Geological Carbon Sequestration in Atlantic Canada

DALHOUSIE UNIVERSITY
Inspiring Minds

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INTRODUCTION

The most significant sources of CO_2 in Nova Scotia are hydrocarbon-burning power plants with annual emissions of nearly 10 million tonnes of CO_2. The Maritime Provinces have a long geological history with several Paleozoic and Mesozoic basins that are candidates for CO_2 storage. Salt can form an excellent seal to potential reservoirs and there are two salt systems present, the Paleozoic Windsor Group and the Mesozoic Argo Formation. Several carbonate and clastic reservoirs are candidates in addition to potential storage opportunities in coal beds and sub-basalt and fractured shale and the very low possibility of fractured granitoids.

REGIONAL GEOLOGY

Geologic settings relevant to carbon storage, containing porous reservoirs and suitable cap rocks are; Onshore and offshore strata of the Magdalen and Sydney basins of Devono-Carboniferous to Permian age. Coarse clastics underlie thick evaporites (gypsum, anhydrite, carbonates) and salt of Mississippian age that in tectonically complex sites form relatively small gas reservoirs; large salt diapirs occur near-surface that could provide small solution cavities for storage. Above the evaporites there are clastic formations and coal beds alternating with shales that could have some interest as potential reservoirs. Diagenesis and relatively deep burial formed high-rank bituminous coal in the Late Carboniferous, followed by inversion in the Triassic, but also reduced porosity and extensively fractured the rocks. Assessment of storage potential in these basins require a careful structural analysis and evaluation of porosity and reservoir capacity of deep aquifers. Fortunately the Province of Nova Scotia has maintained an extensive and excellent archive of cores from onshore and offshore wells that are available for study.

Triassic to Neogene strata in the offshore Orpheus, Abenaki and Sable sub basins to the south offer more realistic possibilities for CO_2 storage, and petroleum exploration provides suitable seismic and petrophysical data from deep wells, to assess the sequestration potential. Autochthonous and allochthonous Jurassic salt provides potential reservoir structures, and the Cretaceous and Cenozoic strata contain significant porous formations that have led to economic oil and gas exploitation. A few of the best suited (Cretaceous) sands for storage are those occupied by compartmentalized and overpressured gas reservoirs in the Sable Subbasin, but they are rather distal from the CO_2 sources (more than 150 km). Suitable sands and subsalt plays in the structurally deformed Orpheus Subbasin should be the focus of carbon sequestration studies. Outcrop analogs are in the region.

SOURCES OF CO_2

There are five Nova Scotia Power generating stations which burn a combination of coal, bunker 'C', light fuel oil and natural gas. The largest producer of CO_2 emissions is the Lingan Power Plant which uses coal as it's primary source of fuel. Lesser sources include cement manufacturing facilities. To be economically feasible, the CO_2 emission source must be close to the storage reservoir. Figure 2 below illustrates the proximity of the power generating stations to the surrounding offshore basins.

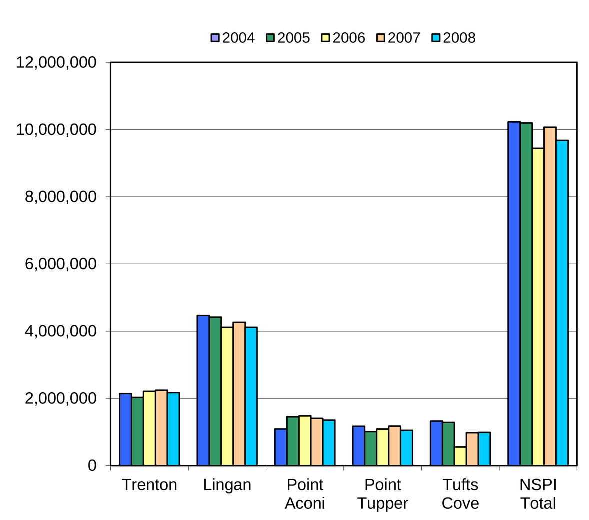

Figure 1: CO_2 Emissions (tonnes) by Nova Scotia Power Generation Stations (Nova Scotia Power Inc. 2009).

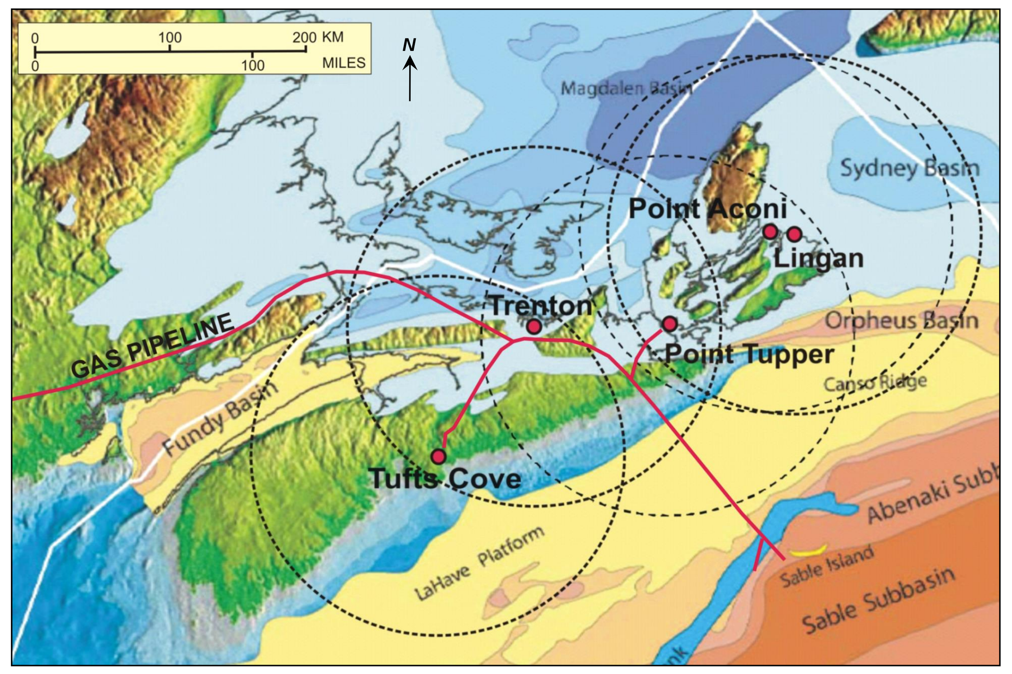

Figure 2: Map of adjacent sedimentary basins, with a radius of 150 km around the Nova Scotia Power generation plants (modified from Geological Survey of Canada-Atlantic).

Potential Locations for CO_2 Sequestration

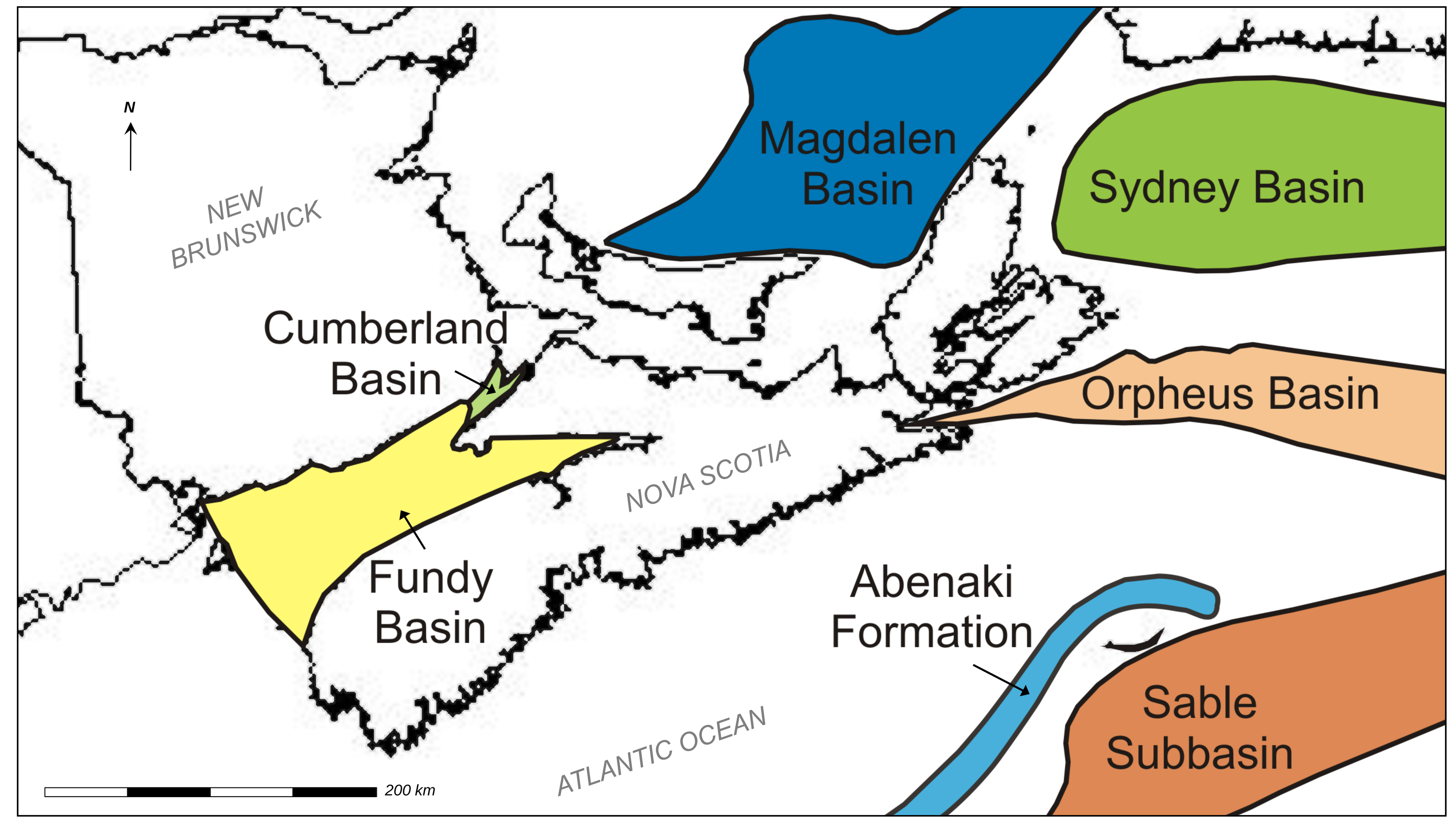

Figure 3: Maritime Basins

Table 1: Basins Characteristics

Basin / Subbasin	Description	Pros	Cons
Magdalen	**Reservoir**- Devono-Carboniferous to Permian age coarse clastics **Seal**- Mississippian evaporites and salt	- Close proximity to emission site	- Low porosity - Low permeability
Sydney	**Reservoir**- Devono-Carboniferous to Permian age coarse clastics **Seal**- Mississippian evaporites and salt	- Close proximity to emission site	- Low porosity - Low permeability
Orpheus	**Reservoir**- fine grained to conglomeratic clastics (Eurydice Fm.) **Seal**- thick evaporites (Argo Fm.)	- Close proximity to emission site - Potential for salt seal	- Offshore Pipeline needed - Offshore seismic surveys for monitoring
Fundy	**Reservoir**- fine grained to conglomeratic clastics (Blomidon and Wolfville Fms.) **Seal**- North Mountain Basalt	- Good porosity	- Far from emissions site - Offshore Pipeline needed
Sable	**Reservoir**- thick deltaic sands (Missisauga Fm.) **Seal**- thick transgressive prodelta shales	- Pipeline in place - Good porosity	- Far from emissions site
Abenaki	**Reservoir**- carbonates with fracture and dolomitic porosity (Abenaki Fm.) **Seal**- thick transgressive prodelta shales	- Pipeline in 2010 - H_2S injection planned	- Far from emissions site - Offshore Pipeline needed
Cumberland	**Reservoir**- Pennsylvanian coarse clastics (Joggins and Polly Brook Fms.) **Seal**- Windsor evaporites	- Close proximity to emission site (Trenton) - Near Maritimes NE Pipeline	- Low porosity - Low permeability
Horton Group	**Reservoir**- fractured shale and sandstone **Seal**- shale and Windsor evaporites	- Widespread distribution	- Probably low injectivity rates into shale

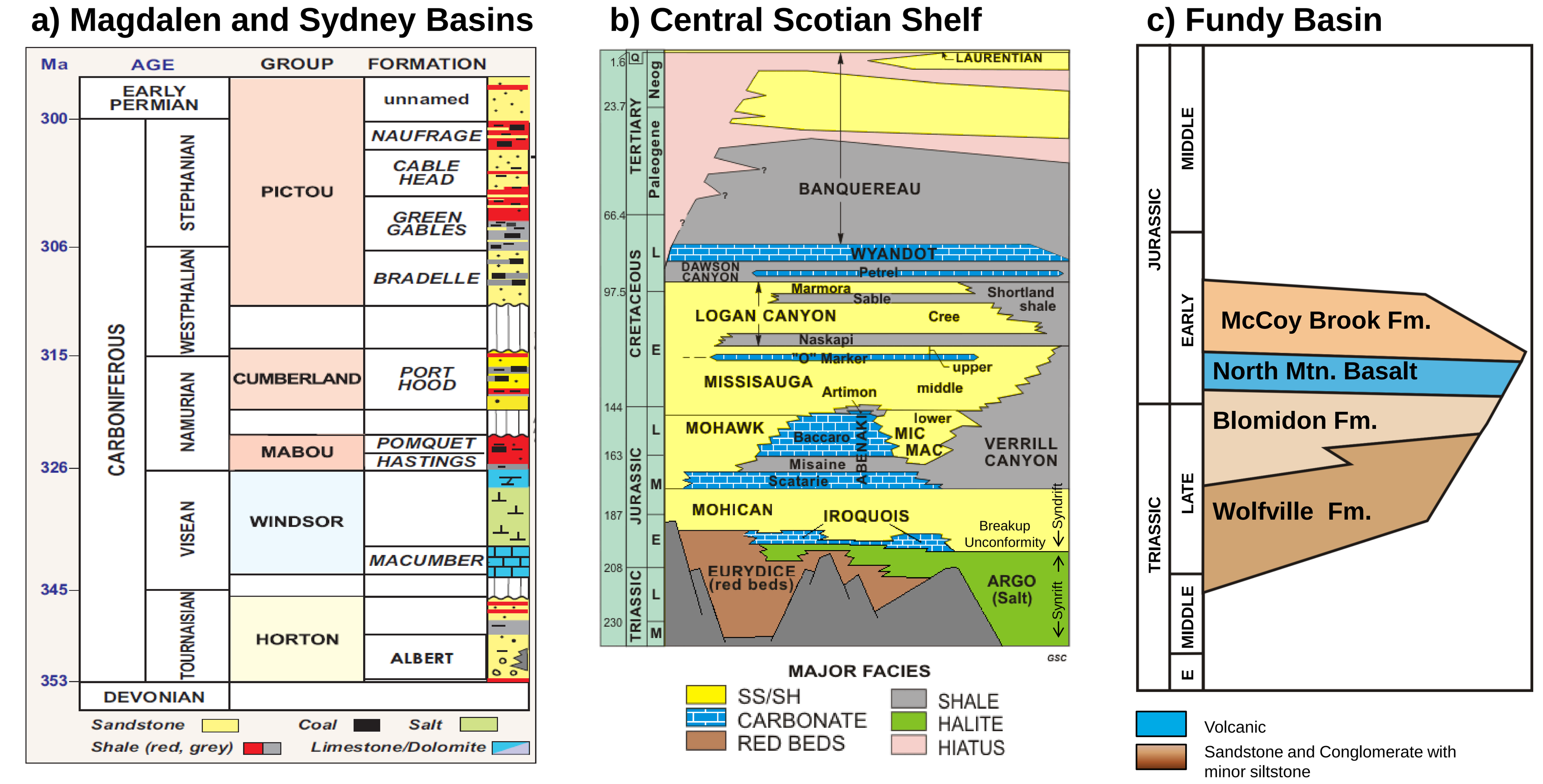

Figure 4: Generalized stratigraphy of a) the Magdalen and Sydney basins (Hu and Dietrich, 2008), b) the Central Scotian Shelf (Natural Resources Canada, 2008), and c) Fundy Basin (Fensome, 2001).

RESERVOIR CHARACTERIZATION AND MODELING

Reservoir and seals pairs can be usually be delineated with a high degree of confidence from well log and 3D seismic data. However subsurface geological data is seldom adequate to properly characterize the bedform scale in reservoirs, needed to monitor the distribution of high volumes of injected CO_2 and the potential diagenetic effects on reservoir performance over time.

Our preferred approach is to use analog reservoir models developed from detailed outcrop study. We incorporate high resolution photography, LiDar, GPR (ground penetrating radar), scintillometer (Gamma Ray) and outcrop permeameter data, with bed-scale outcrop measurements of outcrop geometry to define the architectural elements that are input to geologic and reservoir models using Schlumberger Petrel and Eclipse (Figures 5 and 6). Outcrop samples are examined petrographicaly to enhance our understanding of potential diagenetic effects at bed contacts coupled with detailed measurement of effective and ineffective porosity and permeability (Figure 7).

Figure 8 is an example of a fluvial braid reservoir complex similar to the formations projected to be potential reservoirs for CO_2 sequestration. The architectural elements are highlighted. These are used to populate the detailed geological model for simulation of various fluid types and injection strategies through time.

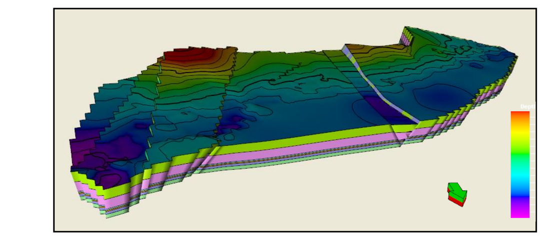

Figure 5: Reservoir model with faults, zones, and layers of Wolfville Fm. Cambridge Cove (Mulcahy, 2006).

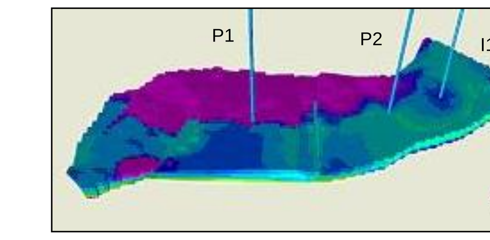

Figure 6: Simulation of production wells and injection well in Wolfville Fm. Cambridge Cove (Mulcahy, 2006).

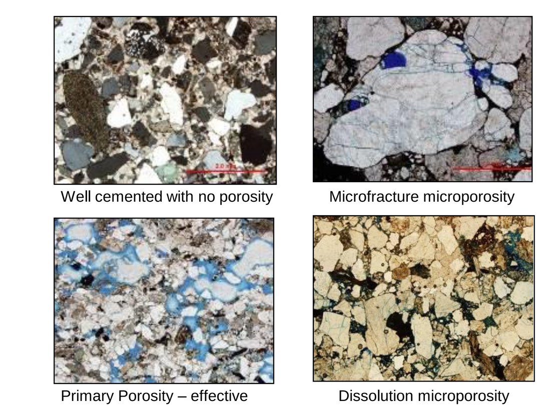

Figure 7: Types of porosity in Wolfville Formation sandstones (Kettanah et al. 2008)

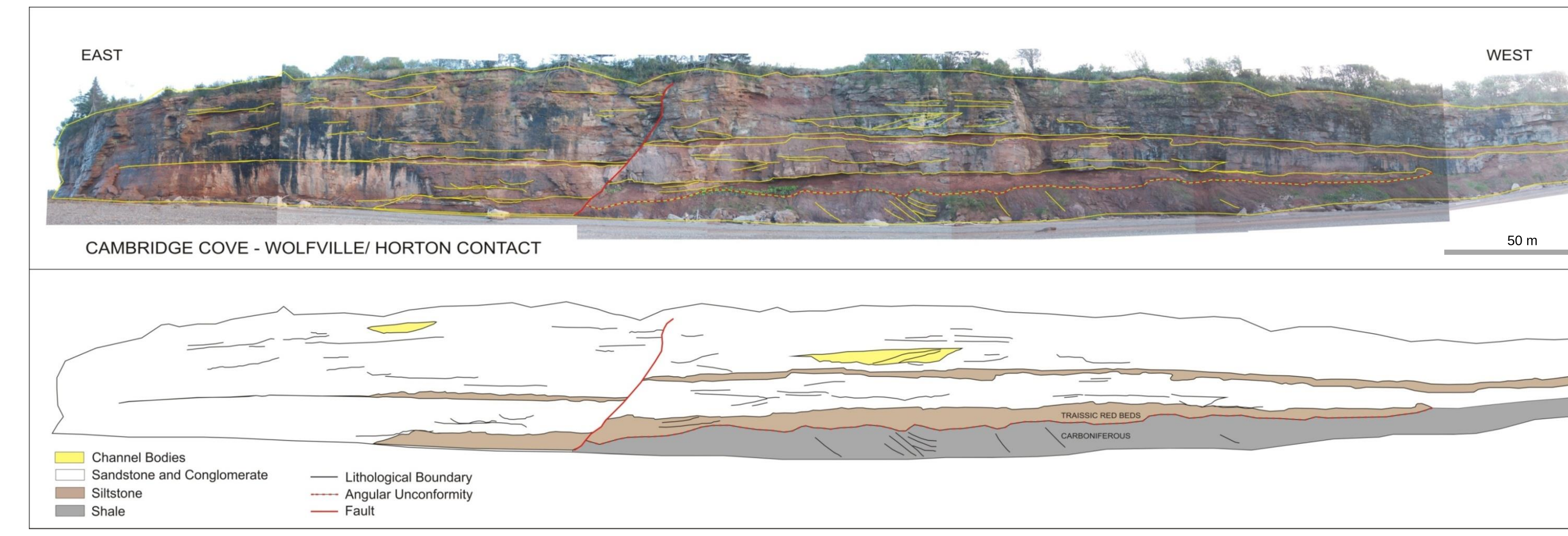

Figure 8: Cliff section in Cambridge Cove showing the Triassic Wolfville Formation which is currently being studied as a reservoir analogue.

CONCLUSIONS

In our ranking of potential sites we have considered the economic constraints due to distance from the major source of CO_2 emissions. Although the Orpheus Graben ranks as the preferred site for storage we do recognize that economic conditions may alter that could change the seriatim we have provided in our ranking of sites (basins and formations). Any storage site will also require long term monitoring of the CO_2. This will require monitoring wells and regular seismic surveys over the area ("4D"). Wells and particularly ongoing seismic surveys may be subject to environmental constraints.

What remains to be completed is detailed analysis of samples to discern storage capacity, including injectivity rates, lateral continuity and characterization of storage reservoirs to determine storage capacity, seal integrity, regional and local stress fields and the effect CO_2 will have on the reservoir through time. We have begun detailed reservoir characterization and modeling of an analogous reservoir in outcrop, the Triassic Wolfville formation exposed along the Minas Basin and Bay of Fundy.

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