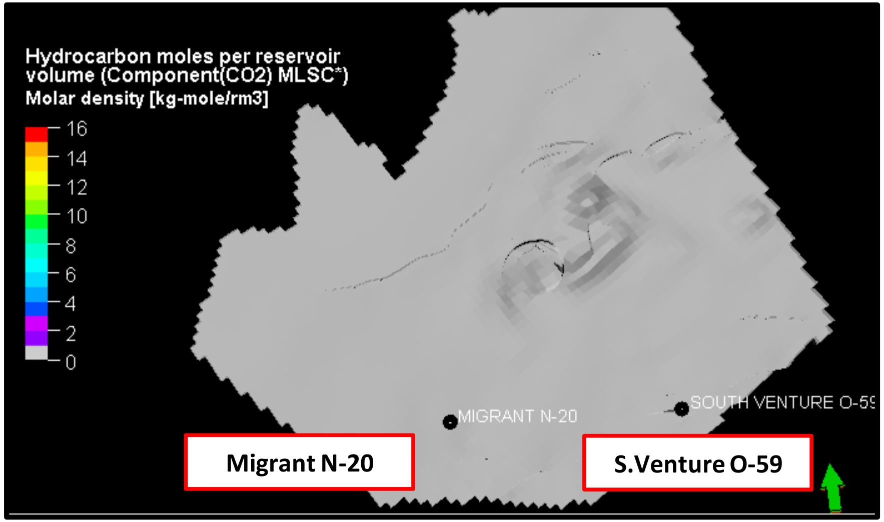
Inject 2.5 Mt / well / year for 50 years – then equilibrate for 5000 years

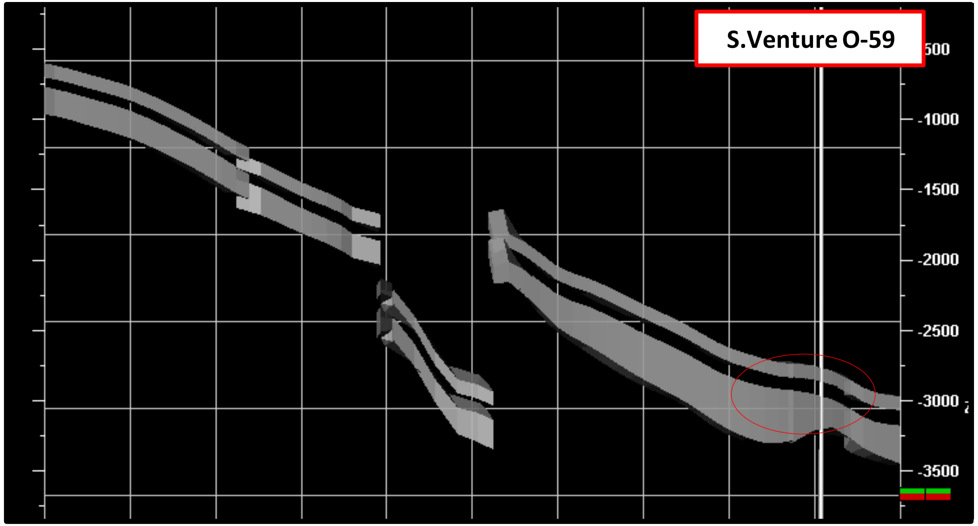
Regional Upper Missisauga Model

- 2.5Mt CO_2 per year per well – for 50 years
- Rate and Time Limit Based on Captain Sandstone Modeling in Moray Firth (Jin, 2012)
- This modeling does not include dissolution of CO_2

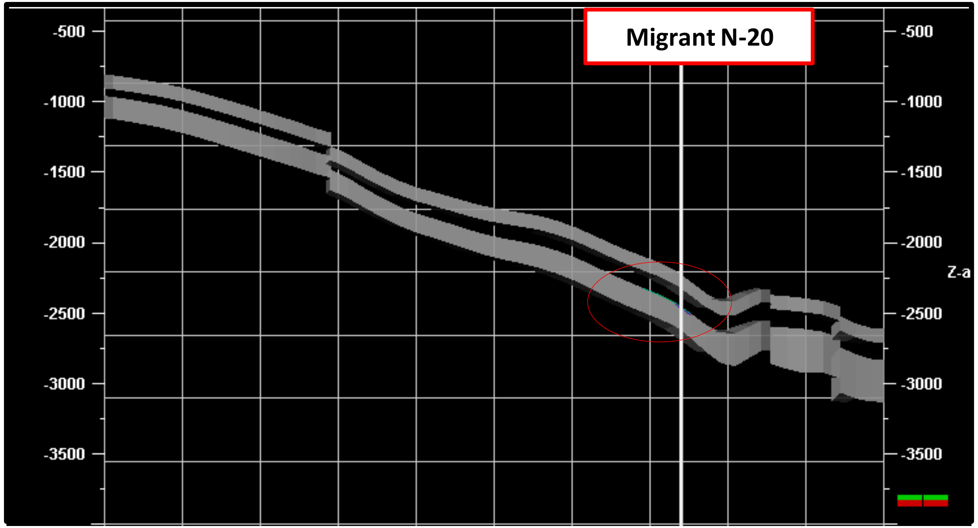


2000: 0 years injection

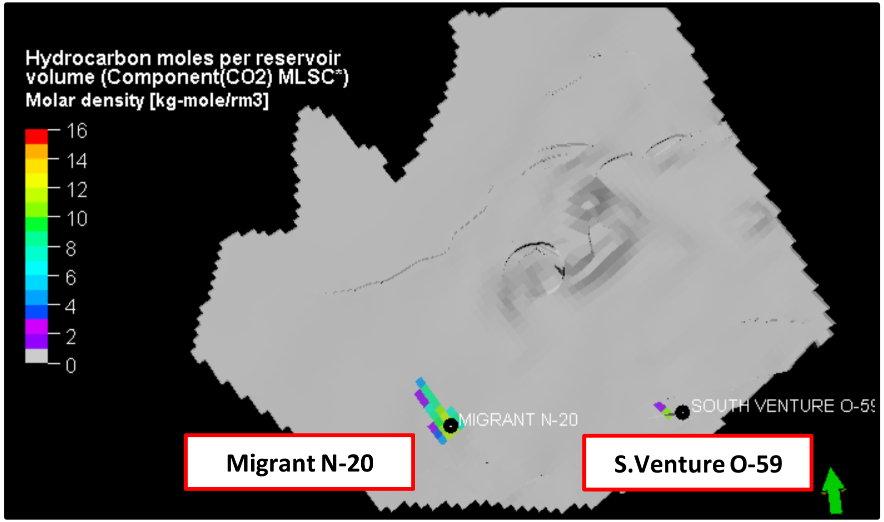


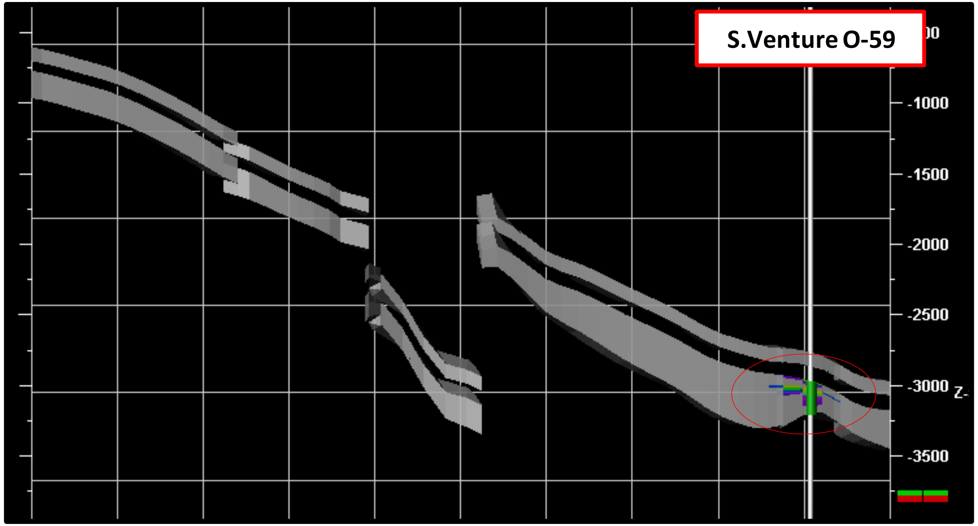


Regional Upper Missisauga Model
2.5Mt CO_2 per year per well – for 50 years



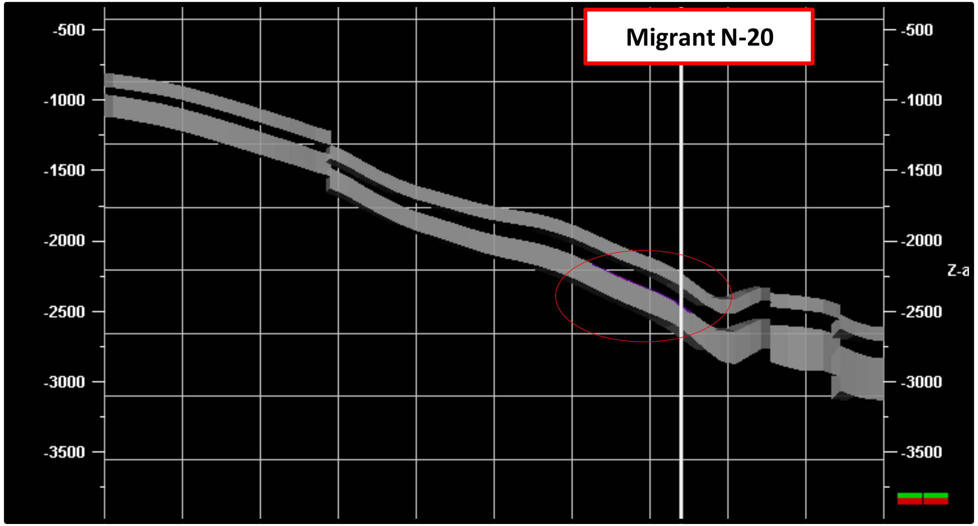
2050: 50 years injection



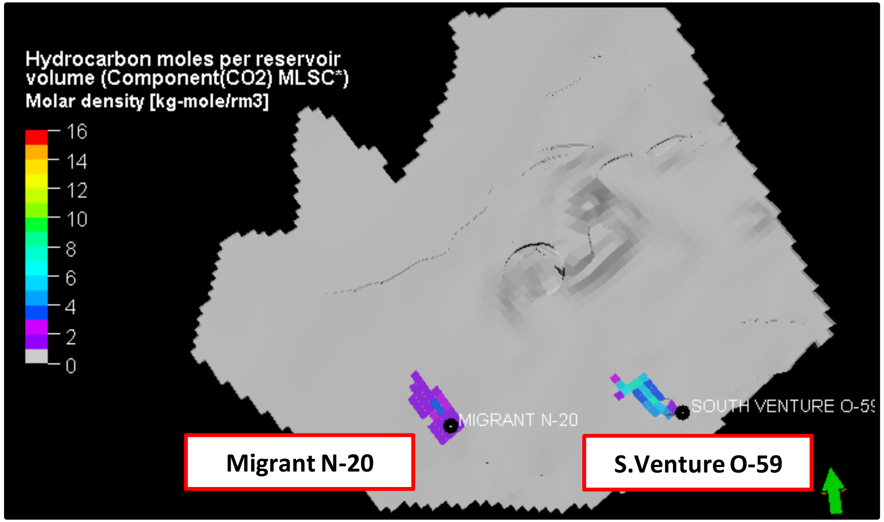


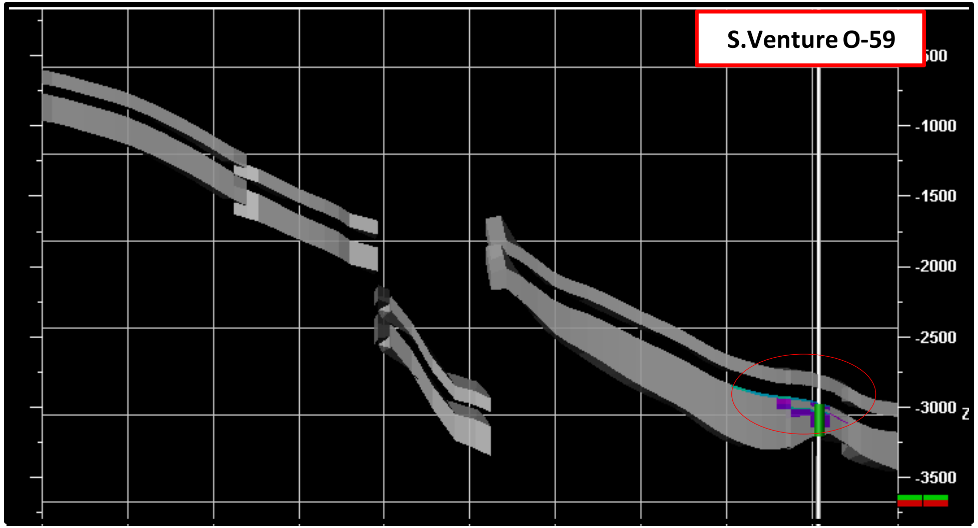
Regional Upper Missisauga Model

2.5Mt CO_2 per year per well – for 50 years



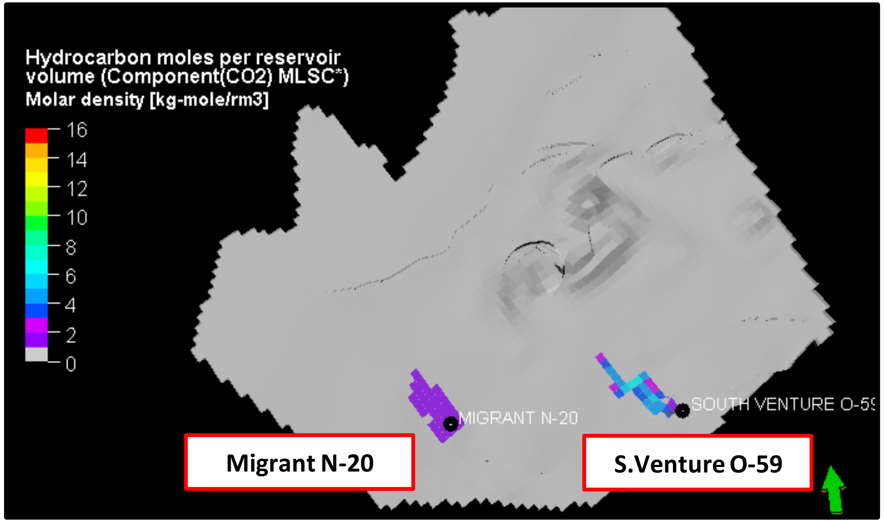
3050: 50 years injection – 1000 years equilibration

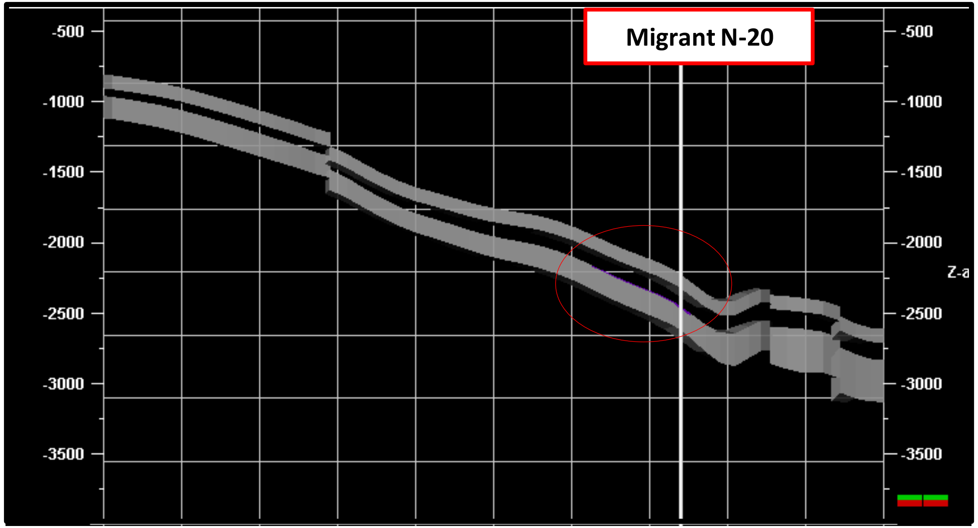


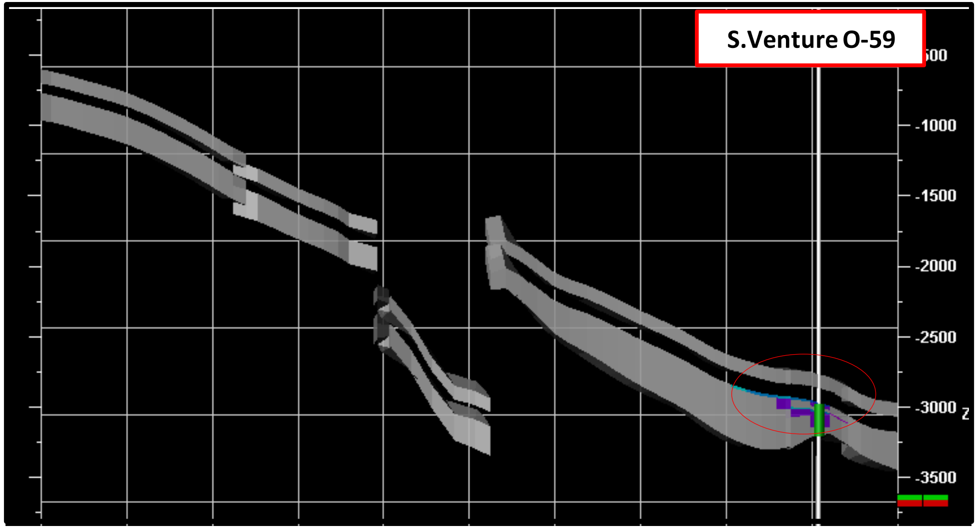


Regional Upper Missisauga Model
2.5Mt CO2 per year per well – for 50 years

4050: 1000 years injection – 2000 years equilibration



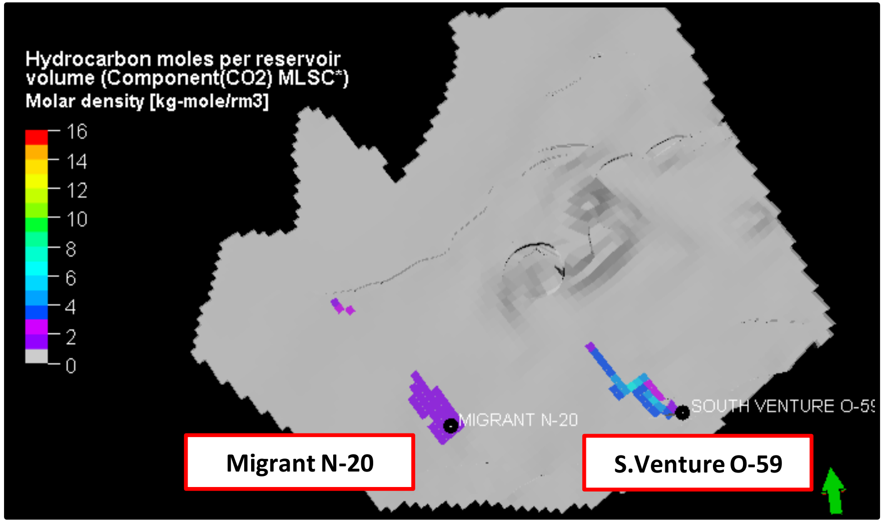


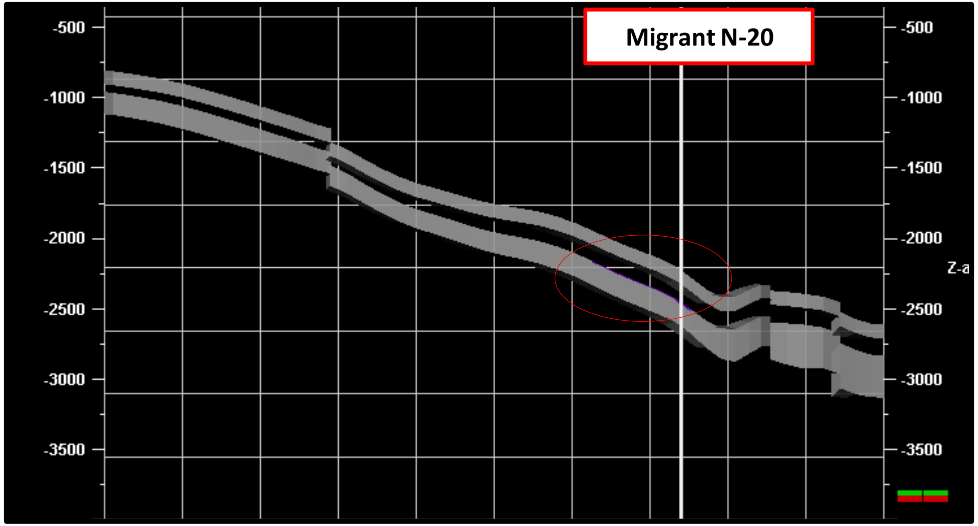


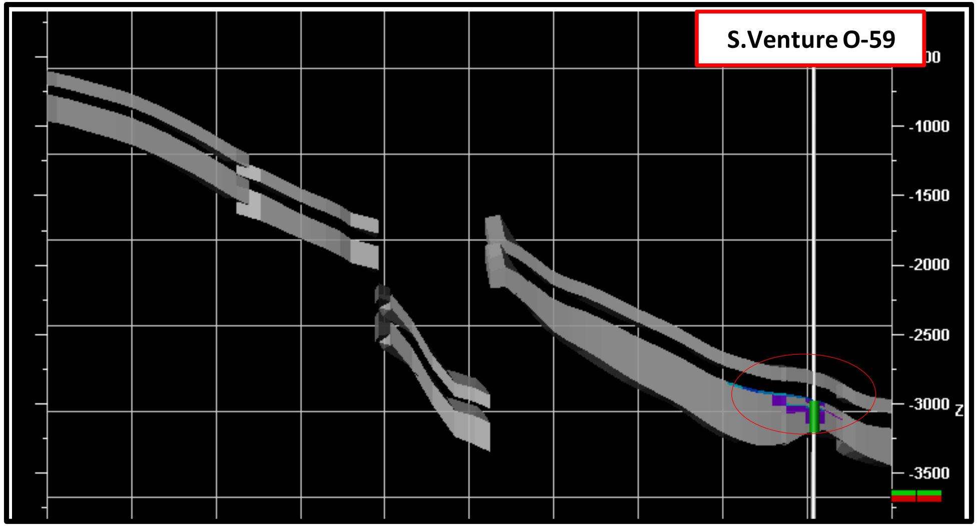
Regional Upper Missisauga Model

2.5Mt CO2 per year per well – for 50 years

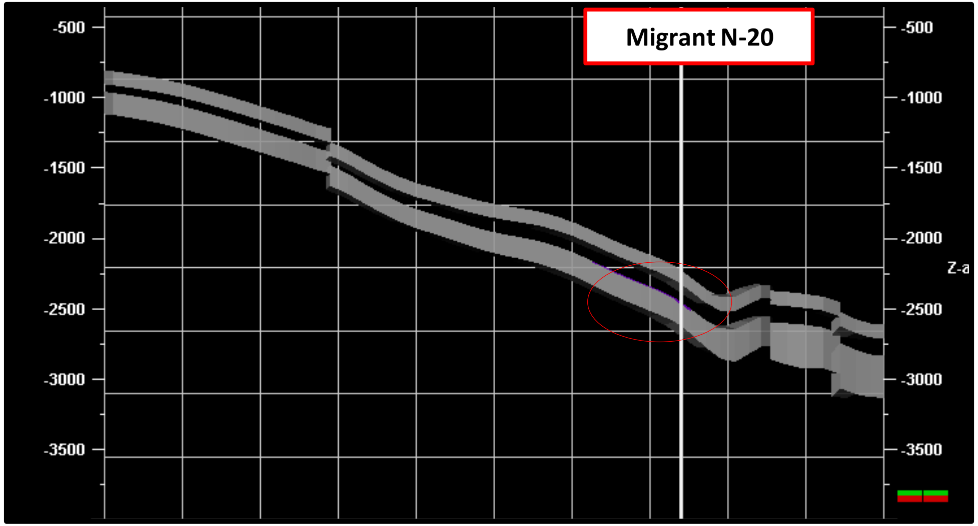
5050: 50 years injection – 3000 years equilibration



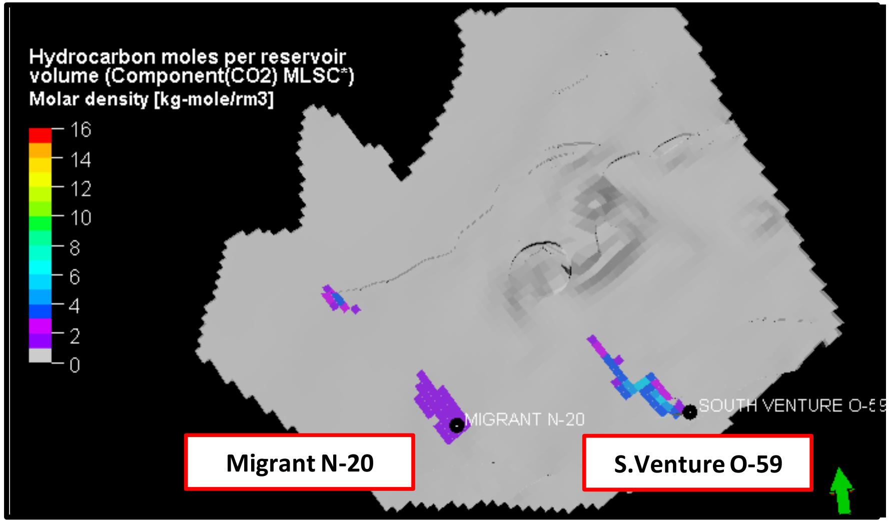


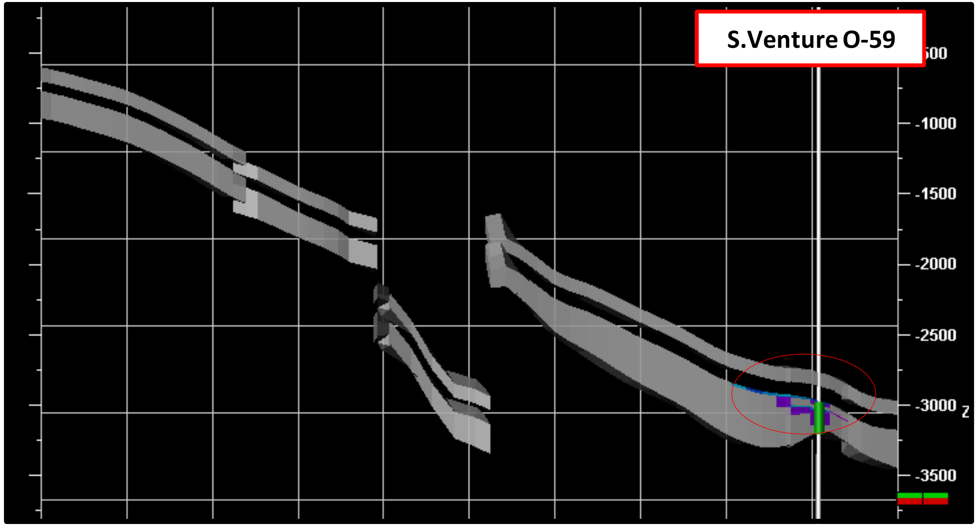


Regional Upper Missisauga Model
2.5Mt CO_2 per year per well – for 50 years

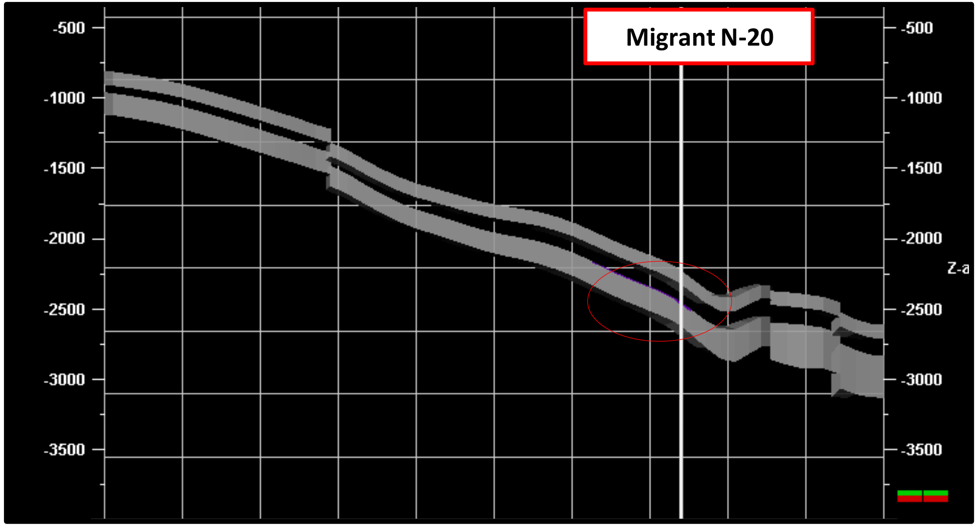


6050: 50 years injection – 4000 years equilibration

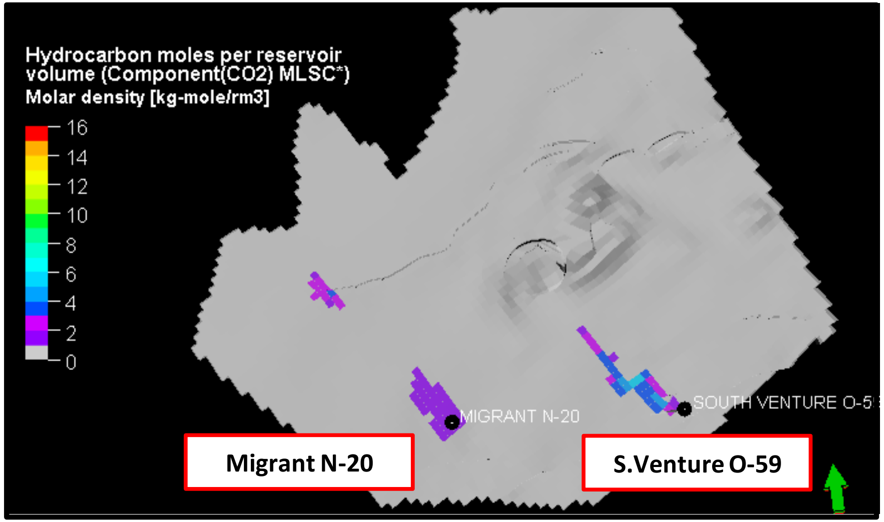


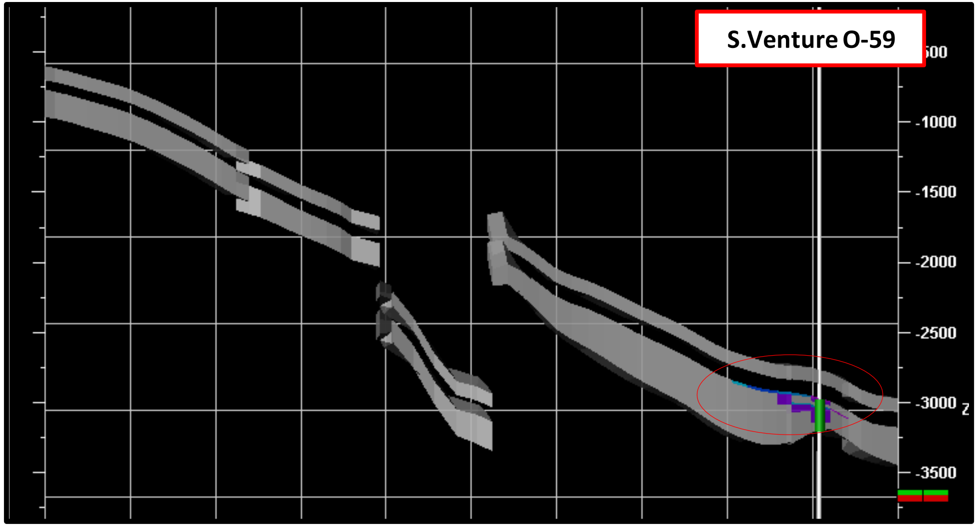


Regional Upper Missisauga Model
2.5Mt CO2 per year per well – for 50 years



7050: 50 years injection – 5000 years equilibration

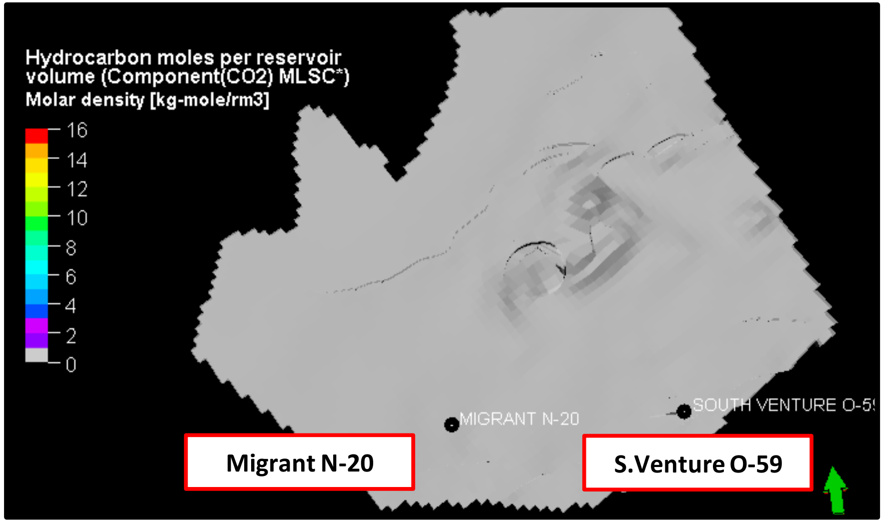


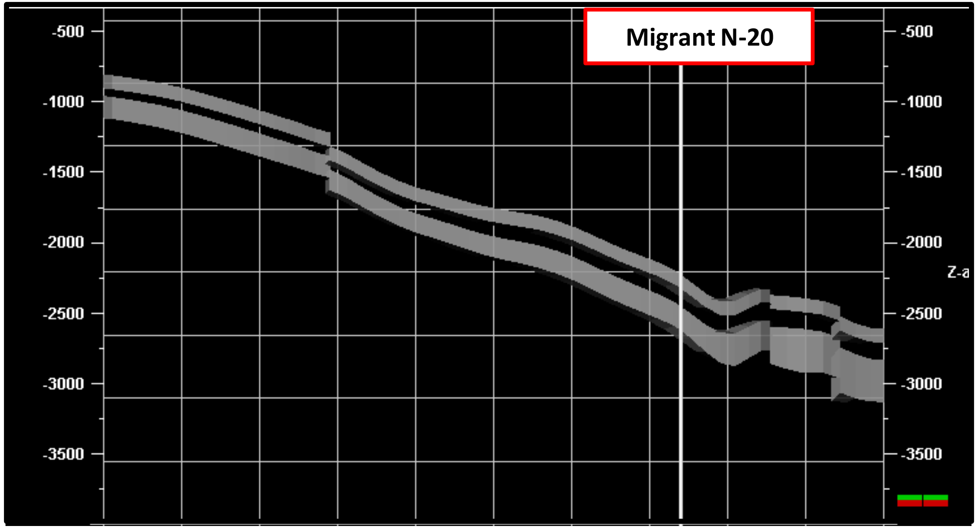


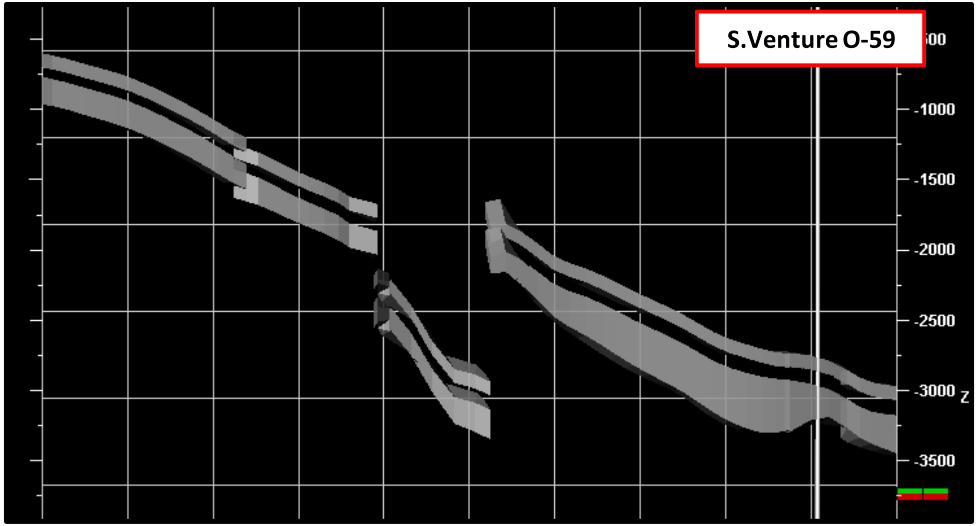
Sensitivity Inject 10 Mt / well / year for 100 years – then equilibrate for 500 years

Regional Upper Missisauga Model
10Mt CO2 per year per well – for 100 years

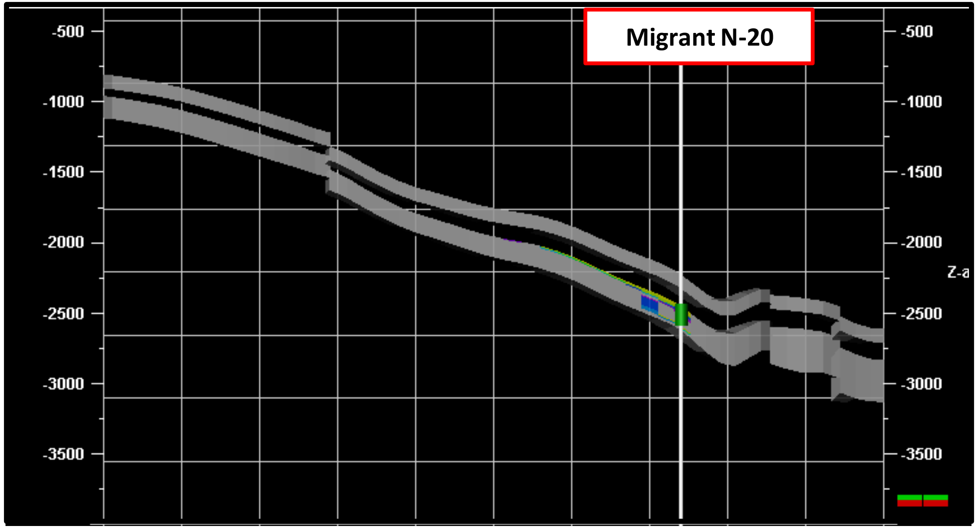
2000: 0 years injection



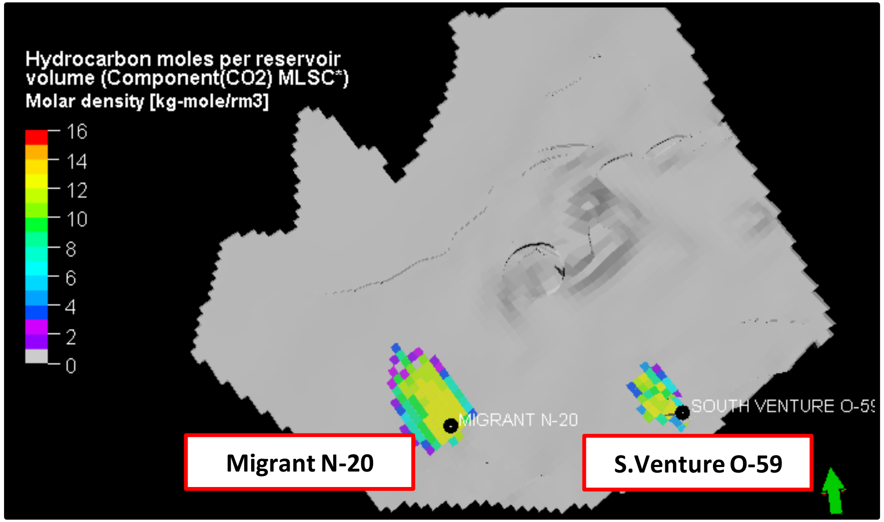


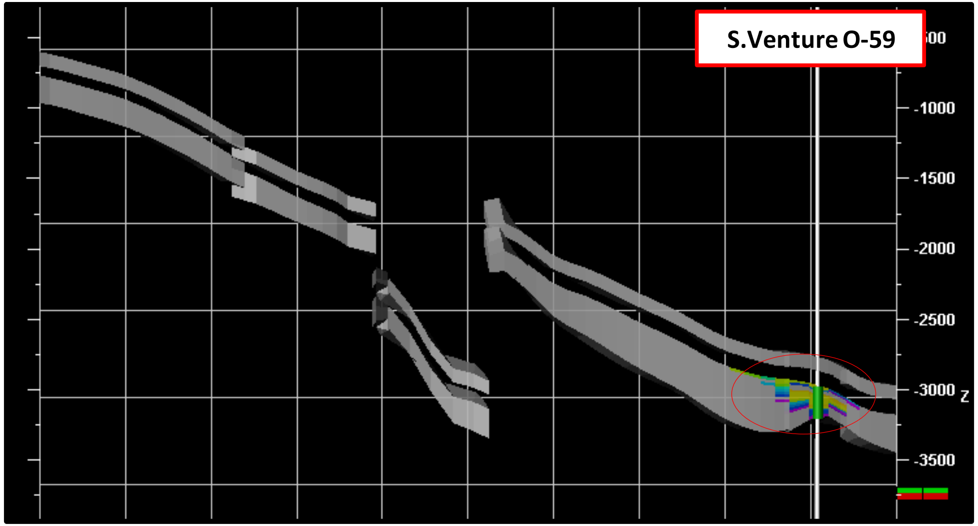


Regional Upper Missisauga Model
10Mt CO_2 per year per well – for 100 years

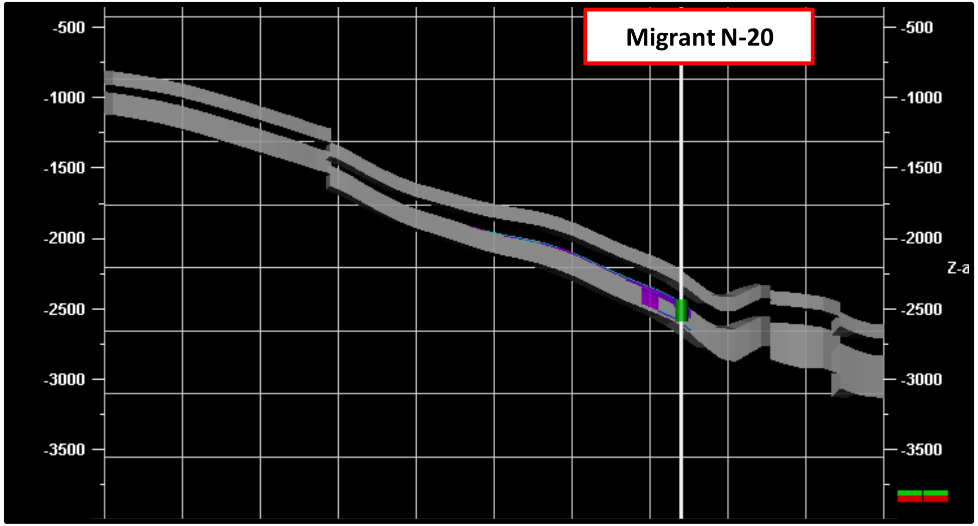


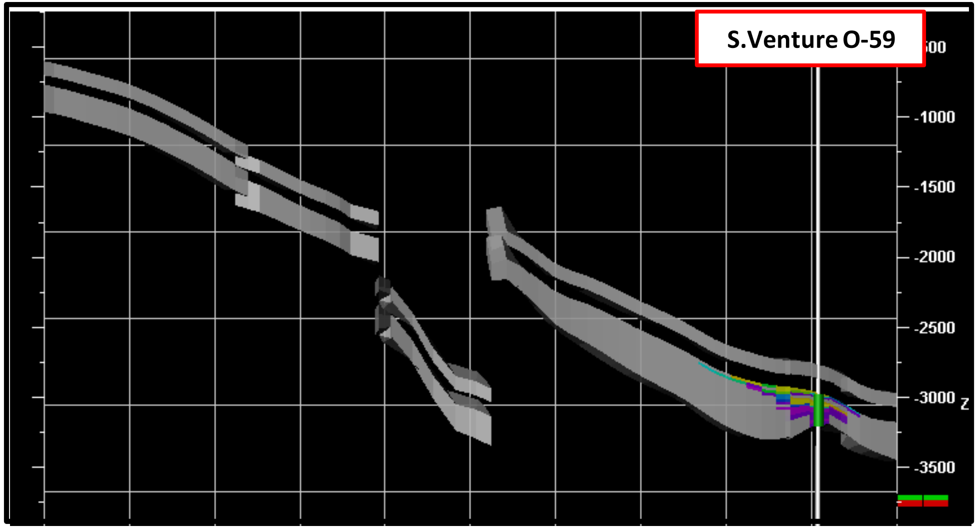
2100: 100 years injection



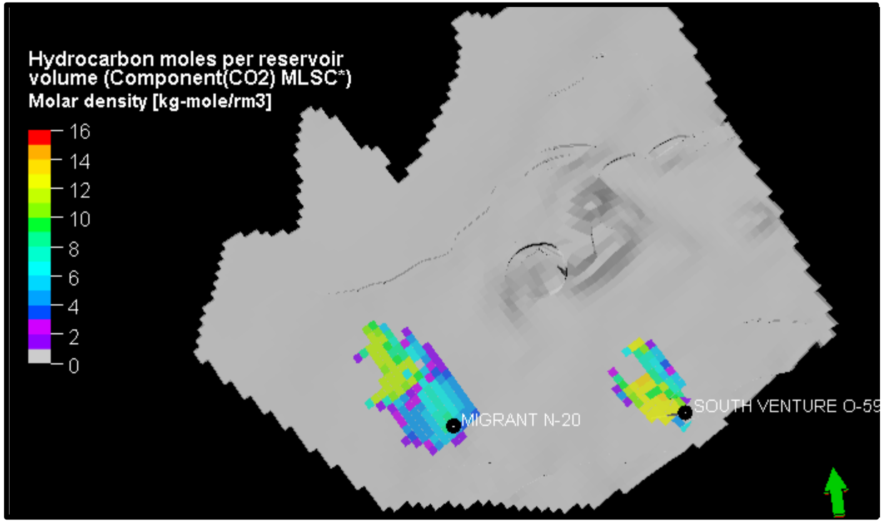


Regional Upper Missisauga Model
10Mt CO_2 per year per well – for 100 years



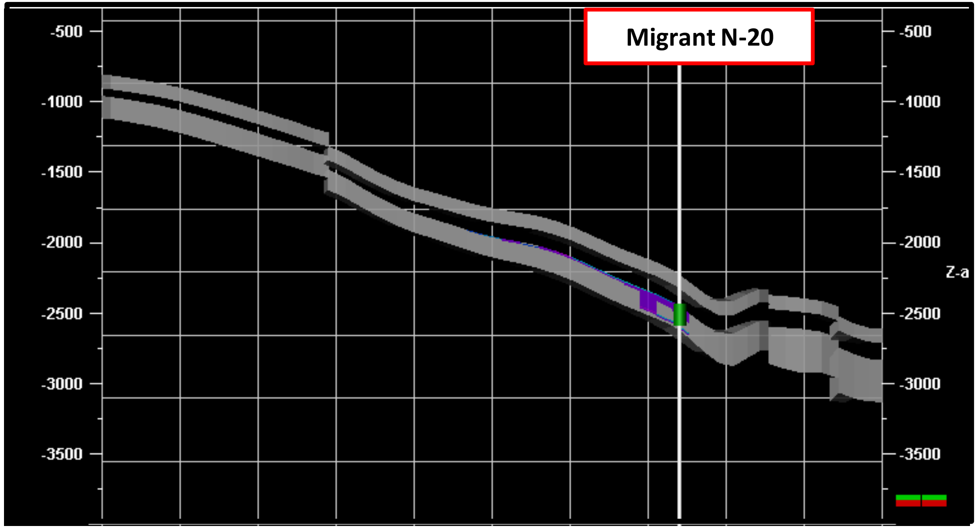


2200: 100 years injection – 100 years equilibration

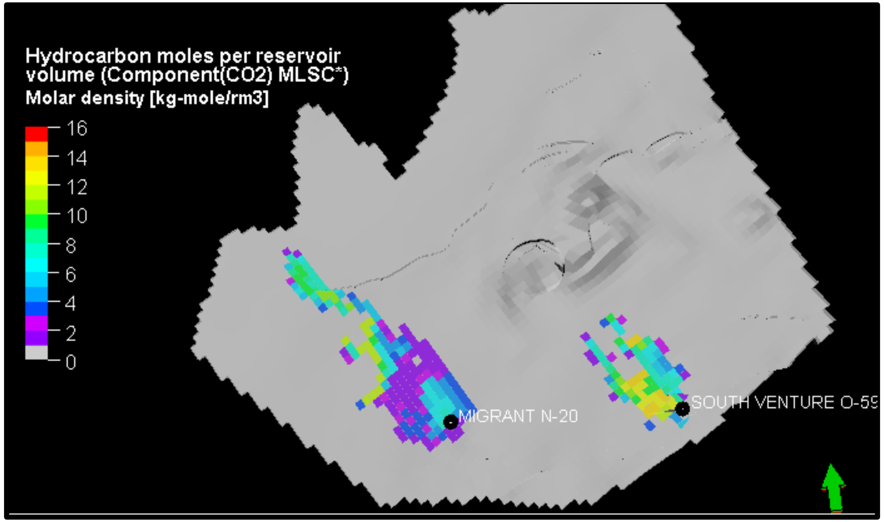


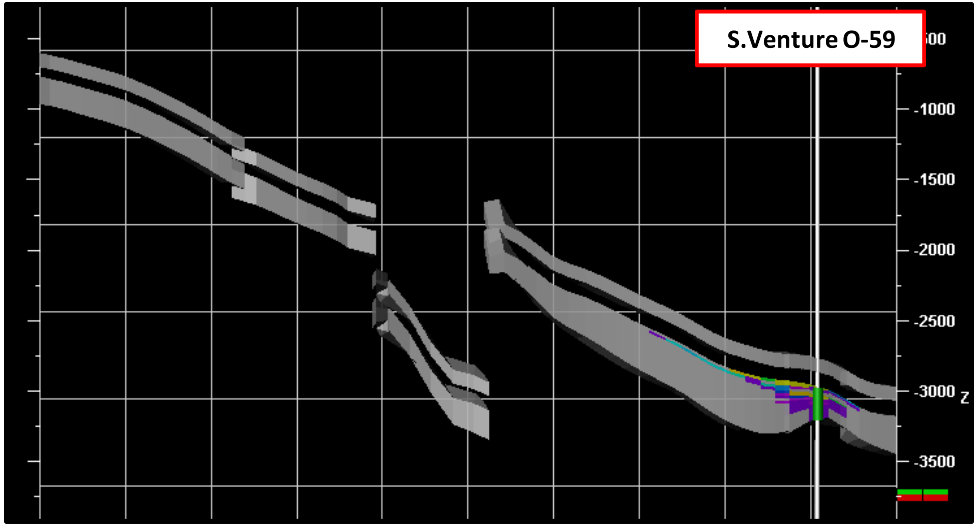
Regional Upper Missisauga Model

10Mt CO_2 per year per well – for 100 years

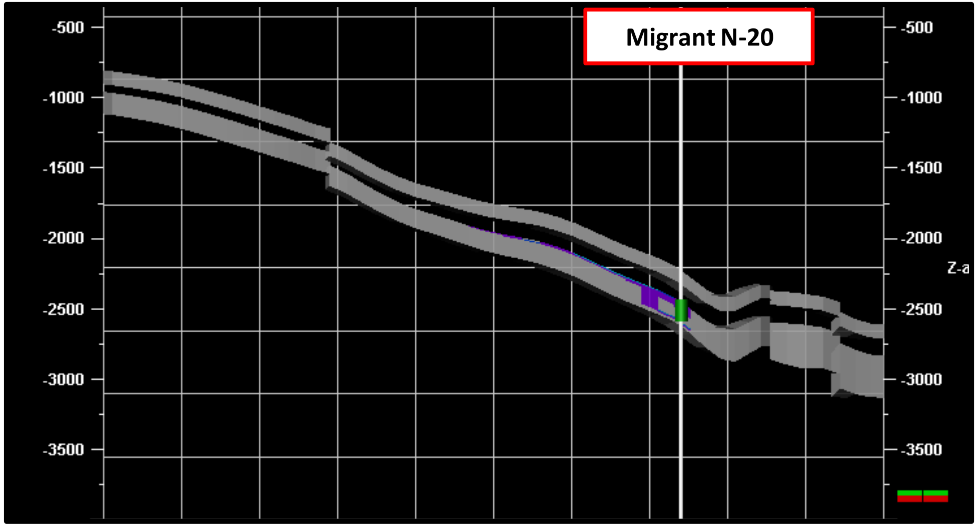


2300: 100 years injection – 200 years equilibration

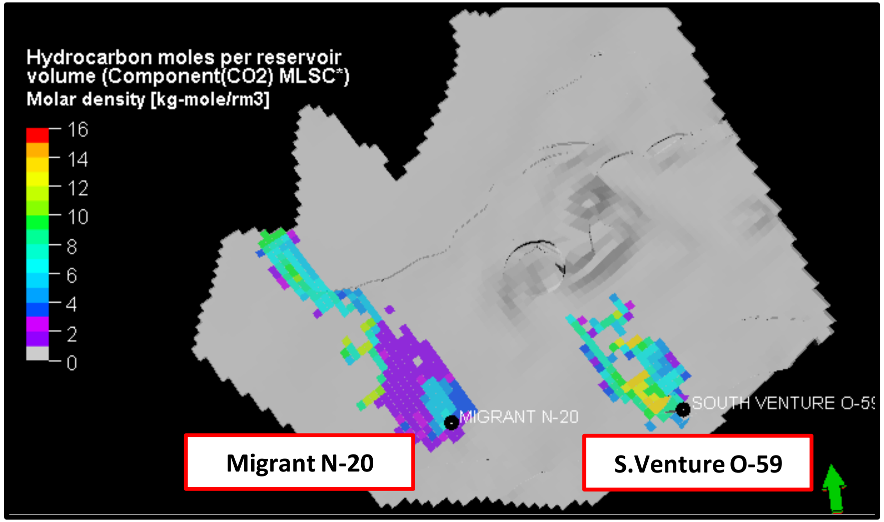


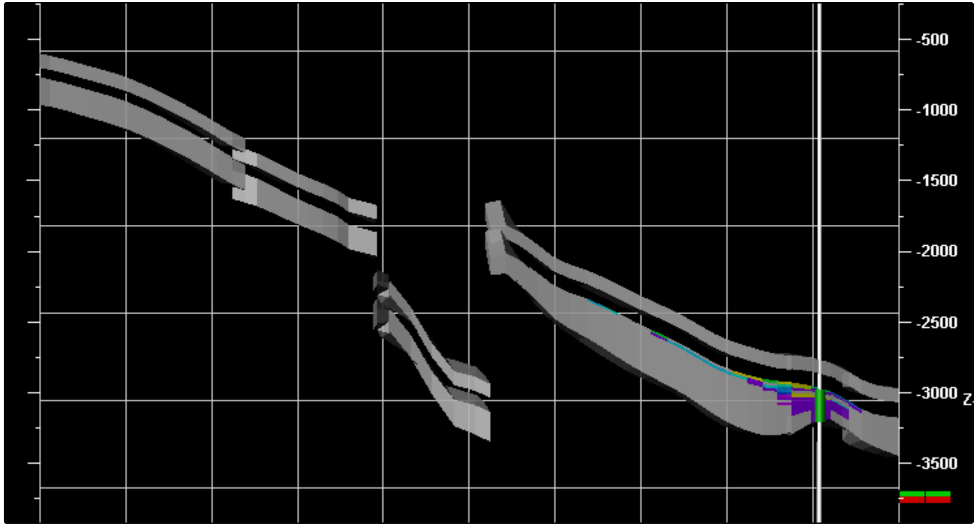


Regional Upper Missisauga Model
10Mt CO_2 per year per well – for 100 years



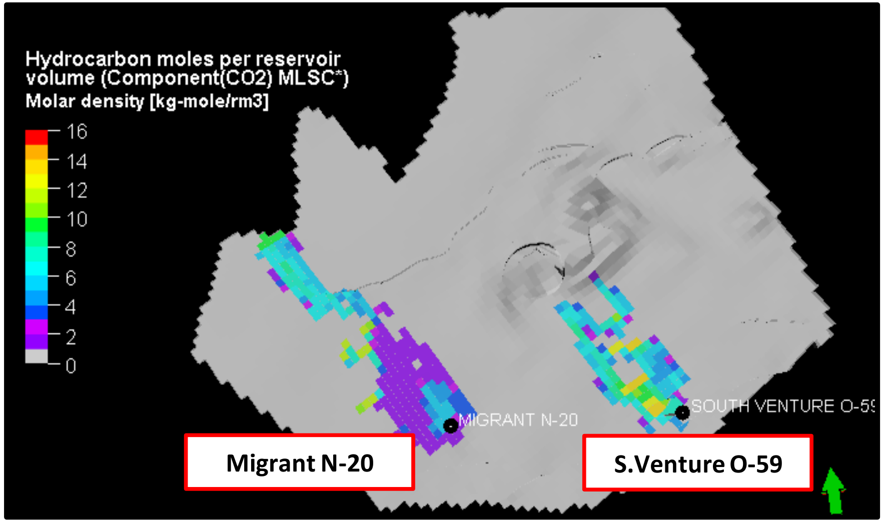
2400: 100 years injection – 300 years equilibration

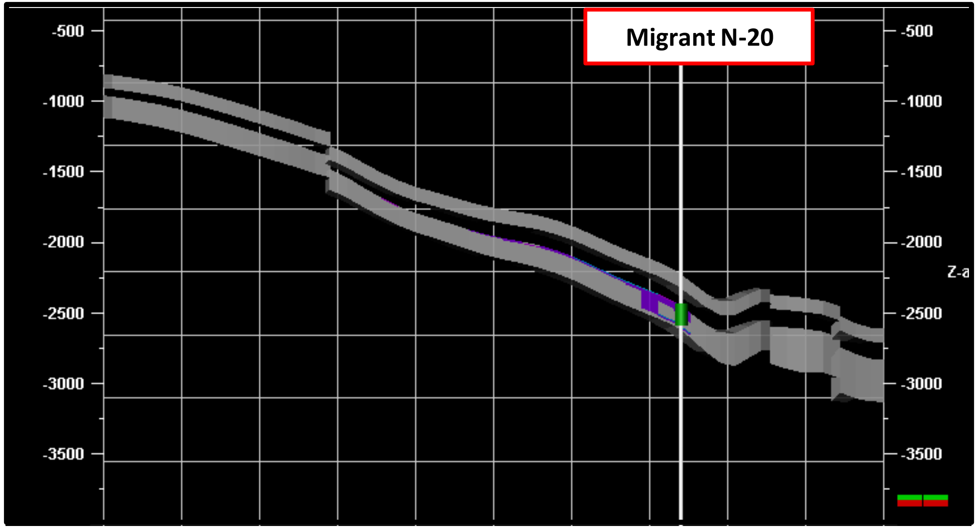


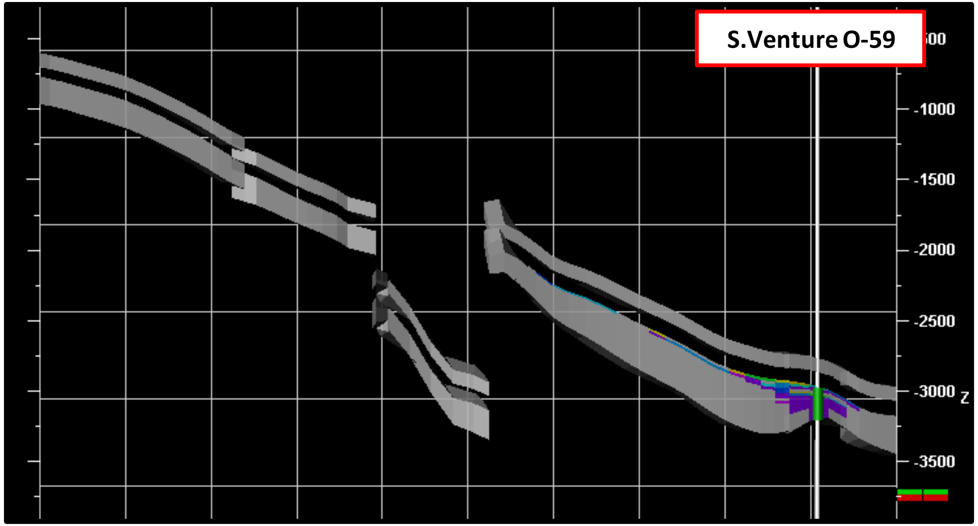


Regional Upper Missisauga Model
10Mt CO2 per year per well – for 100 years

2500: 100 years injection – 400 years equilibration

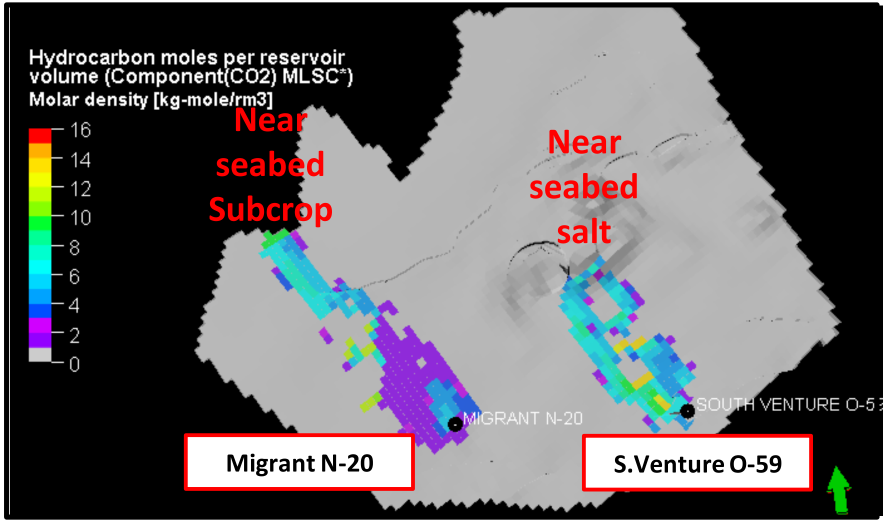


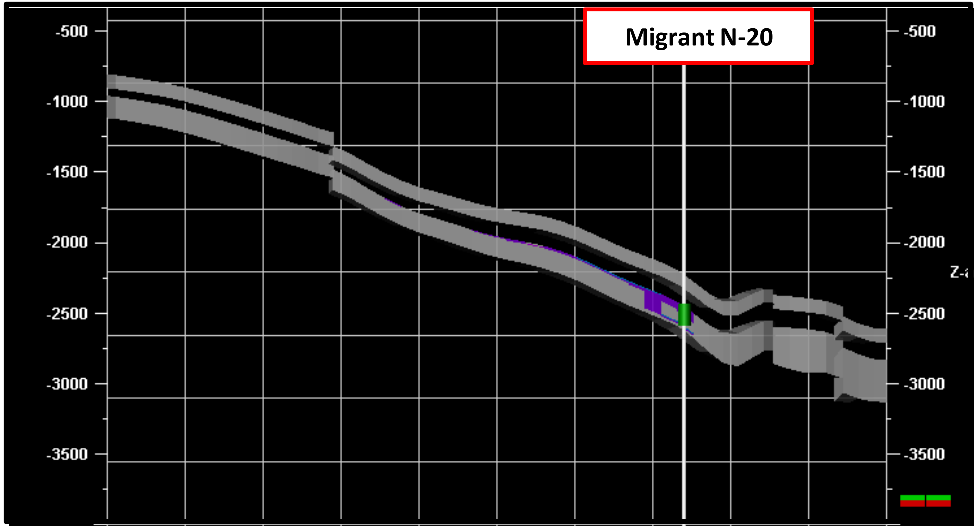


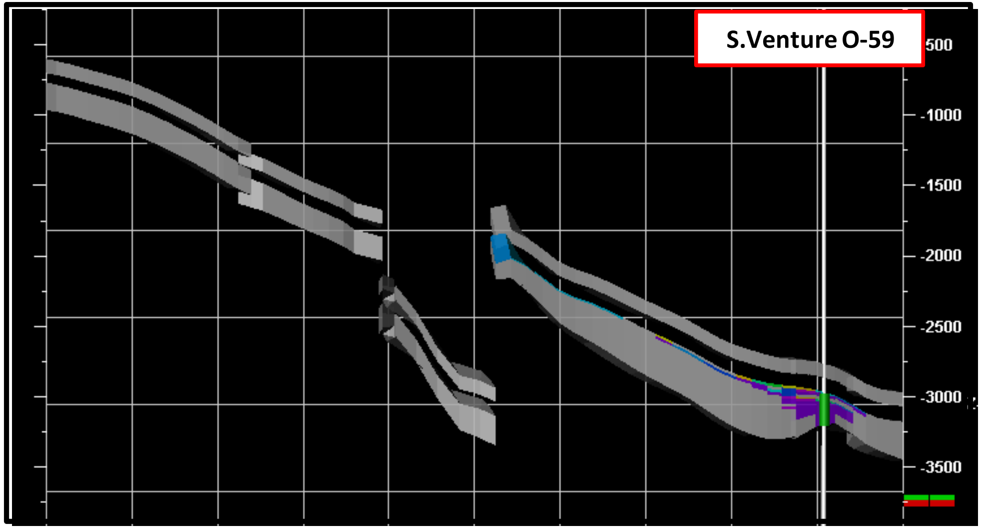


Regional Upper Missisauga Model
10Mt CO2 per year per well – for 100 years

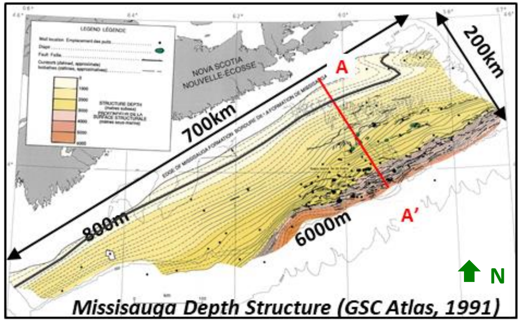
2600: 100 years injection – 500 years equilibration



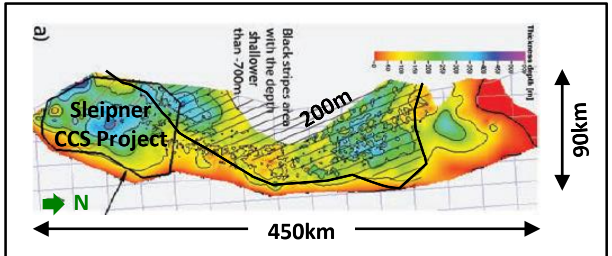




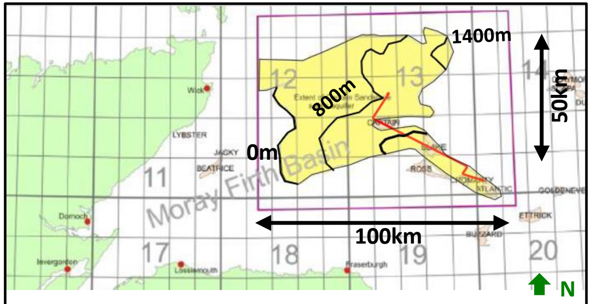
CCS Potential: Comparison Sable, Utsira, Captain



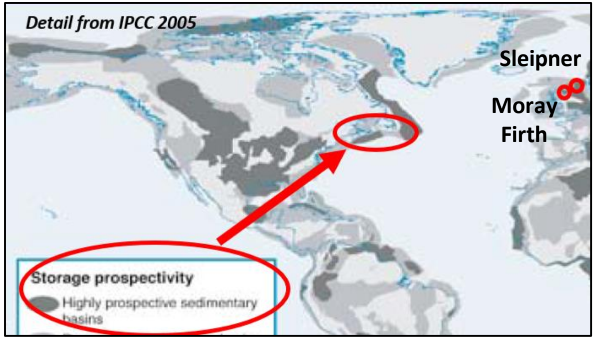
Missisauga Depth Structure (GSC Atlas, 1991)



Utsira isopach with depth contours
Pham, 2011 & Norwegian Petroleum Directorate CO2 Atlas



Captain Sandstone (Jin, 2012; depths Williams 2018)



	Thickness	Dimension	million tonnes		
	m	km	Low	High	
Captain	0-600	60 x 100	358	1668	2011 SCCS
Utsira & Skade	0-1000	90 x 450	500	1500	2011 NPD
Missisauga	0-5000	150 x 700	?	?	Calc here
Sable depleted hydrostatic reservoirs			~50		
NS Power annual emissions			~8		2012 NSP
Canada Fossil CO2 emissions 2017			~600		Wikipedia
Global Fossil CO2 emissions 2017			~37,000		Wikipedia

What Next for Sable?

- Drill more leaky ‘rollover anticlines’ & ‘carbonate drapes’?
- Scotian Margin identified as having world class CCS potential in 2005 (IPCC)
- CCS storage capacity could exceed estimates for Sleipner, Norway (ongoing 20 years) and the Captain Sandstone (planned project in the Moray Firth) which similarly rise to the seabed (or within a few hundred meters) .
- What physical mechanisms prevent buoyant CO2 from reaching seabed?
  - ➢ migrating CO2 plume leaves about 30% residually trapped gas & over thousands of years migrating CO2 dissolves in saline aquifers and sinks
- What injection rates and pressures enable safe storage? Of how much CO2?
  - ➢ Addressed through dynamic modeling, here and in N. Sea (Eclipse 300)
- CCS investigated onshore Nova Scotia – lacks suitable reservoirs
- **Poster by Max Angel – scoping potential costs of CCS in the Sable Subbasin**