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Dynamic Modeling of Buoyant Fluids:

Implications for Hydrocarbon Distribution and Potential Carbon Capture and Storage (CCS)

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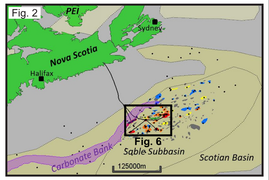
Summary

Many intergovernmental organizations, international panels, and global scientific institutions have come to an objective, scientific based understanding that anthropogenic release of CO_2 to the atmosphere is one of the major contributors to human-induced climate change. The 2005 IPCC report on CCS identified the Scotian Margin as one of few world class locations for storage of CO_2 in deep saline aquifers.

Fig. 1

Fig. 2

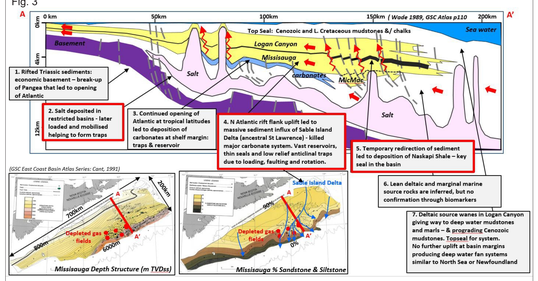


Above: From the IPCC report on CCS. Map identifying the CO2 storage prospectivity of global geologic basins.
Right: Map of the Scotian Basin showing the main geologic features (Jurassic carbonate bank, petroleum system of the Sable Subbasin) as well as the pipeline infrastructure.

Here we present a series of static and dynamic fluid flow models to illustrate the trapping mechanisms, or lack thereof, of hydrocarbons in the Sable Subbasin (Scotian Margin). Following this we present our evaluation of carbon capture and storage (CCS) potential in regional aquifers in the subsurface Sable Subbasin region. We conclude that CCS in depleted gas fields carries the least risk of leakage but has limited potential due to the small size and low relief of the structures. In contrast, CCS in regional aquifers offers huge storage potential but there are serious concerns regarding leakage through their updip subcrop near the seabed.

Geology - Scotian Basin

Fig. 3



Data & Methods

Data: Data used in this project included pressure, geochemistry, temperature, maturity, lithostrat, and biostrat basin data collected from the GSC "BASIN" database. Formation structure maps, well logs, and seismic cross sections were collected from the GSC 2011 East Coast Basin Atlas Series. Seismic data, both 2D and 3D, as well as associated maps and reports were collected from the Canadian Nova Scotia Offshore Petroleum Board and their Data Management Center website. This included the Penobscot 3D seismic survey and wells L-30 and B-41. Offshore well data for wells Migrant N-20 and South Venture O-59 are part of a larger dataset purchased from Divestco.

Methods: The above data were combined in order to build representative 3D geocellular models of structural closures of reservoirs and regional aquifers (Missisauga Fm.) in the offshore Scotian Margin. These models were constructed in Petrel 2018. Petrophysical properties were calculated at the wells (porosity and permeability) and were propagated through the models using the nearest point algorithms. Gas injection wells were inserted into the models. Using ECLIPSE simulation software, gas was injected into the base of each well for 50 or 100 years and then injection was stopped. Following this, each model was allowed to equilibrate for thousands of years. A detailed overview of the methods is too extensive for this presentation. Please contact the author for additional details.

Fluid Trapping

Fig. 4

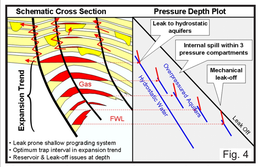
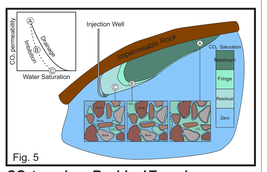


Fig. 5



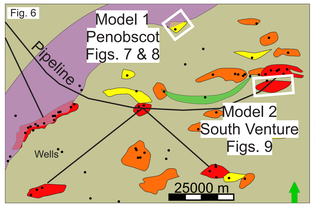
Hydrocarbon trapping predominant in rollover anticlines in Scotian Basin:
- Deeper reservoirs controlled by fault (and salt) movement.
- NTG increases upwards as reservoirs are proximal upward as shelf prograded.
- Reservoir connectivity increases upwards, traps less effective, and overpressure (recent charge) is released in steps until the system becomes equilibrated.

CO_2 trapping - Residual Trapping:
- Buoyancy from injected CO_2 overcomes capillary entry pressure of pore
- CO_2 fills the pore space to a minimum relative permeability of water
- The CO_2 plume passes the pore, but residual droplets are snapped off and left behind as water renters the pore.

Dissolution and structural trapping are other mechanisms of CO_2 trapping

HC Distribution Models

Fig. 6



Left: Map outlining the structural enclosures of the Sable Subbasin, the location of infrastructure in place, and the location of the dynamic models presented below.
Right: Examples showing 2D slices of static models constructed for this study. For each of the models, data from the wells was propagated in the model using the 'closest point' algorithm to maximize the topseal effectiveness. Shown are the porosity, permeability, and net to gross.

Fig. 7a

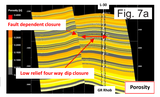


Fig. 7b

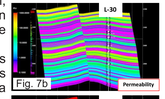
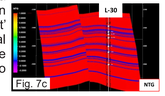


Fig. 7c



Dynamic fluid flow models: We present two examples 1) a "leaky" hydrocarbon system and 2) a high integrity trap system. These models are constructed and populated using 2D & 3D seismic and well data. Gas (CH4) is injected into the base of each brine saturated structure for 100 years. Following this, models are equilibrated over a period of ~7000 years. The results are shown below.

	Model 1 "Leaky" Penobscot	Model 2 "High Integrity Trap" South Venture
	Figs. 8	Figs. 9
Year 2020 Both models are brine saturated		
Year 2120 Following 100 years of CH4 injection at the base of both models. Cross fault juxtaposition of sands allows upward leakage of gas in "leaky" Penobscot Model (Model 1)		
Year 3120 Equilibrated for 1000 years. Gas continues to climb along sands in contact on either side of Penobscot Model (Model 1). Gas is contained in structural closure of South Venture (Model 2)		
Year 5120 Equilibrated for 3000 years. Gas continues to climb along fault juxtaposed sands of Penobscot Model (Model 1). Gas is contained in structural closure of South Venture (Model 2)		
Year 7120 Equilibrated for 5000 years. Gas continues to climb along fault juxtaposed sands of Penobscot Model (Model 1). Most gas has escaped from the western most structure.		
Year 9120 Equilibrated for 7000 years. Eastern model of Penobscot is still equilibrating at limit of simulation. The simulation was continued in separate model with shallower injection wells and younger stratigraphy, showing almost completed escape of gas from the system		

CCS Saline Aquifer Models

Fig. 10

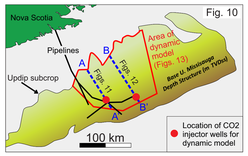


Fig. 11 a

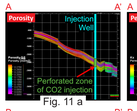


Fig. 11 b

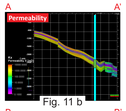


Fig. 12 a

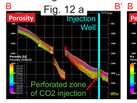
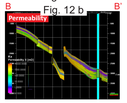


Fig. 12 b



Above: The Scotian Margin showing the top of the sand rich Upper Missisauga Formation, the pipeline infrastructure, the area of dynamic modelling, and location of CO_2 injection wells in this study. Also shown are cross sections from static model showing porosity and permeability.
Right: A summary of the dynamic modelling. Two injection wells were used to inject 2.5 Mt/well/year CO_2 for 50 years into the Missisauga Formation. Following injection of CO_2, the system was allowed to equilibrate passively for 5000 years. Results are shown here.

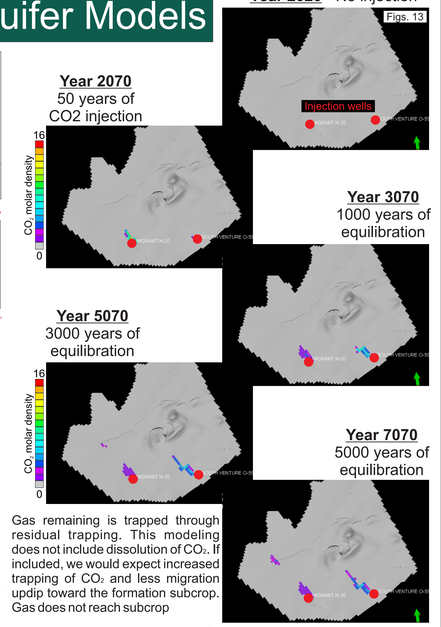
Year 2020 - No injection

Year 2070
50 years of CO2 injection

Year 3070
1000 years of equilibration

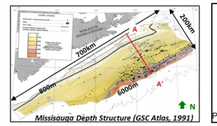
Year 5070
3000 years of equilibration

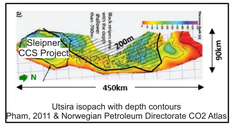
Year 7070
5000 years of equilibration

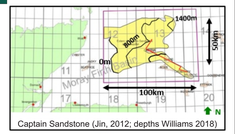


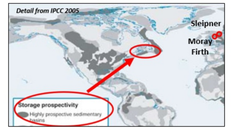
Gas remaining is trapped through residual trapping. This modeling does not include dissolution of CO_2. If included, we would expect increased trapping of CO_2 and less migration updip toward the formation subcrop. Gas does not reach subcrop

Global Comparison









	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	?	?	
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