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Executive Summary

Geological Survey of Canada Atlantic conducted a scoping assessment of the potential for geologic carbon sequestration (GCS) in Atlantic Canada. The objective was to determine whether saline aquifers and basalts in Atlantic Canada are viable storage sites for CO_2, and could be used to store CO_2 produced in Ontario and Quebec, as well as within Atlantic Canada, thereby contributing to meeting Canada's carbon emission targets. The intent was to identify promising regions and rock formations worth further investigation, rather than to recommend specific storage sites. The work was funded by the Office of Energy Research and Development (OERD) under their Carbon Capture, Utilization and Storage program.

This assessment relied on published and internal data sources including petroleum resource assessments, geophysical logs, sample descriptions and core analysis data from wells, subsurface maps from seismic and gravity data, surface geologic maps and outcrop descriptions. No new field data was collected, nor was any new seismic interpretation conducted for this research.

Chance of Success (COS) maps for saline aquifers were generated using a probabilistic approach adapted from the petroleum resource assessment methodology used by the Marine Conservation Targets program. Maps of the COS for reservoir, seal and trap were generated and multiplied together to create a total COS map. The results include COS maps for late Paleozoic rocks in Nova Scotia, New Brunswick, Prince Edward Island, the Gulf of St. Lawrence, and Cabot Strait, and Mesozoic-Cenozoic rocks of offshore Labrador and Nova Scotia. Potential reservoir-seal pairs in Newfoundland and its surrounding offshore area were identified, but no maps were created. The general locations of late Paleozoic and Mesozoic basalts in the Maritime provinces were identified, and their suitability for carbon storage as injection sites or sources of basalt for carbon sequestration through enhanced rock weathering were briefly discussed.

The Paleozoic sedimentary rocks onshore in Atlantic Canada have low to moderate permeability and porosity, which may limit their capacity and ability to support high injection rates. However, these rocks could be suitable for storage of emissions from local emitters. Promising reservoirs may be present in Prince Edward Island, southeastern New Brunswick, northern Nova Scotia and south of the Minas Basin.

Mesozoic and Cenozoic rocks in both the Labrador and Nova Scotia offshore areas have multiple reservoirs with high permeability and porosity. The Sable Sub-basin offshore Nova Scotia is particularly attractive due to relatively good geologic constraints and proximity to infrastructure as well as favourable geology. These rocks could potentially support large-scale projects capable of storing emissions from outside Atlantic Canada. Although COS maps were not generated for the sedimentary basins of offshore Newfoundland, they are similarly expected to have high potential for GCS.

The most promising sites for basalt injection are the North Mountain Basalt north of the Annapolis Valley and the Fountain Lake Group basalts in the eastern Cobequid Highlands, both in Nova Scotia. The North Mountain basalt and the Royal Road basalts in New Brunswick may be potential sources of material for enhanced rock weathering through agricultural application.

Atlantic Canada has significant potential for GCS and could play a significant role in Canada's quest to achieve net zero. This study highlights regions and rock formations where further work should be done to establish the viability of GCS programs in Atlantic Canada.

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1 Introduction

The *International Energy Agency* (2021) predicts that the Carbon Capture, Utilization, and Storage (CCUS) industry will need to grow by about three orders of magnitude in order to reach Net Zero Emissions by 2050. *Environment and Climate Change Canada* (2022) similarly projects that the CCUS industry in Canada must rapidly expand in order to meet emission reduction targets. Although the "utilization" component of CCUS can include a wide range of technologies, the vast majority of captured CO_2 will be destined for "storage" or, more specifically, geological carbon sequestration (GCS). As part of net-zero pathway modelling, wherever there are major CO_2 emitters expected to persist to 2050, geological reservoirs suitable for storing their captured emissions must be identified.

Efforts to map the GCS potential of geological basins in Canada have focused primarily on the Western Canada Sedimentary Basin (e.g. *Bachu and Stewart*, 2002; *Cote and Wright*, 2010), which has been also considered in conjunction with corresponding basins in the United States in a series of Carbon Storage Atlas publications by the *U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory* (2015). However, there has been relatively little information published on GCS potential in eastern or Atlantic Canada, such that they are not mentioned *U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory* (2015) atlas and the *International CCS Knowledge Center* (2021) deemed them "unassessed for storage".

The densely populated regions southern Ontario and Quebec sit mainly on very shallow sedimentary basins or directly on crystalline basement, and although their geologies both present some local opportunities for GCS (*Shafeen et al.*, 2004; *Wright et al.*, 2008; *Malo and Bédard*, 2012), they are restricted to a only a few locations and modest in scale. In contrast, the geology of Atlantic Canada consists substantially of large, deep sedimentary basins (*Keen and Piper*, 1990) that are likely to contain significant GCS potential (*Bradshaw and Dance*, 2005). This is especially true in its offshore regions such as the Newfoundland Shelf and Scotian Shelf that have seen significant geological exploration in search of oil-and-gas deposits (Figure 1). GCS in Atlantic Canada may prove to be important not only to store its own emissions, but because it is relatively close, compared to basins in western Canada, to the industry-dense Ontario and Quebec.

This study aims to identify and assess potential GCS reservoirs in Atlantic Canada. Rather than quantitative estimates of CO_2 storage potential by mass, such as the formal analyses completed by the *U.S. Geological Survey, Geologic Carbon Dioxide Storage Resources Assessment Teams* (2013) national CCUS assessment, this study takes on a qualitative chance-of-success mapping approach, similar to that introduced for petroleum resource potential mapping by *Lister et al.* (2018). This not only simplifies the treatment of spatial variation in data density (and data quality), but it eliminates the need to assume parameters, such as a CO_2 storage efficiency, that are poorly constrained in general yet can greatly affect final, quantitative storage capacity estimates (*Goodman et al.*, 2011). Note that this report does not review the fundamental mechanics of GCS, or review how GCS potential has previously been assessed in much detail, but such reviews are available from *Metz et al.* (2005), *Brennan et al.* (2010),and *Zhang and Song* (2014), among others.

After introducing our data sources and describing our approach to defining chance-of-success, we apply the methodology to basins in stratigraphic order. We begin, therefore, with the early Paleozoic basins in the northern Gulf of St. Lawrence, followed by the Carboniferous basins that make of the southern Gulf of St. Lawrence as well as much of onshore New Brunswick and Nova Scotia, and ending with Mesozoic-Cenozoic basins found offshore Nova Scotia, and Labrador. The latter basins also exist on the Newfoundland margin, where they notably contain the province's oil-and-gas resources; however, we will not address the Newfoundland margin in detail in this work, and instead leave that to follow-up studies.

Finally, we note that mafic and ultramafic rocks, most notably basalts, can be potential GCS reservoirs (e.g. *Matter et al.*, 2016). As the total GCS potential of mafic rocks in Atlantic Canada is probably small, and because tend to have no associated porosity or permeability data, we omit mafic rocks from our chance-of-success mapping and instead briefly describe them in a subsequent section. In addition to addressing their

GCS potential, we also briefly discuss their potential agricultural application in enhanced rock weathering for direct CO_2-adsorption.

2 Regional Geology

The sedimentary basins of eastern Canada can be subdivided into three groups characterised by their age of deposition: early Paleozoic, late Paleozoic and Mesozoic-Cenozoic (*Keen and Piper*, 1990). Figure 1 shows the distribution of these basins in Atlantic Canada. These three groups of basins formed under distinctly different tectonic regimes, resulting in distinctive structural styles and basin-fill patterns, and are, therefore, discussed separately in this report.

Early Paleozoic sediments underlie the northern Gulf of St. Lawrence, Anticosti Island, the Gaspé Peninsula, and parts of northwestern New Brunswick and western Newfoundland (*Bell and Howie*, 1990; Figure 1). The succession records a passive margin setting formed during the Cambrian and early Ordovician that subsequently developed into a foreland basin during the Taconic Orogeny in the middle to late Ordovician (*Lavoie*, 2019). This succession is well-documented in western Newfoundland (*James et al.*, 1989; *Lavoie et al.*, 2003). Sediments associated with younger orogenic events during the Silurian and Devonian are recorded in the Gaspé Belt (*Lavoie*, 2019).

Late Paleozoic rocks related to the closing of the proto-Atlantic ocean underlie Prince Edward Island (PEI), parts of Nova Scotia, Newfoundland, and New Brunswick, most of the Gulf of St. Lawrence, Cabot Strait and parts of the shelf north and south of Newfoundland (Figure 1). These sedimentary basins, collectively referred to as the Maritimes Basin, formed during a complex series of tectonic events following the collision of Gondwana and Laurasia, and are predominantly, but not exclusively, of non-marine origin (*Gibling et al.*, 2019).

The Mesozoic-Cenozoic rocks of Atlantic Canada are widely distributed offshore but are restricted onshore to a small area around the Bay of Fundy (Figure 1). These basins formed during the rifting events that culminated in the opening of the North Atlantic (*Keen and Piper*, 1990) and are characterised by an initial phase of terrestrial sedimentation and volcanic activity followed by marine deposition.

3 Data Sources

Suitability for carbon sequestration was determined purely from geological parameters in this study; i.e. logistic factors such proximity to CO_2 sources and existing land-use designations were not considered. The major factors evaluated were the presence of a porous and permeable reservoir at a depth where CO_2 is expected to behave as a supercritical fluid (*Shukla Potdar and Vishal*, 2016), the presence of an overlying relatively impermeable rock formation to prevent upward migration of the injected CO_2, and structural and stratigraphic barriers to lateral fluid migration.

No new field data or geologic maps were generated for this project. Data assessed can be subdivided into surface geological information, and subsurface geological and geophysical information. These data were supported by insights from previous petroleum resource assessments, for which many of the same properties must be evaluated.

3.1 Surface Geological Data

Geologic maps and studies of the sedimentary rocks in onshore areas of Atlantic Canada have been ongoing since the mid-19th century (e.g. *Logan*, 1845; *Lyell*, 1843). Formation outcrop patterns on geologic maps, descriptions of sedimentary rocks from outcrop, measurements of formation thicknesses, structural measurements such as bedding dip angles, and published cross-sections based on these data can all be used

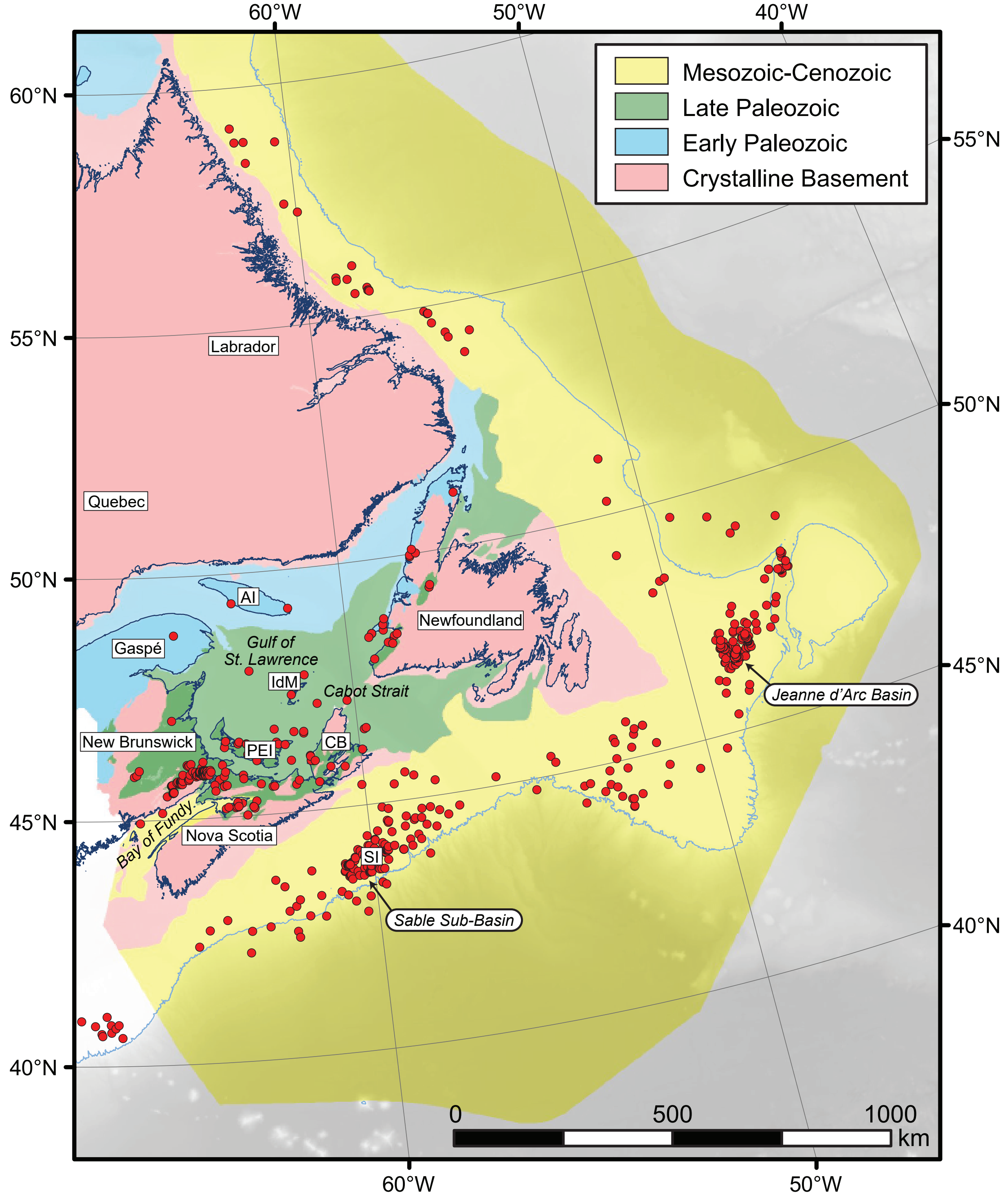

Figure 1. Sedimentary basins of Atlantic Canada, subdivided by age. Based on shapefiles from *Mossop et al.* (2004). Red dots show location of wells with >800 m penetration. Abbreviations used are: AI = Anticosti Island, CB = Cape Breton, IdM = Les Îles-de-la-Madelaines, PEI = Prince Edward Island, SI = Sable Island.

to infer the geology in the subsurface. There is significant uncertainty in the estimated depths of rock formations derived from these methods, and changes in the character of sedimentary rocks can be anticipated with depth below the surface and distance from outcrop. However, in view of the scarcity of subsurface information in some areas of Atlantic Canada, review of the scientific literature of outcrop-based studies was an important component of this study.

3.2 Subsurface Geological Data

Holes drilled for petroleum or mineral exploration provide direct information about the properties of the rocks at depth from cores, chip samples and geophysical logs. However, most boreholes sample only relatively shallow layers, and the availability of these data at sufficient depths for carbon storage in Atlantic Canada is limited. Eastern Canada and the Atlantic continental margin are very sparsely drilled overall, with most of the wells concentrated in three small areas of the region: southeast New Brunswick, the Sable Sub-Basin, offshore Nova Scotia and the Jeanne d'Arc Basin, offshore Newfoundland (Figure 1). A review of the BASIN database (*Natural Resources Canada*, 2023) and provincial data sources (*New Brunswick Department of Energy and Mines*, 2023; *Newfoundland and Labrador Department of Industry Energy and Technology*, 2023; *Nova Scotia Department of Natural Resources and Renewables*, 2017) turned up only 1027 wells penetrating sedimentary rocks at depths greater than 800 m (note that wells in Quebec were viewed as outside the study area and not included unless in BASIN). This is in stark contrast to the Western Canada Sedimentary Basin where over 400,000 wells have been drilled in Alberta alone—an area less than 1/3 the size of the sedimentary basins in Atlantic Canada. The relatively sparse data in Atlantic Canada will pose challenges for GCS development, but fewer wells also means less risk of CO_2 leakage through old well bores.

3.3 Geophysical Data

Another important source of subsurface information reviewed for this report were insights from geophysical surveys. Published and unpublished structure and isopach maps based on seismic surveys were available for some areas evaluated in this report. Through correlation to well data, these surveys can be used to map formations of interest in the subsurface. For areas where no published seismic information existed, gravity and magnetic surveys (*Jutras et al.*, 2007) were used to constrain the thickness of sedimentary cover present but these cannot be used to determine the depth to specific formations.

3.4 Petroleum Resource Assessments

Petroleum resource assessments evaluate many of the same rock properties as those needed to determine carbon sequestration potential, such as the porosity and permeability of reservoir rock, the integrity of a caprock or seal, and structural traps. Therefore, petroleum assessments for the Atlantic region were valuable resources for this report. This was especially true of recent assessments done for the Marine Conservation Targets program because of the similarity in approach (*Atkinson et al.*, 2020; *Carey et al.*, 2020).

4 Methods: Approach to Chance of Success (COS) Mapping

The methods applied in this study were adapted from the methodology developed by the Marine Conservation Targets (MCT) team at Natural Resources Canada (NRCan) for petroleum resource assessments (*Lister et al.*, 2018). The core technique is a probabilistic assessment of the chance of success (COS) for each component of a petroleum system. Assuming that the COS for each component is independent of the others, the total chance of success (TCOS) is computed as a product of each individual component COS. Applied to CO_2 sequestration, the TCOS can be computed as:

$$\mathrm{TCOS} = \mathrm{COS}_{\mathrm{RESERVOIR}} * \mathrm{COS}_{\mathrm{SEAL}} * \mathrm{COS}_{\mathrm{TRAP}} \tag{1}$$

Where $\mathrm{COS}_{\mathrm{RESERVOIR}}$ is the chance of a sufficiently porous and permeable formation being present, $\mathrm{COS}_{\mathrm{SEAL}}$ is the chance of reservoir lying beneath an impermeable layer to prevent upward migration, $\mathrm{COS}_{\mathrm{TRAP}}$ is the chance that the resulting reservoir cannot migrate laterally. Petroleum resource assessments include a fourth factor, $\mathrm{COS}_{\mathrm{SOURCE}}$, that expresses the chance of a thermally mature source rock being present and allowing hydrocarbons to migrate into the trap. However, for the purposes of CO_2 sequestration, $\mathrm{COS}_{\mathrm{SOURCE}}$ need not be considered. Also, because hydrocarbons behave differently from CO_2 in the subsurface, and injecting additional fluids has different consequences for the reservoir than extracting fluids, assessment of each COS parameter for this project differs slightly from the MCT mapping. These differences are discussed below.

An additional component of the MCT methodology was the Global Scale Factor, which characterizes the size of potential hydrocarbon accumulations to a giant offshore petroleum field (*Lister et al.*, 2018). GCS is a much less mature economic activity than petroleum extraction, making it difficult to assess what a "giant" GCS opportunity of global significance means. Thus, for purposes of this study we have not assigned global scale factors, although it is recognised that the potential capacity and injectivity of some of the plays is clearly greater than others. These differences are discussed for the various plays in the text rather than explicitly covered in the mapping.

The MCT methodology also allows for stacking multiple play TCOS maps to create a single map expressing the chance of all potential plays. In petroleum assessment this is important because extraction of hydrocarbons from multiple horizons at the same location is common. In this iteration of the work, we have not done this, in part because it is not clear this would be a likely scenario for GCS, but also because the global scale factor which we have not assessed becomes an important component. Instead, the chance of success for each play is presented in separate maps. The aim of this work is not to model every possible GCS target but to focus on the plays deemed most likely to succeed based on current knowledge, which is rather limited in some areas. Stacked multiple play maps could be generated in future research, potentially using scaling factors that reflect the logistical advantages and disadvantages of particular locations.

4.1 Reservoir

Three major factors determine reservoir suitability for GCS. The first is storage capacity, which is largely a product of the porosity, thickness, and areal extent of the reservoir; the second is having sufficient permeability to allow injection at a significant rate (*Wendt et al.*, 2022). Both of these are essentially the same as for petroleum reservoirs. A third factor specific to CO_2 storage is that the pressure and temperature regime in the reservoir should enable injection of the CO_2 as a supercritical fluid (*Ajayi et al.*, 2019). Although the actual depth where CO_2 becomes supercritical varies with temperature and pressure regimes (*Bachu*, 2003), for purposes of a broad regional study where there remains considerable uncertainty about the depths to reservoir formations in many areas, the COS was reduced sharply where prospective reservoir was expected less than 800 m below the surface.

4.2 Seal

Like hydrocarbons, supercritical CO_2 is more buoyant than the saline water in the reservoir formation and, therefore, tends to migrate upward (*Ajayi et al.*, 2019). The COS for seal was assessed by evaluating the thickness, continuity and consistently impermeable character of the rock overlying the reservoir expected to act as a seal. The characteristics of a good seal for GCS are similar to a petroleum system, although an extra consideration for GCS is that minerals can dissolve through contact with CO_2 or CO_2-saturated brines (*DePaolo and Cole*, 2013), potentially impacting seal integrity.

4.3 Trap

In hydrocarbon exploration, trapping is important because hydrocarbons are held in the reservoir through structural or stratigraphic configurations of the associated rock formations. For CO_2 storage, the concern is not whether the trap has been adequate in the past but whether it will hold in the future as fluids are injected. CO_2 injection displaces reservoir fluids, increasing fluid pressure and potentially fracturing surrounding rocks (*Surdam et al.*, 2013). Low-stress regimes are preferred for CO_2 storage to reduce the risk of induced seismicity (*Wendt et al.*, 2022). For purposes of this study, trapping COS was viewed more negatively for highly deformed and fractured rocks than it would be for petroleum assessment.

However, there are circumstances where trapping for CO_2 is more forgiving than for hydrocarbons, as it has additional trapping mechanisms aside from stratigraphic and structural traps. Although CO_2 should be injected as a supercritical fluid, it does not need to remain in place as a discrete phase in the subsurface indefinitely. Other forms of trapping such as precipitation of carbonate minerals and dissolution in the surrounding aquifer (*Bacon*, 2013) can add to the reservoir capacity. Effective traps for hydrocarbons may require keeping them in place for tens of millions of years, whereas GCS models typically consider any timescale beyond 10,000 years "permanent" (*Alcalde et al.*, 2018). For this reason, reservoirs which were sufficiently distant from any potential leakage path were judged to have high COS for trapping, even in the absence of a structural or stratigraphic closure.

5 Early Paleozoic Basins

The early Paleozoic Basins are not given a detailed assessment in this report, but some possible reservoirs are briefly discussed here. The major occurrences of early Paleozoic sediments in eastern Canada can be categorized as undeformed largely Cambrian-Ordovician rocks of the Laurentian platform, the equivalent-age deformed rocks of the Humber Zone, and the late Ordovician to Devonian variably deformed rocks of the Gaspé Belt (Figure 2).

5.1 Cambrian and Ordovician Rocks of the Laurentian Platform Margin

The stratigraphy of the platform rocks of western Newfoundland is illustrated in Figure 3. Correlative rocks farther west in mainland Quebec and Anticosti Island show broadly similar patterns (*Lavoie et al.*, 2003) characterised by a coarse basal sandstone (the Bradore Formation in Figure 3) grading upward to finer clastics overlain by a thick carbonate platform succession. During the Taconic Orogeny in the middle Ordovician, sheets of the deep water sediments equivalent to this succession were thrusted over the platform rocks in the Humber Zone and a foreland basin developed (*Lavoie et al.*, 2003).

The principal targets for petroleum exploration in the region have been dolomitized carbonates (*Hicks and Owens*, 2014) within the St. George Group; these are likely to be the most suitable rocks for carbon storage. Good reservoir rocks are present locally. The Port au Port 1 well (Figure 2) tested a 35 m thick section that averaged 14% porosity and produced 1500–4000 barrels of water ($\sim$250 to 600 m^3/day) from the Watts Bight Formation (*Cooper et al.*, 2001). Porosity development is associated with dolomitization and dissolution related to either hydrothermal fluids moving along faults and fractures or meteoric waters from subaerial exposure (*Azmy et al.*, 2008; *Azmy and Conliffe*, 2010). Interbedded micritic rocks are potential seals (*Azmy and Conliffe*, 2010). Hydrothermal dolomites with vuggy porosity have also been reported from

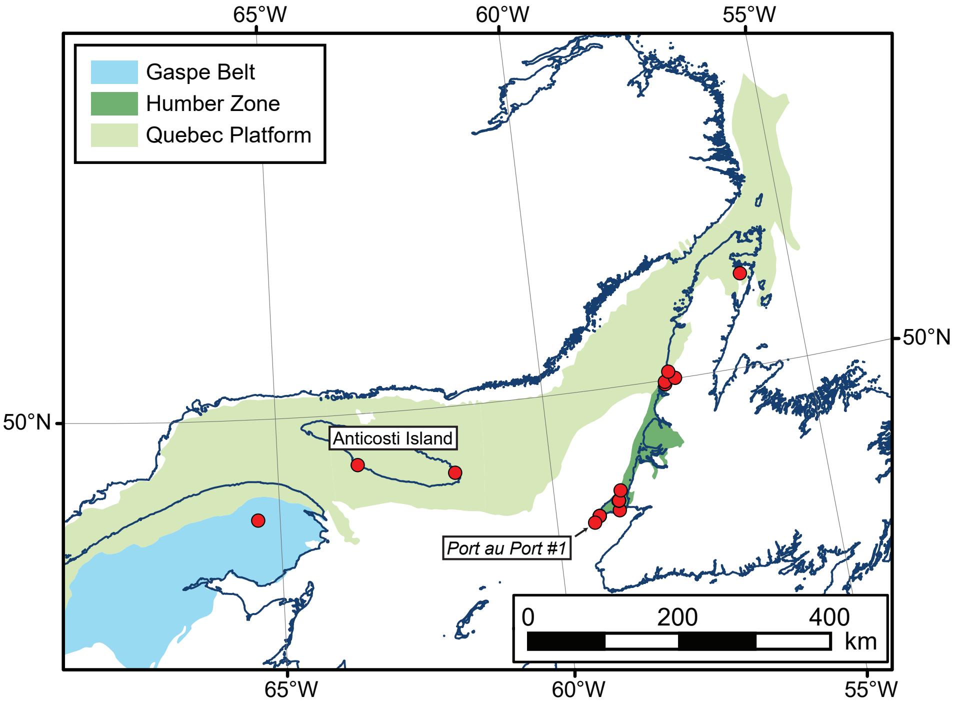

Figure 2. Major occurrences of early Paleozoic sedimentary rocks in the region and deep wells drilled into them. Basin boundaries modified from *Mossop et al.* (2004). Note that there was no attempt to screen for wells in Quebec for this study; additional wells exist there but are not shown.

the early Ordovician Romaine Formation on Anticosti Island (*Lavoie et al.*, 2005; Figure 2). These rocks were viewed as potentially suitable for carbon sequestration by *Malo and Bédard* (2012).

Cambrian sandstones are also promising conventional reservoirs for hydrocarbons (*Hogg and Enachescu*, 2015) and may be suitable for carbon storage. Intervals of the Hawkes Bay Formation (Figure 3) with porosities of 10-12% were reported from two wells in Western Newfoundland (*Cooper et al.*, 2001).

Preliminary evaluation of the Cambro-Ordovician rocks of Western Newfoundland and Anticosti Basin suggests moderate carbon sequestration potential. The best porosities have been reported from hydrothermally altered rocks within the Humber Zone, but these may be potentially riskier from a trapping perspective due to structural deformation. Geographic and stratigraphic distribution of reservoir in the most prospective rocks (the carbonates) is complex and controlled by diagenetic processes (*Lavoie et al.*, 2005; *Azmy et al.*, 2008; *Azmy and Conliffe*, 2010). Reservoirs may have excellent porosity and permeability but be of limited thickness and lateral extent.

5.2 The Gaspé Belt

The rocks of the Gaspé Belt were deposited in a successor basin that developed after the middle Ordovician Taconic orogeny and range in age from late Ordovician to middle Devonian (*Bourque et al.*, 2001). These rocks were subsequently deformed during the Devonian Acadian Orogeny; the intensity of deformation and metamorphism increases from north to south (*Malo and Bédard*, 2012).

Several hydrocarbon plays in the Gaspé Belt were identified and discussed by *Lavoie et al.* (2009). As with the primary play in western Newfoundland, hydrothermal dolomites in carbonate successions of various ages were noted as a prospective play. However, the presence of these dolomites was poorly documented except within the early Silurian Sayabec Formation (*Lavoie et al.*, 2009). Where present, they were described

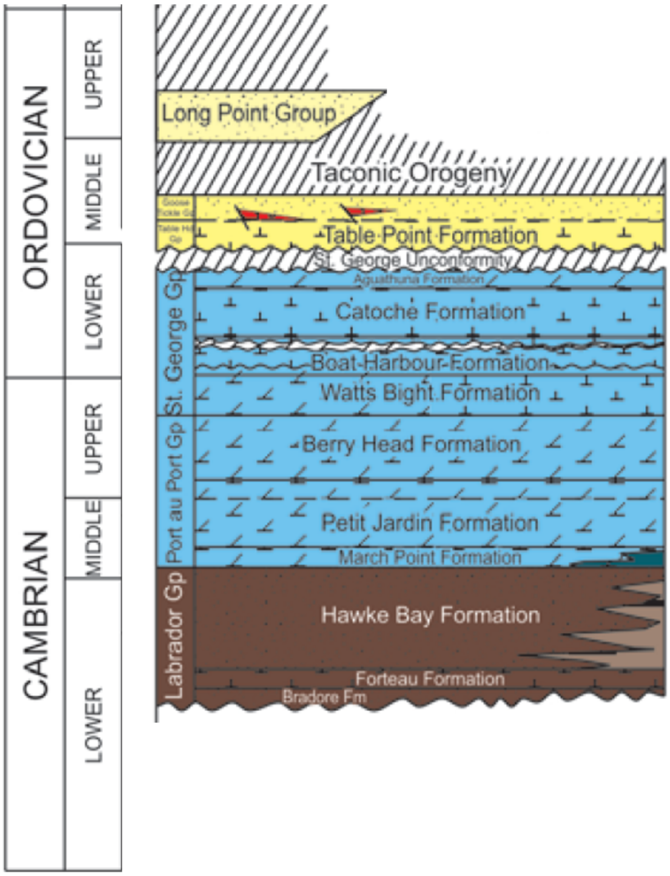

Figure 3. Cambrian-Ordovician stratigraphy of Western Newfoundland. Modified from *Hogg and Enachescu* (2015).

as highly fractured and brecciated; seal risk was considered high (*Lavoie et al.*, 2009). Of the clastic units, the most promising reservoir appears to be the lower Devonian Gaspé Sandstones with porosities of 5-15%, but seal was seen as a risk for these units due to an overlying coarsening upward succession (*Lavoie et al.*, 2009). *Malo and Bédard* (2012) viewed the carbon sequestration potential of the Gaspé Belt as very low (though partly for infrastructure and informational reasons) and did not regard them as worthy of further investigation.

The GCS potential of rocks in the Gaspé Belt appears to be low, though only a cursory investigation was made during this study.

5.3 Other Early Paleozoic Rocks in Atlantic Canada

Rocks that were originally deposited as sediments in the early Paleozoic are seen elsewhere in Atlantic Canada, particularly in the Meguma Terrane of Nova Scotia and the Avalon Terranes of Nova Scotia and Newfoundland. However, many of these rocks have undergone significant deformation and metamorphism (*MacDonald et al.*, 2002) and would have no storage capacity. These rocks were not evaluated in this study. There are also early Paleozoic rocks underlying younger basins in parts of Atlantic Canada, such as the Ordovician carbonates in offshore Labrador (*Bell and Howie*, 1990; *Bingham-Koslowski et al.*, 2019). Although these rocks have proven reservoir quality, at least locally (*Carey et al.*, 2020), they have not been evaluated in this study. They are difficult to map seismically (*Bingham-Koslowski et al.*, 2022; *Dickie et al.*, 2011), and are unlikely to be used for carbon storage because there are promising reservoirs in the overlying rock (*Carey et al.*, 2020) that would provide better economics.

6 Late Paleozoic Basins

The Maritimes Basin is a large, under-explored sedimentary basin in eastern Canada that underlies parts of the four Atlantic Provinces and adjacent offshore areas (Figure 1). The Maritimes Basin comprises several onshore and offshore structural basins. Deep structural basins onshore are generally restricted to eastern New Brunswick, northern and central Nova Scotia including Cape Breton Island, and southwestern Newfoundland. Deep offshore structural basins underlie the southern Gulf of St. Lawrence and Cabot Strait (*Bell and Howie*, 1990). Onshore structural basins tend to be small (tens of kilometres across) whereas the offshore basins span hundreds of kilometres (*Atkinson et al.*, 2020; *Kendell et al.*, 2017). However, development costs are typically significantly lower for onshore drilling and infrastructure, which potentially makes smaller GCS projects more viable.

6.1 Stratigraphy

Rocks in the Maritimes Basin range in age from late Devonian to Permian and are subdivided using complex stratigraphic nomenclature, which is based primarily on the study of onshore structural basins. These basins subsided at different rates and their basin fill was influenced by basin margin faults. The reservoir, seal and trap characteristics of one structural basin may be different from an adjacent structural basin. The onshore lithostratigraphy commonly deserves subdivision at the formation and member levels (see *Waldron et al.*, 2017), whereas the lithostratigraphy in the offshore basins may be adequately described through subdivision at the group level.

In this report, we describe potential carbon storage seal and reservoir rocks in relation to group-level stratigraphic subdivisions. The approximate time spans of the lithostratigraphic groups in Atlantic Canada is summarized in Figure 4. Inevitably, formation and member names are referenced in this report. Descriptions of prospective reservoirs and seals in the literature typically use these names, but in this report, they will be described in relation to the group name in the assessment of the potential storage characteristics of the group. A summary of the group-level stratigraphic nomenclature, from oldest to youngest, is presented in the following paragraphs.

6.1.1 Fountain Lake, Horton, and Sussex Groups

Fountain Lake Group is the name applied to volcanic and minor clastic rocks that outcrop in the Cobequid Highlands and occur in the subsurface in the core of the Scotsburn Anticline, where 2638 m of Fountain Lake Group strata were intersected in the Irving-Chevron Scotsburn No. 2 well (*Irving Oil Limited and Chevron Standard Limited.*, 1981; *Nova Scotia Department of Energy*, 2017). The lower part (Byers Brook Formation) comprises mainly rhyolite and felsic pyroclastic rocks with minor interbeds of basalt flows and clastic rocks. The basaltic rocks in this unit are up to 100 m thick in the Scotsburn well (*Irving Oil Limited and Chevron Standard Limited.*, 1981). The upper part of the Fountain Lake Group (Diamond Brook Formation) consists of basalt and red and grey sandstone, siltstone and conglomerate of continental origin (*Dessureau et al.*, 2000). The upper part of the Fountain Lake Group contains mid-Tournaisian palynomorphs (*Utting et al.*, 1989).

The Horton group is similar age to the Fountain Lake Group and its equivalents (late Devonian to Tournaisian; *Waldron et al.*, 2017), but their distribution is more widespread. Rocks of similar age and character are known as the Anguille Group in Newfoundland (*Gibling et al.*, 2019). They were deposited in half-graben, extensional basins (*Hamblin and Rust*, 1989) that are widely distributed throughout the Maritimes Basin (*Knight*, 1983; *Durling*, 1993, 1997). In broad terms, the Horton Group basin fill is characterised by

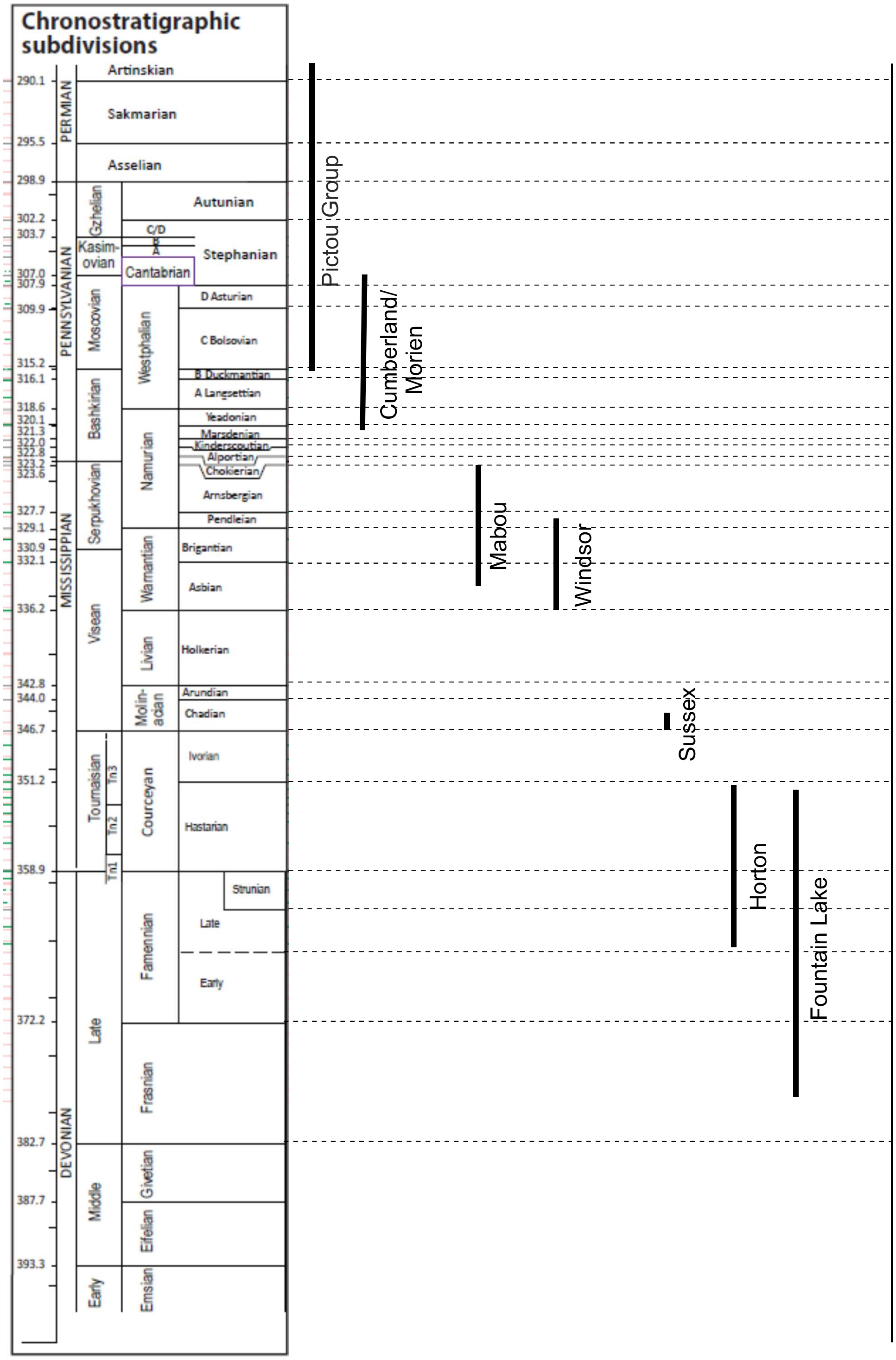

Figure 4. Approximate time spans of lithostratigraphic groups in the Maritimes Basin after *Waldron et al.* (2017).

Table 1. AOIs where COS mapping was conducted by group.

	Group-Level Reservoir Targets		
	Horton Group	**Cumberland Group**	**Pictou Group**
AOIs Assessed	Antigonish Central Cape Breton Cumberland Magdalen Moncton New Brunswick Platform Shubenacadie Southeast Cape Breton St. Mary's Sydney Western Cape Breton Windsor	Cumberland Magdalen Moncton Stellarton Sydney Western Cape Breton	Magdalen

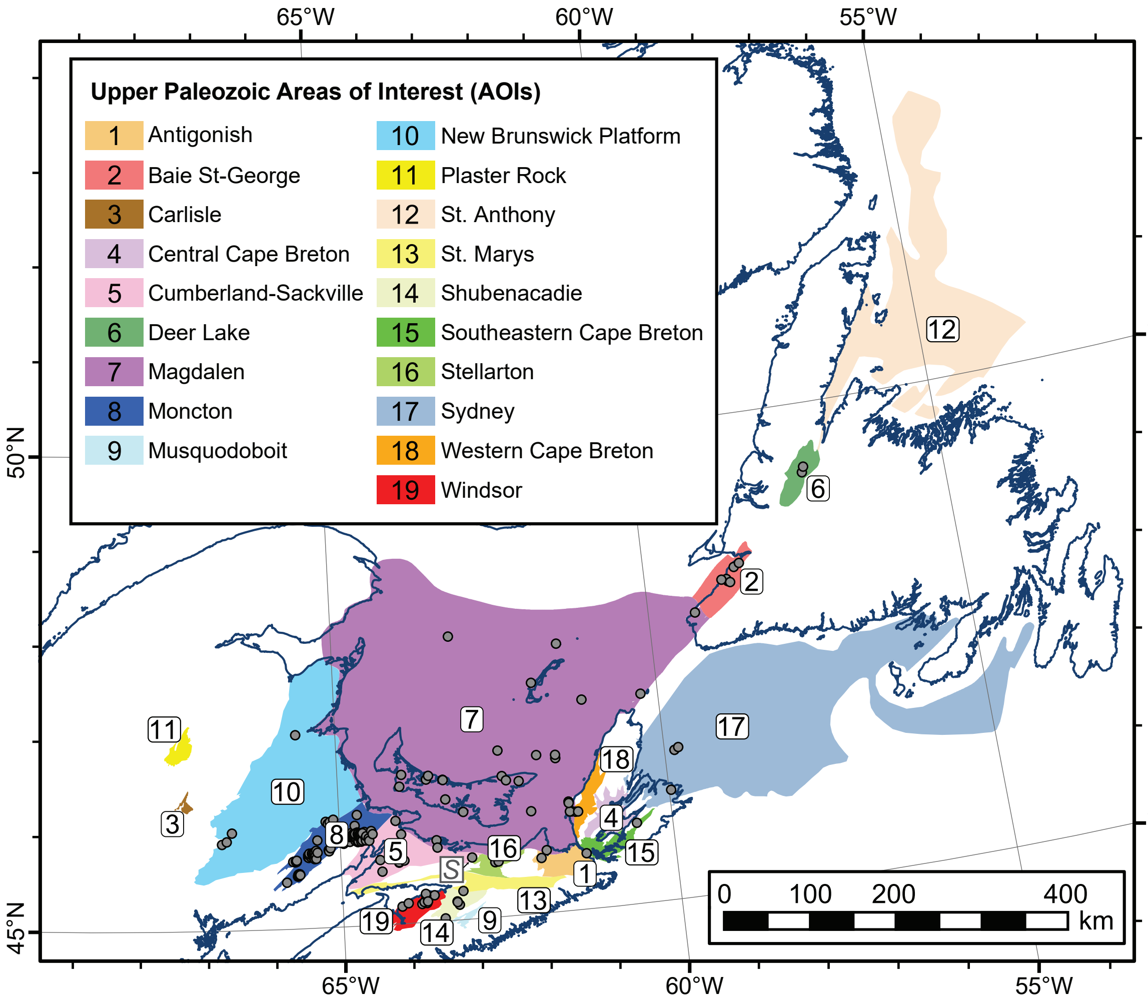

Figure 5. Late Paleozoic Areas of Interest (AOIs) listed in alphabetical order. The Scotsburn #2 well is labeled with an "*S*".

a tripartite stratigraphy comprising basal continental alluvial clastics, medial lacustrine and fluvial deposits, and an upper alluvial-fluvial succession (*Martel and Gibling*, 1996; *Murphy*, 1998). The Horton and Anguille groups are commonly subdivided into formations on the basis of this tripartite stratigraphy. Although their stratigraphy may vary somewhat throughout the Maritimes Basin, the medial succession generally comprises grey sandstone, siltstone and mudstone, including dark grey organic-rich shale.

'Sussex Group' is the name used to describe late Tournaisian continental clastic rocks that lie unconformably on the Horton Group in southwestern New Brunswick (*St. Peter and Johnson*, 2009). Strata commonly comprise red and grey, fine- to coarse-grained alluvial and fluvial clastic rocks. Locally, playa evaporite rocks may occur within fine-grained sections. *Atkinson et al.* (2020) note that the Sussex Group may be more widely distributed in the Maritimes Basin than previously recognized. Rock units such as the Wilkie Brook and Coldstream formations in Nova Scotia may be Sussex Group equivalent rocks, since they contain the same palynological assemblages as the Sussex Group (*Utting et al.*, 1989). Further, rocks of similar age and composition are recognized in boreholes drilled onshore PEI (*Giles and Utting*, 1999). Sussex Group rocks commonly overstep the basin boundaries of the underlying Horton and Anguille group extensional basins. *Atkinson et al.* (2020) mapped the Sussex Group throughout the Gulf of St. Lawrence using seismic reflection data.

6.1.2 Windsor and Mabou Groups

The Windsor Group consists predominantly of carbonate and evaporite rocks with varying amounts of terrigenous clastic rocks. Equivalent strata are assigned to the Codroy Group in southwestern Newfoundland. Both units lie disconformably to unconformably on older rocks, depending on the basin setting in relation to basin-bounding faults. The Windsor Group was deposited in a series of up to 30 transgressive-regressive cycles (*von Bitter et al.*, 2006) that commonly comprise (in ascending order) carbonate, anhydrite, halite and clastic rocks (*Giles*, 1981). In the upper parts of the Windsor and Codroy groups individual cycles may be represented locally by carbonate overlain by thick clastic rocks; there is a tendency toward increasing clastic abundance in younger strata (*Giles*, 1981).

The Mabou Group, of Serpukhovian to Bashkirian age, generally lies conformably on the Windsor Group (*Waldron et al.*, 2017). It comprises interstratified siltstone, shale, and fine-grained sandstone (*Ryan and Boehner*, 1994); coarse-grained deposits may occur adjacent to basin margins. The lower part of the Mabou Group (Hastings Formation) was deposited in a shallow lacustrine environment (*Hamblin*, 2001). Dominant lithologies include grey mudstone intercalated with siltstone and sandstone. These rocks intertongue and grade upward with red siltstone and fine- to medium-grained sandstone (Pomquet Formation) deposited in a subaerial floodplain environment (*Hamblin*, 2001).

6.1.3 Cumberland, Morien, and Pictou Groups

The Cumberland and Morien groups consist of mainly grey, and minor red, continental clastic rocks with locally significant coal bearing strata (*Gibling et al.*, 2019; *Ryan and Boehner*, 1994). This thick, and locally heterogeneous succession, has been subdivided in to some 27 different formations from various structural basins (*Waldron et al.*, 2017). These strata are Bashkirian-Moscovian in age and rest unconformably on Mabou Group and older rocks. In many parts of the Maritimes Basin, the oldest Cumberland Group strata (e.g. Boss Point Formation) record the deposition of coarse-grained strata following the end of the Mabou Group deposition. *Belt* (1964, 1965) introduced the informal term 'Coarse Fluvial Facies' to describe rocks currently assigned to the oldest Cumberland Group and all younger strata. Although the term did not gain wide acceptance, the concept is appealing since it aptly describes a change in basin-wide deposition from fine-grained (Mabou) to coarse-grained sedimentation. Aside from the presence of coal bearing strata, the

Cumberland and Morien groups are notable for the presence of multi-story channel sandstone units tens-of-metres thick (*Boehner and Giles*, 2008; *Ryan and Boehner*, 1994).

The Pictou Group overlies the Cumberland and Morien groups and is distinguished by its predominantly red colour. It comprises mainly sandstone and mudstone with rare thin coal seams. *Ryan and Boehner* (1994) note that mudrocks may be interbedded with thin (<1 m), planar stratified, fine-grained sandstone beds, which contrast the thick (>10 m), cross-stratified multi-story sandstone beds. The age of the Pictou Group is generally latest Muscovian and younger; however, late Bashkirian to Moscovian age rocks (Cumberland Morien equivalents) are included in the group in New Brunswick (*St. Peter and Johnson*, 2009).

6.2 Chance of Success Mapping

The widespread Maritimes Basin is made up of many structural basins, both onshore and offshore in eastern Canada. For ease of discussion, the region was subdivided into Areas of Interest (AOIs; Figure 5). The AOIs may or may not correspond to a structural basin; the large Magdalen AOI corresponds to the study area of *Atkinson et al.* (2020). Furthermore, the preserved basin-fill in each AOI and, therefore, the most prospective intervals, differ between areas. Twelve areas were assessed for the Horton Group, six for the Cumberland Group, and only the Magdalen Basin was assessed for the Pictou Group; Table 1 summarizes the reservoir intervals assessed for each AOI. The following sections summarize the regional patterns. More details on the structural and stratigraphic settings within specific AOIs are provided in the Appendix, along with a discussion of how they were assessed. Owing to the limited time available, some AOIs within the Maritimes Basin were not assessed in this study. These include the basins in and around Newfoundland (Bay St. George, Deer Lake and St. Anthony AOIs) and some small basins elsewhere in Atlantic Canada (Carlisle, Musquodoboit, and Plaster Rock AOIs).

The primary reservoir target of the petroleum industry in the Maritimes Basin was the Horton Group, largely due to the numerous associated surface petroleum seeps. During exploratory drilling, younger rocks with associated porous intervals were often intersected. These rocks are commonly associated with the Cumberland and Pictou groups. The Horton, Cumberland and Pictou groups tend to include thick intervals dominated by sandstone with fair to good porosity development. Consequently, these three stratigraphic units were assessed in this study for carbon sequestration potential. The sand-prone intervals within them are commonly overlain by mudstone-dominated intervals that provide potential seals (*Atkinson et al.*, 2020). However, the evaporite-rich Windsor Group lies stratigraphically above, but not necessarily in direct contact with, the Horton Group. This provides additional seal potential for the Horton Group reservoirs.

6.2.1 Horton Group

Within the Magdalen AOI (Figure 6), *Atkinson et al.* (2020) reported reservoir COS values for the Horton Group. These values were used in this study, except in areas where the reservoir was unlikely to be sufficiently deep for supercritical CO_2 injection. In these areas the values were substantially reduced. Areas where the structure contour map of the top Horton Group in *Atkinson et al.* (2020) indicated that this unit was likely to be shallower than 800 m were assigned a low probability of reservoir success. The top of the Horton was used as the indicator because examination of logs in the most densely drilled parts of the basin (the Moncton and Windsor AOIs) indicated that the upper part of the succession had the best reservoir.

Elsewhere in the Maritimes Basin, the degradation of porosity with depth reported by *Bibby and Shimeld* (2000) was considered as well as the need to be at sufficient depth for supercritical injection. This was unnecessary within the Magdalen AOI because degradation of porosity with depth was already factored in by *Atkinson et al.* (2020). Horton Group reservoirs were viewed as having the highest chance of success where the top Horton was greater than 800 m but less than ∼2500 m, and reduced chance of success with greater depths. In cases where the Horton Group was at the surface, the lack of an overlying Windsor Group seal implies that the seal would need to be the middle Horton Group shales. As the lower Horton Group is assumed to be less prospective for reservoir, a modest chance of success was assigned where the Windsor Group was absent and the base Horton inferred to be greater than ∼1000 m. Low chance of success were also assigned to parts of the Antigonish and Southeast Cape Breton AOIs because of the impact of low-grade metamorphism on potential Horton Reservoirs in these areas (*Force*, 2006; *Ténière et al.*, 2005).

A map of Horton Group reservoir COS is presented in Figure 6. The areas with the highest chance of reservoir success in the Horton Group were found to be the western Magdalen AOI, parts of the Sydney Basin AOI, and smaller areas onshore in the Moncton, Cumberland, and Windsor AOIs (Figure 6a).

For areas within the Magdalen AOI, the seal COS determined by *Atkinson et al.* (2020) was used. Elsewhere, the Horton seal COS was assessed to be high wherever the Horton is overlain by the Windsor Group, because of the abundance of thick evaporite deposits in the succession (*Giles*, 1981; *Howie*, 1988) A moderate chance of success was assigned to areas where the Windsor Group is absent but the mud-prone lower Mabou Group or Sussex Groups could provide a lower quality seal, such as parts of New Brunswick (*St. Peter and Johnson*, 2009; Figure 6b).

A poor COS for seal was assigned in most areas where the Horton Group was present at the surface, such as much of the St. Mary's AOI and the eastern Antigonish AOI (Figure 6b). Upper Horton Group sediments are typically terrestrial red-beds that contain considerable coarse-grained material, such as the Cheverie Formation in the Windsor AOI (e.g. *Martel and Gibling*, 1996). While these formations include some shales and calcretes, their thickness and continuity may not be sufficient to provide an adequate seal. In a few areas where there was a well-documented shaly middle unit, a better chance of success was assumed. An example of this is the northern St. Mary's AOI where a fine-grained lower Stewiacke Formation (Horton Group) is present (*Murphy*, 1998).

The COS for trapping within Horton reservoirs was largely based on the distance from Horton outcrop and basin-bounding faults, the locations of which were determined from geologic maps. The COS within 5 km of these potential leakage points was generally assessed as low, a distance of 5–15 km as moderate, and greater than 15 km as high. These values are arbitrary but were deemed reasonable by the authors given the relatively low permeability and high heterogeneity of Horton reservoirs. In a few areas seismic data indicated structures that would impede updip migration to the subcrop, such as an antiformal structure noted in the Windsor AOI (*Cen*, 2017). In such cases, the COS was adjusted upward to reflect this.

Figure 6c shows the assessed trap COS for the Horton Group. Note that the large red area in New Brunswick is where Horton is not known to exist. In adjacent areas where the Horton pinches out below younger units rather than outcropping on the surface, the COS becomes high where the Horton Group is present. The COS for trap is high for much of the Magdalen AOI and Sydney AOI. Only localized areas of high trap COS exist onshore due to the risk of migration updip to nearby basin margins.

The total assessed COS for the Horton Group is shown in Figure 6d. The highest COS is in the western Magdalen AOI, including western PEI. There are a few local areas where conditions are favorable onshore, including parts of the Moncton AOI in New Brunswick and the Windsor AOI in Nova Scotia.

6.2.2 Cumberland/Morien Group

Atkinson et al. (2020) considered the Cumberland and Morien groups together in their assessment, and we have followed their approach. Within the Magdalen AOI, reservoir was assessed in the same way as with the Horton Group. The reservoir COS from *Atkinson et al.* (2020) was used, except in areas where the reservoir was likely shallower than ∼800 m. For purposes of this assessment, the reservoir of interest was assumed to be the Bradelle Formation, for which *Atkinson et al.* (2020) provided a structural map. This may understate the potential of the interval in areas where the burial depth is less, as the basal clastic unit of the Cumberland Group (e.g. Boss Point Formation; *St. Peter and Johnson*, 2009) is also a potential reservoir. The reservoir COS was found to be best in the northern and northwestern Magdalen AOI, with more moderate values in the southern Gulf (Figure 7a) where there were indications of more immature mineralogy (*Atkinson et al.*, 2020).

In most of the remainder of the Maritimes basin, the basal clastic interval of the Cumberland/Morien interval, which is variously known as the Boss Point, Port Hood, lower Stellarton and South Bar formations in different areas (*Waldron et al.*, 2017), was viewed as the most prospective. Therefore, low COS was interpreted for areas where that lower unit was estimated to be less than 800 m below the surface, high COS where it was 800–2000 m below the surface and lower COS where it was deeper. In the deepest parts of the Cumberland AOI, the COS is high again based on the presence of the Malagash and Ragged Reef formations, in the 800–2000 m depth range, which are dominated by coarse-grained sandstones (*Kelly and Wach*, 2019). High reservoir COS is found around the edges of the Sydney Basin, much of the Cumberland-Sackville AOI and small portions of the Stellarton and Moncton AOIs (Figure 7b).

For the Magdalen AOI, the seal values from *Atkinson et al.* (2020) were used. Elsewhere, high COS was assigned to all areas where a coal-bearing, mud-rich terrestrial interval overlies the reservoir, such as the Joggins Formation (*Davies and Gibling*, 2003) or the Sydney Mines Formation (*Kendell et al.*, 2017) in the northern Cumberland-Sackville and Sydney AOIs, respectively (Figure 8b). Lower chances of seal success were assigned to areas where the overlying intervals were redbeds with a greater coarse-grained component, such as New Brunswick (*St. Peter and Johnson*, 2009) and the deepest parts of the southern Cumberland-Sackville AOI where the best reservoir likely lies above the coal-rich Joggins Formation (Figure 7b).

The trap COS for the Cumberland Group was evaluated using the distance from potential leakage points such as surface outcrops and faults. The subcrop edges of potential Cumberland Group reservoirs were determined using the structure surfaces of *Atkinson et al.* (2020) and geologic maps of New Brunswick and Nova Scotia. The same parameters (less than 5 km, 5 to 15km and greater than 15 km buffer distances from subcrop) that were applied to the Horton Group were used to define, low, moderate and high COS. In addition, COS was judged lower for highly deformed areas. This was particularly significant for the eastern Magdalen AOI and southeastern Sydney Basin, where the extensive salt tectonics described by *Atkinson et al.* (2020) were viewed as potential trap risks. However, in areas very near the basin edge, the COS was slightly higher where salt was present due to the possibility of small-scale structural trapping, but still low compared to undeformed areas away from basin edges. The best trapping potential was determined to be in the western and central Magdalen AOI, including PEI and the central Sydney AOI (Figure 7c). Moderate COS was assigned to the more promising areas onshore due to the short distances to subcrop edges posing potential leakage risks (Figure 7c).

Figure 7d illustrates the total chance of success obtained for the Cumberland and Morien Groups. The most promising areas are offshore in the northwestern Magdalen AOI, and western and Southern Sydney Basin. The best onshore prospects are likely in the northern part of the Cumberland-Sackville AOI and a narrow sliver of the Moncton AOI.

6.2.3 Pictou Group

Reservoir COS was estimated for the Pictou Group using the values assigned by *Atkinson et al.* (2020) within the Magdalen AOI. The most prospective reservoir is the Cable Head Formation in the lowermost part of the group. Based on the mapping of *Atkinson et al.* (2020), the COS was reduced in areas where the Cable Head Formation was likely shallower than 800 m. Elsewhere in the Maritimes Basin, the Pictou Group is relatively shallow and likely lacking an effective seal, making it unlikely to be a suitable target for GCS. The Pictou reservoir COS is greatest in the central Magdalen AOI (Figure 8a) with a moderate chance of success in eastern PEI.

The mud-dominated Naufrage Formation is the potential seal for Pictou Group reservoirs. The Seal COS for this study was taken directly from *Atkinson et al.* (2020). Seal effectiveness is likely good throughout the Magdalen AOI except along its western and eastern margins (Figure 8b). On the west, the Naufrage

Formation thins toward New Brunswick, while on the east, the stratigraphy is disrupted by salt diapirs (*Atkinson et al.*, 2020).

For areas adjacent to Nova Scotia the distance to outcrop of basal Pictou sandstone units were used to estimate distance to potential updip leakage points in undeformed areas of the Magdalen AOI. Low, moderate and high COS were assigned based on the same 5 km and 15 km offset differences as were used for the Horton and Cumberland Groups. The muddy Naufrage Formation thins westward toward New Brunswick (*Atkinson et al.*, 2020) and the Pictou Group on the New Brunswick platform is sand-dominated (*St. Peter and Johnson*, 2009). In the absence of a clear reservoir and seal pair in the New Brunswick platform Pictou succession, there is assumed to be a risk of leakage in any areas near the New Brunswick shoreline north of the Cumberland-Sackville AOI (Figure 8c). The other area where the COS for trap is reduced is the area with extensive salt tectonics in the eastern part of the Magdalen AOI (Figure 8c).

Figure 8d shows the calculated total chance of success for the Pictou Group. The best chance of success is in the west-central portion of the Magdalen AOI, with low to moderate chances of success in eastern PEI and Les Îles de la Madeleines.

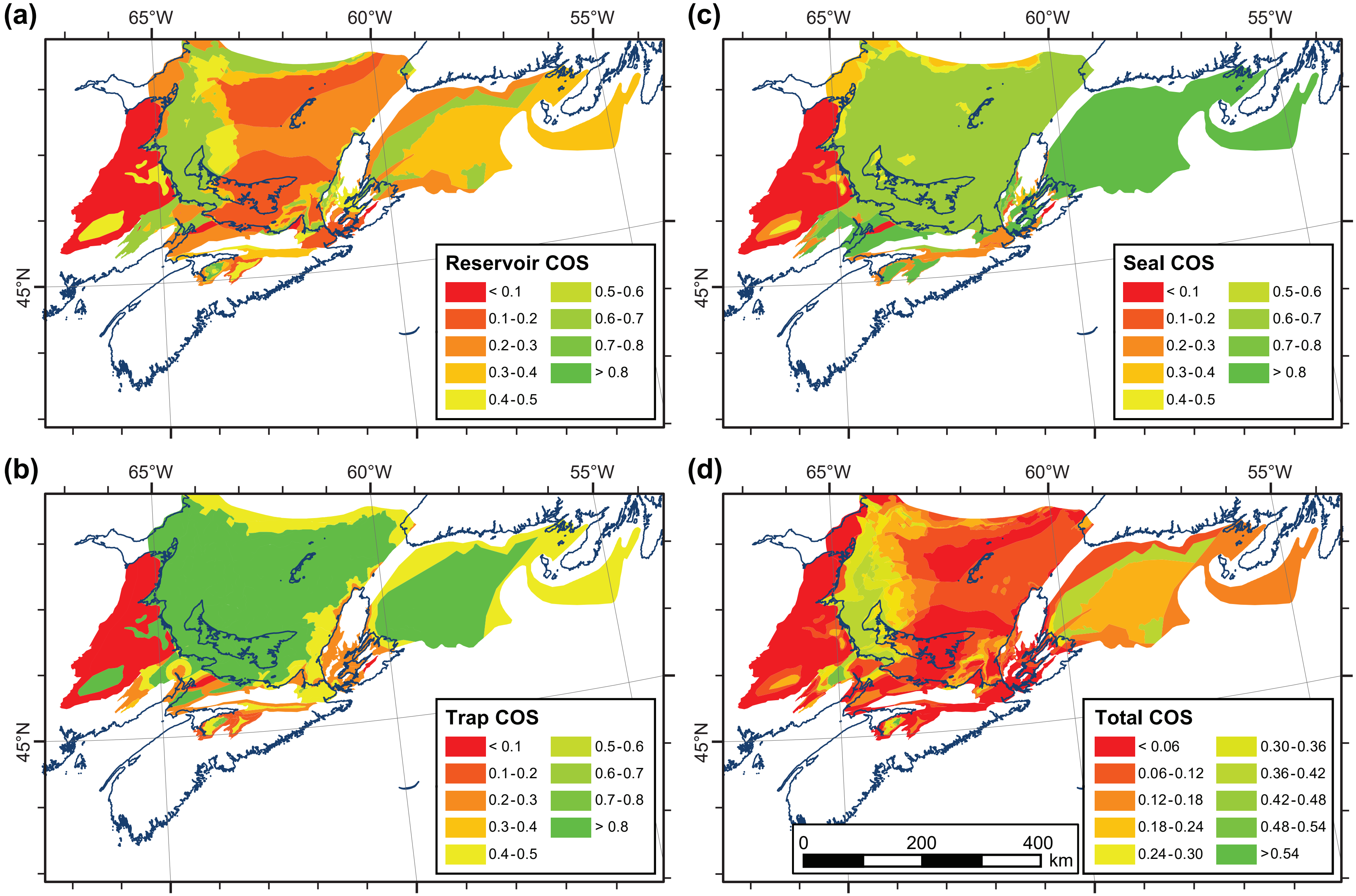

Figure 6. COS maps of the Horton Group. (a) Reservoir COS, (b) Trap COS, (c) Seal COS, and (d) Total COS.

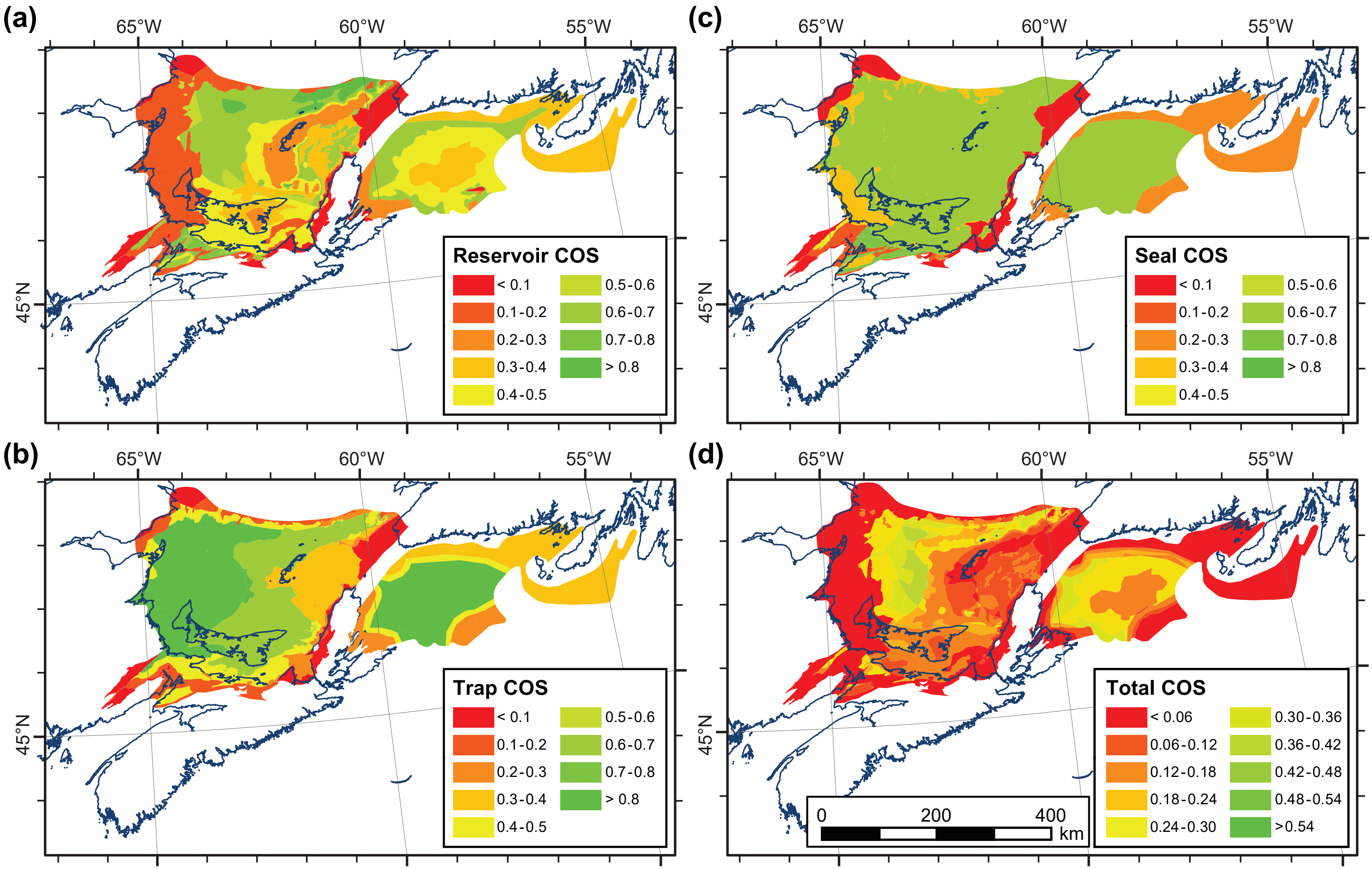

Figure 7. COS maps of the Cumberland and Morien Groups.(a) Reservoir COS, (b) Trap COS, (c) Seal COS, and (d) Total COS.

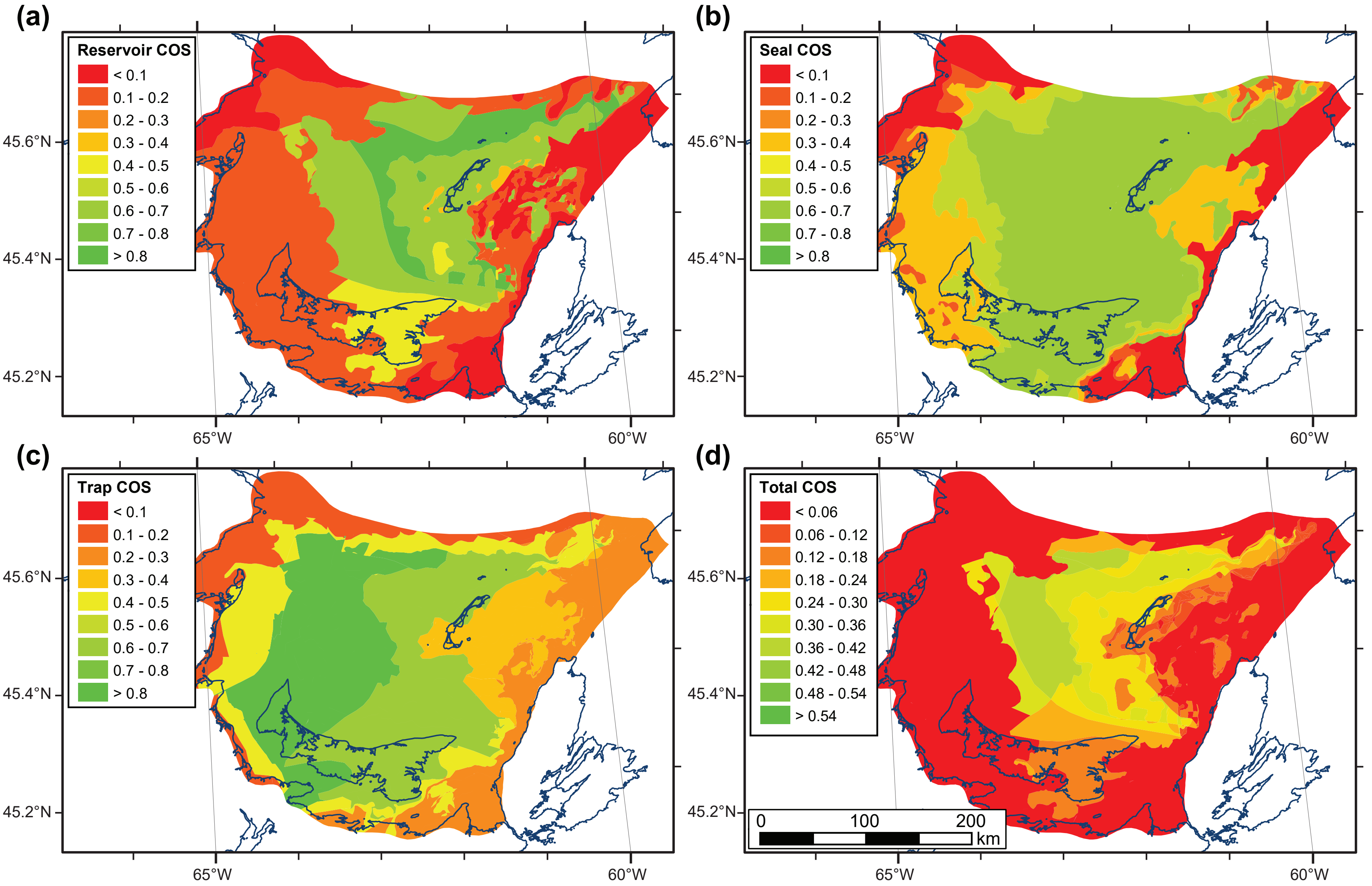

Figure 8. COS maps of the Pictou Group.(a) Reservoir COS, (b) Trap COS, (c) Seal COS, and (d) Total COS.

7 Mesozoic-Cenozoic Basins

The most extensive sedimentary rock accumulations in Atlantic Canada are those associated with the separation of North America from Europe and Greenland beginning in the Mesozoic (Figure 1). These basins developed through crustal stretching, normal faulting and the development of rift basins with the age of breakup decreasing northward (*Keen et al.*, 1990). For purposes of this study, the Atlantic margin will be subdivided into three large regions by the Newfoundland Transform and Charlie Gibbs Fracture (Figure 9). This same subdivision was used by *Keen and Williams* (1990) who discussed the geology of the margin in three chapters: one on the Scotian Margin (*Wade and MacLean*, 1990), a second on the Newfoundland Margin (*Grant and McAlpine*, 1990), and a third covering the remainder of the margin (*Balkwill and McMillan*, 1990). Subsequent workers have tended to continue to discuss these compartments of the margin separately (*Keen et al.*, 2022; *Peace and Welford*, 2020).

All the Mesozoic-Cenozoic basins were formed through crustal stretching and rift initiation and share some broad similarities in their gross characteristics. These similarities can be seen in generalized stratigraphic columns of the Scotian Margin, Newfoundland Margin and Labrador (Figure 10). Initial rifting was followed by deposition of terrestrial sediments, volcanics and (except in Labrador) salt deposition. Subsequent flooding resulted in the deposition of shallow marine sands, and accelerated subsidence following initiation of seafloor spreading (*Dickie et al.*, 2011), and led to deeper marine sedimentation as the margin evolved. The presence of widespread shale-dominated intervals in the latter stages of margin development provides generally favourable seal rocks for CO_2 storage reservoirs. The Fundy Basin and Orpheus Graben differ from the others in that rifting ended before the continental crust separated (*Balkwill and McMillan*, 1990), and are here considered separately from the remainder of the Nova Scotia offshore areas.

7.1 Fundy Basin

7.1.1 Geological Setting

The Fundy Basin is a rift basin found beneath the Bay of Fundy and adjacent areas with an area of approximately 16,500 km^2 (*Wade et al.*, 1996). The basin developed through extensional reactivation of old faults between the Avalon and Meguma Terranes (*Wade et al.*, 1996). The overall morphology is of a half-graben developed with border faults along its northern margin and little deformation along the southern margin (*Wade et al.*, 1996; *Withjack et al.*, 1995). It evolved initially along similar lines to the basins on the Scotian margin with the deposition of predominantly coarse-grained, terrestrial clastics of the Wolfville Formation in the middle to late Triassic, followed by the predominantly lacustrine sediments of the Blomidon Formation (*Leleu and Hartley*, 2010). These units are overlain by the North Mountain Basalt, a thick extensive volcanic unit considered part of the Central Atlantic Magmatic Province; recent work indicates that it is of latest Triassic age (*Cirilli et al.*, 2009). The North Mountain Basalt is overlain by additional coarse clastics of the McCoy Brook Formation (Figure 11). Unlike the margins of the Scotian Basin where rifting and subsidence resulted in development of a marine basin in the Jurassic (*Wade and MacLean*, 1990), the Fundy Basin experienced an interval of compression, basin inversion, uplift and erosion (*Withjack et al.*, 1995, 2009). As a result, it lacks the thick deeper marine post-rift sediments seen in other Mesozoic-Cenozoic basins.

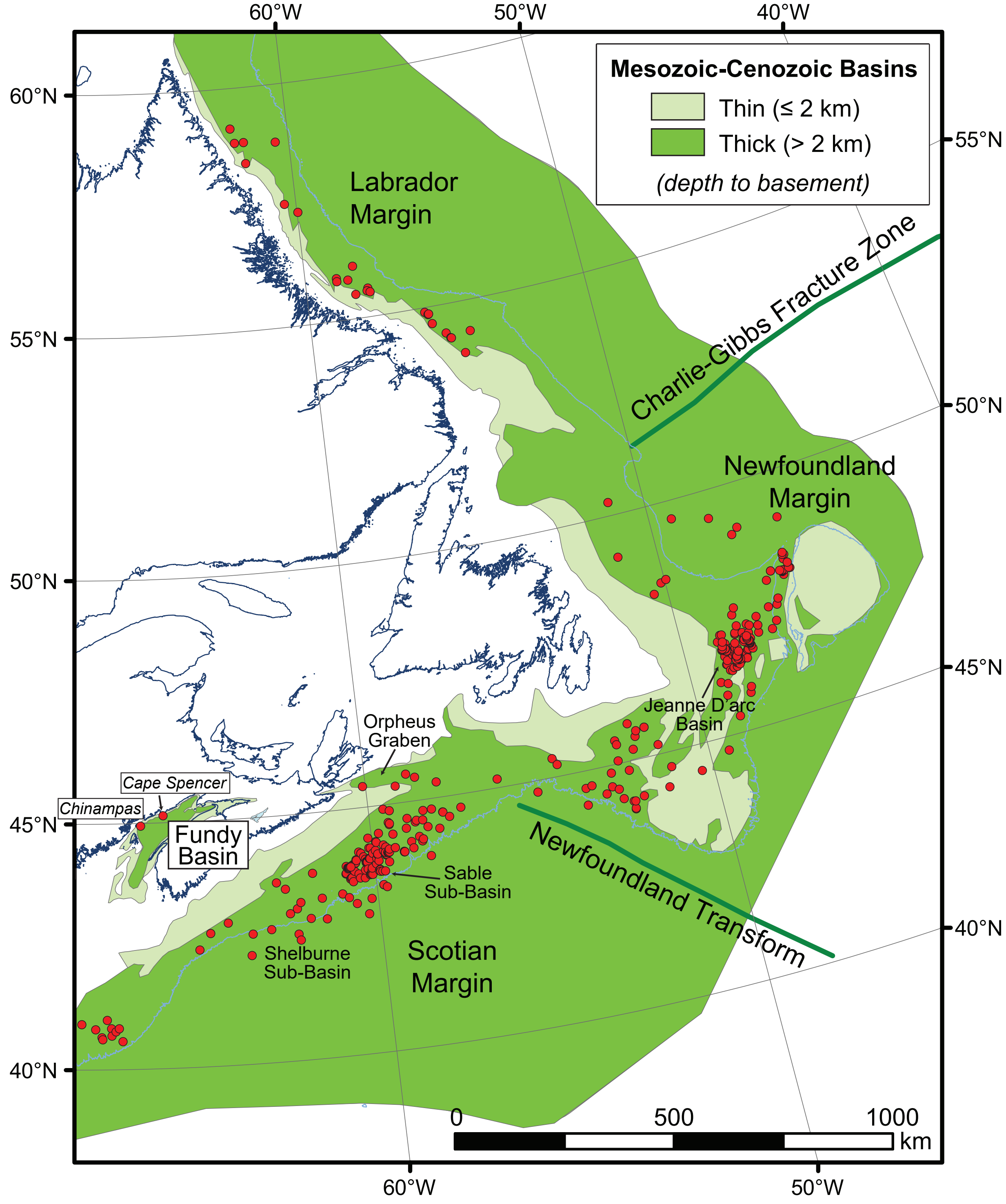

Figure 9. Mesozoic-Cenozoic basins of Atlantic Canada after *Mossop et al.* (2004). Light and dark green areas are where depth to basement is <2 km and >2 km, respectively, according to *Grant and McAlpine* (1990). Red dots are locations of deep (>800 m) wells into Mesozoic-Cenozoic strata.

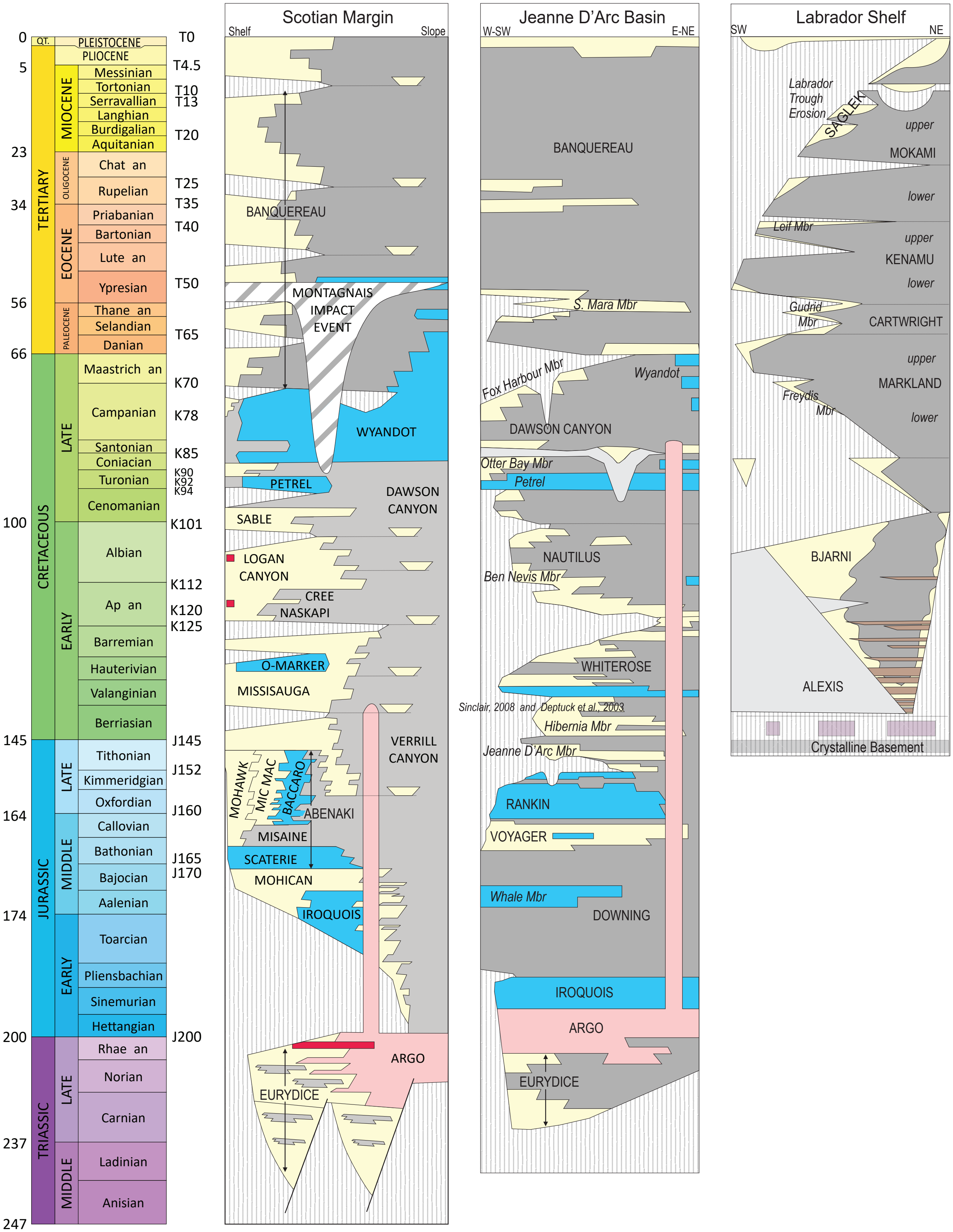

Figure 10. Generalized stratigraphic columns for the Mesozoic-Cenozoic sections of the Scotian Margin (*Weston et al.*, 2012; *Deptuck and Kendell*, 2020), Jeanne d'Arc Basin and Labrador (*Dickie et al.*, 2011).

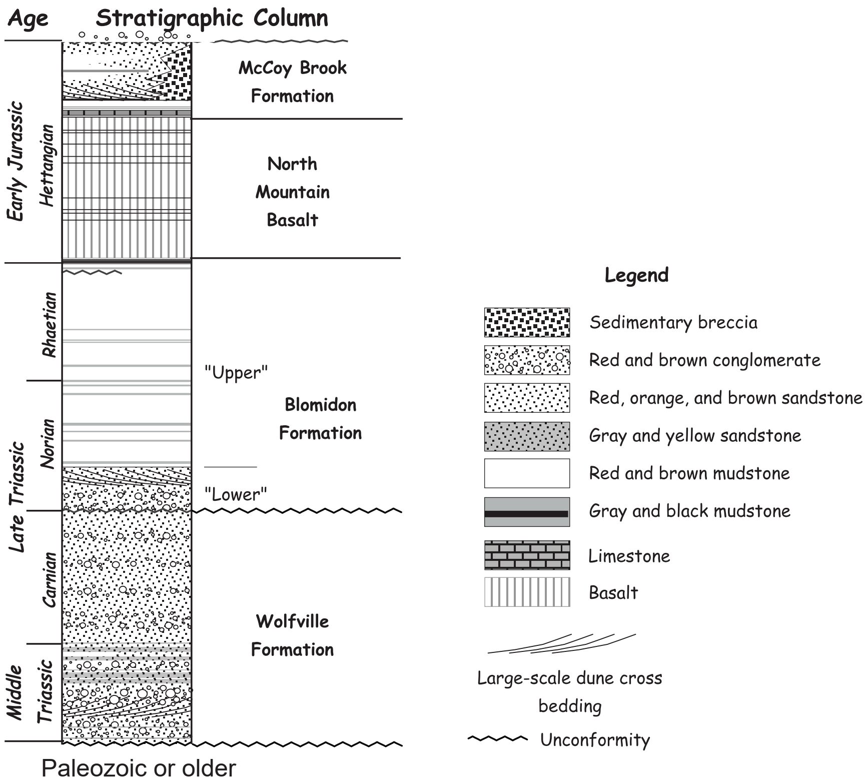

Figure 11. Stratigraphic column for Fundy Basin modified from *Withjack et al.* (2009). Note that some recent workers (e.g. *Cirilli et al.*, 2009; *Leleu and Hartley*, 2010) consider the North Mountain Basalt and McCoy Brook to be latest Triassic rather than Jurassic.

Although well-exposed onshore, Fundy Basin is poorly known in the subsurface with only two deep borehole penetrations (*Wade et al.*, 1996). Our COS mapping is based on the seismic mapping of (*Wade et al.*, 1996); significant uncertainty exists due to poor imaging of the section beneath the North Mountain Basalt.

The most attractive reservoir target in Fundy Basin is the Wolfville Formation, particularly the eolian sandstones which exhibit good to excellent porosity in outcrop (*Wade et al.*, 1996). Good reservoir was found within Wolfville-equivalent strata from both wells that have been drilled into the basin. The Cape Spencer well contained 100 m of reservoir sands with porosity averaging more than 20% (Chevron Canada Resources, 1984). Thick (∼280 m) fluvial sandstones were found in the Chinampas N-37 well with lower porosities (3-16%, *Wade et al.*, 1996). A drill stem test of the Wolfville Formation from 2179.3 to 2195.2 m yielded a 1228 m column of salt water but no permeability estimate was made due to a hydrospring failure (*Mobil Oil Canada*, 1977). Lacustrine shoreline sands in the overlying Blomidon Formation could also be reservoir targets. The thick and extensive North Mountain Basalt should be an effective seal for the Wolfville-Blomidon succession. The Scots Bay Formation (also called the McCoy Brook Formation; Figure 11) contains eolian sands similar to those in the Wolfville (*Hubert and Mertz*, 1984) and could be a good reservoir but appears to lack a suitable overlying seal.

7.1.2 COS Mapping

The estimated depths of the top basement (Paleozoic) was used to determine reservoir COS, as the best reservoir is in the lower part of the succession. Areas where the basement was less than 800 m were assigned a low COS because any reservoir would be too shallow for supercritical injection. A high COS was assigned for areas where basement lies 800–2500 m below the surface. A lower COS for reservoir was assumed for areas where it was deeper than 2500 m due to potential for porosity degradation with depth and the inference from basin-filling models that deeper parts of the basin may be dominated by finer grained sediments (*Wade et al.*, 1996). The resulting map shows extensive areas with good potential reservoir, between areas of very low potential along the basin margins and moderate potential in the deeper sub-basins (Figure 12a).

Seal COS was determined from the presence and depth of the North Mountain Basalt. Areas where the North Mountain basalt is absent was assigned a very low COS. A moderate COS was given to those areas where the base of the North Mountain basalt was shallower than 800 m, as CO_2 migrating upward from the reservoir could cease to be supercritical before reaching the seal. High COS was assigned wherever it was deeper than 800 m. Seal COS is, therefore, high in the middle of the basin and less toward its edges (Figure 12b).

Trap COS was by determined from structural deformation and the distance from outcrop of Blomidon and Wolfville formations. A very low COS was estimated along the southern margin of the basin within 10 km of mapped outcrop because there is no structural impediment to updip migration on the undeformed southern edge of the basin (Figure 12c). A minimum distance of 10 km was used because the Wolfville Formation reservoirs are expected to have significantly greater permeability than the Carboniferous reservoirs. Along the northern edge structural deformation could result in local traps and impede updip migration but the faults themselves could be escape conduits. Therefore, the trap COS was slightly higher than for the southern margin, but still low. A moderately high COS was given to areas more than 10 km from outcrop and a high COS to a small area in the center of the basin more than 30 km from outcrop (Figure 12 c).

The Total COS map indicates that the best potential for carbon sequestration in Fundy Basin is likely to be found beneath the Bay of Fundy a short distance offshore (Figure 12d). Onshore areas have very low potential, and the deepest parts of the basin have moderately low potential for carbon storage.

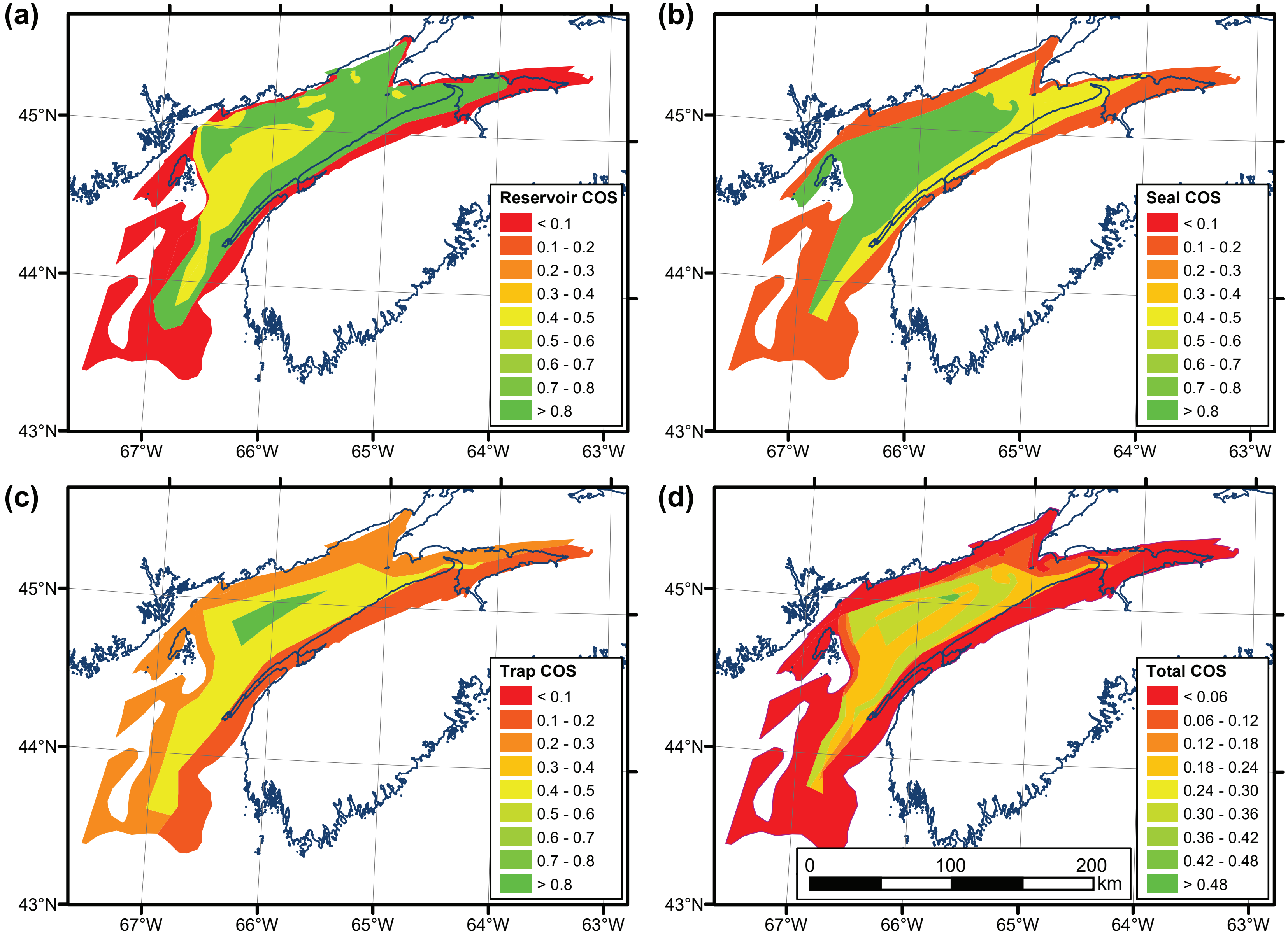

Figure 12. COS Maps for Fundy basin. (a) Reservoir COS, (b) Trap COS, (c) Seal COS, and (d) Total COS.

7.2 Orpheus Graben

Although contiguous with the Scotian Basin with which it shares stratigraphic nomenclature, the Orpheus Graben trends southeast rather than northeast and has a similar structural setting to the Fundy Basin. Like Fundy Basin, Orpheus Graben formed through reactivation of older faults between the Meguma and Avalon terranes (*Tanner and Brown*, 2003), and is a half-graben with a border fault on its northern edge and a relatively undeformed southern margin (*MacLean and Wade*, 1992). Rifting began in the Triassic; the terrestrial clastics of the Euridice Formation (Figure 10) comprise the earliest post-rift fill (*Hanafi et al.*, 2022; *Lyngberg*, 1984). Continued extension and subsidence through the late Triassic resulted in a marine incursion (*O'Connor et al.*, 2018) and a restricted marine environment favoring the deposition of the evaporite-dominated Argo Formation (Figure 10; *Tanner and Brown*, 2003; *Wade and MacLean*, 1990). *Hanafi et al.* (2022) interpret mini-basins associated with salt mobilization and igneous sills possibly time-equivalent to the North Mountain Basalt in the youngest synrift deposits but these features have not been seen in wellbores.

Although the basin-fill is predominantly synrift, as in the Fundy Basin, the post-rift succession can exceed 3 km in thickness (*Wade and MacLean*, 1990) and is largely composed of Jurassic terrestrial to shallow-marine clastics and carbonates (*Lyngberg*, 1984). A prominent late Jurassic unconformity is overlain by Cretaceous alluvial plain clastics (*Lyngberg*, 1984); paleogeographic maps suggest that a river system in the Orpheus Graben may have fed the Sable Delta (*Brown*, 2008).

The Orpheus Graben was not included in the Nova Scotia Play Fairway Atlas and we have not created COS maps for it, but there is some potential for carbon storage within it. The coarse clastics within the Eurydice Formation could provide good reservoir rock, particularly in the shallower parts of the basin where *MacLean and Wade* (1992) anticipate porosities of about 15%. The overlying salt-rich Argo Formation should provide an excellent seal. *Hanafi et al.* (2022) expect coarse-grained clastics in the mini-basins based on analogs and igneous sills could provide seals. *MacLean and Wade* (1992) also view the Jurassic Mohican Formation as a potential reservoir. Cretaceous reservoirs could exist but are likely to be too shallow for supercritical CO_2 injection and it's not clear how they would be sealed, although there are locally occurring volcanics in the upper part of the Missisauga Formation (*Wade and MacLean*, 1990).

7.3 Scotian Margin

7.3.1 Regional Structural Setting

The Scotian Margin is a narrow northeast trending continental basin that extends from Georges Bank in the southwest to the southern Grand Banks in the northeast, with an approximate total area of 300,000 km^2 (*Wade and MacLean*, 1990; *Sable Offshore Energy Project*, 1997; *Hansen et al.*, 2004). The basin formed as a result of the rift of Pangea, and its rift-drift-sag development is detailed in many publications (e.g., *Wade and MacLean*, 1990; *MacLean and Wade*, 1992; *Kidston et al.*, 2005; *Brown*, 2008; *BEICIPFranLab*, 2011; *Weston et al.*, 2012; *Deptuck and Altheim*, 2018; *DesRoches and Wade*, 2019). Pangea rifted while the supercontinent was at a low latitude, which influenced the regional structural and stratigraphic style of the basin due to the interaction between depositing sediments from mixed siliciclastic-carbonate systems and the basement structure, gravity tectonics, and salt tectonics. Rifting in the late Triassic to early Jurassic caused extensional faulting, forming a series of basement ridges/platforms and sub-basins. Sub-basins include (southwest to northeast) Shelburne, Mohawk, Emerald, Naskapi, Mohican, Sable, Abenaki, and Orpheus (*Smith et al.*, 2014).

7.3.2 Regional Stratigraphy

Several stratigraphic frameworks have been applied to the basin (locally and/or regionally) including lithostratigraphy, biostratigraphy, chronostratigraphy, and sequence stratigraphy (*McIver*, 1972; *Given*, 1977; *Weston et al.*, 2012). The stratigraphy of the basin can be broadly divided into five groups: Triassic pre- and syn-rift sediments, early to middle Jurassic post-rift clastics and carbonates, late Jurassic to early Cretaceous deltaic wedge sediments, middle to late Cretaceous transgressive marine sediments, and Cenozoic regressive marine sediments (*Weston et al.*, 2012). Numerous salt structures of assorted styles are found below the slope, salt deformation is associated with basement architecture and post-rift sediment loading (*Shimeld*, 2004; *Leleu et al.*, 2016; *Decalf and Heyn*, 2023). Seaward of these structures the continental crust transitions to oceanic crust, and is overlain with extensive post-rift sediments (*Kidston et al.*, 2002; *Shimeld*, 2004).

Crustal attenuation and basement faulting during the middle Triassic to early Jurassic rifting formed grabens and half grabens that were filled with the synrift continental clastics of the Eurydice Formation (*Smith et al.*, 2014) . These were followed by the deposition of the Argo Formation evaporites and unnamed clastics. Following the breakup unconformity was the deposition of the shallow marine dolomites of the Iroquois Formation. These formations reflect the shift from non-marine to marine depositional environments as a result of the opening of the North Atlantic Ocean (*Sable Offshore Energy Project*, 1997).

Widening of the Atlantic during the Jurassic created more open marine conditions along the Scotian Basin margin. This led to a significant marine transgression and allowed for the development of a carbonate bank on the shelf edge, recorded in the Abenaki Formation (Scatarie, Misaine, and Baccaro members) (*Kidston et al.*, 2005). The shelf edge steepened resulting in a change from shallow to deep marine conditions over a short distance. Deposition of deepwater marine shales of the lower Verrill Canyon Formation (*Sable Offshore Energy Project*, 1997) occurred seaward of the carbonate bank, while shallow shelf calcareous sands, shales, and carbonate muds of the Mic Mac Formation were deposited on the landward side. Locally within the Sable Sub-basin area, structural downwarping provided high accommodation for clastic sediments preventing the development of the Abenaki carbonate bank in that area; instead, a small Mic Mac Formation delta was established (*Smith et al.*, 2014).

During the late Jurassic to early Cretaceous, clastic sediment deposition increased through a major continental drainage system that created the Sable Delta complex. The delta prograded into the basin creating sand-rich delta, delta front and delta plain sediments of the Missisauga Formation and the prodelta shales of the Verrill Canyon Formation (*Wade and MacLean*, 1990). The sandstones of the Missisauga and Mic Mac formation delta complexes form the reservoirs of the Sable Sub-basin. A marine transgression over the delta sequence covered the unit with the thick marine shale of the Naskapi Member of the Logan Canyon Formation (*Wade and MacLean*, 1990).

The rest of the early Cretaceous is associated with passive margin development and the deposition of the delta to shallow marine progradational lobes of the Logan Canyon Formation interfingered with the basinal-equivalent marine shales of the Shortland shale (*Sable Offshore Energy Project*, 1997). The Logan Canyon comprises four members, which in ascending order, are the Naskapi, Cree, Sable and Marmorai. These members represent alternating regressive (Cree and Marmora) and transgressive (Naskapi and Sable) successions.

During the final stages of passive margin development in the late Cretaceous, the, a marine transgression deposited the Petrel limestone. Deposition of deep-water shales of the Dawson Canyon Formation and chalky limestones of the Wyandot Formation followed subsequently. Finally, this was all capped by deposition of the Paleogene and Neogene Banquereau Formation clastics (*Sable Offshore Energy Project*, 1997).

7.3.3 COS Mapping

The Scotian Basin was subdivided for the COS assessment (oldest to youngest): (1) Bathonian to Kimmeridgian, (2) Tithonian to Berriasian, (3) Valanginian to Hauterivian, (4) Barremian, (5) Aptian to mid-Albian, and (6) mid-Albian to Cenomanian. Subdivisions generally correspond to unconformities on the shelf and slope. For each subdivision, the potential reservoirs and seals were evaluated on their ability to store and contain injected CO_2 based on available formation descriptions including lithologies, depositional environments, and erosional events. Most of this evaluation is based on the Play Fairway Analysis, a project commissioned by the Offshore Energy Technical Research (OETR) Association of Nova Scotia and coordinated by RPS Energy in 2009 (*BEICIPFranLab*, 2011). This preliminary assessment of the Scotian Margin CCUS COS does not consider trap, but this may be addressed in further research.

For reservoirs, a higher COS (0.66–1) was assigned to areas where more clastic sediments were deposited and/or where permeability and porosity were expected to be better, a moderate COS (0.35–0.65) was assigned where less clastic sediments were deposited and/or where permeability and porosity were expected to be reduced, and a low COS (0 – 0.34) where little to no clastic sediments were deposited and/or where permeability and porosity were expected to be poor. A low COS was also assigned in areas of expected erosion or non-deposition. For seals, a higher COS (0.66–1) was assigned to areas where more fine-grained sediments (shales) were deposited and/or where permeability and porosity were expected to be low, a moderate COS (0.35–0.65) was assigned where less fine-grained sediments were deposited and/or where permeability and porosity were expected to be higher, and a low COS (0–0.34) where little to no fine-grained sediments were deposited and/or where permeability and porosity were expected to be good. A low COS was also assigned in areas of expected erosion or non-deposition.

In the assessed area, only depths greater than 800 m TVDSS (True Vertical Depth Subsea) were considered, to allow for supercritical injection of CO_2. It should be noted that this assessment is not on the engineering COS for injection which would necessitate a much more detailed evaluation of various PVT (Pressure Volume Temperature) relationships.

7.3.3.1 Bathonian to Kimmeridgian

The reservoir units during the Bathonian to Kimmeridgian are the Mohawk and Mic Mac formations. The western side of the Scotian shelf had more carbonate facies (carbonate reef, lagoon) while clastic sediments (prodelta, turbidite channel) dominated the eastern side. The basin was largely filled by hemipelagic shales. The paleo-shoreline was parallel to the current shoreline but approximately 150–200 km further southeast. Reservoir facies were deposited proximal to source, with a larger sediment source on the eastern end of the basin, and, therefore, a higher COS (Figure 13a).

The seal unit for the Bathonian to Kimmeridgian reservoirs is the Verrill Canyon, which had several transgressive/regressive cycles, resulting in stack repeating sequences of reservoir-seal pairs. The Verrill Canyon Formation was extensively deposited over the basin, resulting in a higher COS, except in areas where carbonate facies dominated and/or there was slope failure/erosion (Figure 13b).

The total COS map (Figure 13c), which combines the reservoir and seal COS maps, suggests that the best potential for carbon sequestration would be in the eastern side of the basin in the Sable Island region and then the southeast half of the study area. The western part of the basin has much lower potential due to the predominance of carbonates. Injection of CO_2 in carbonates may be problematic because of the rapid rate of carbonate dissolution, causing dissolution cavities, which is intensified by the acidic character of CO_2 solutions, and could impact the geomechanical stability of the injection site.

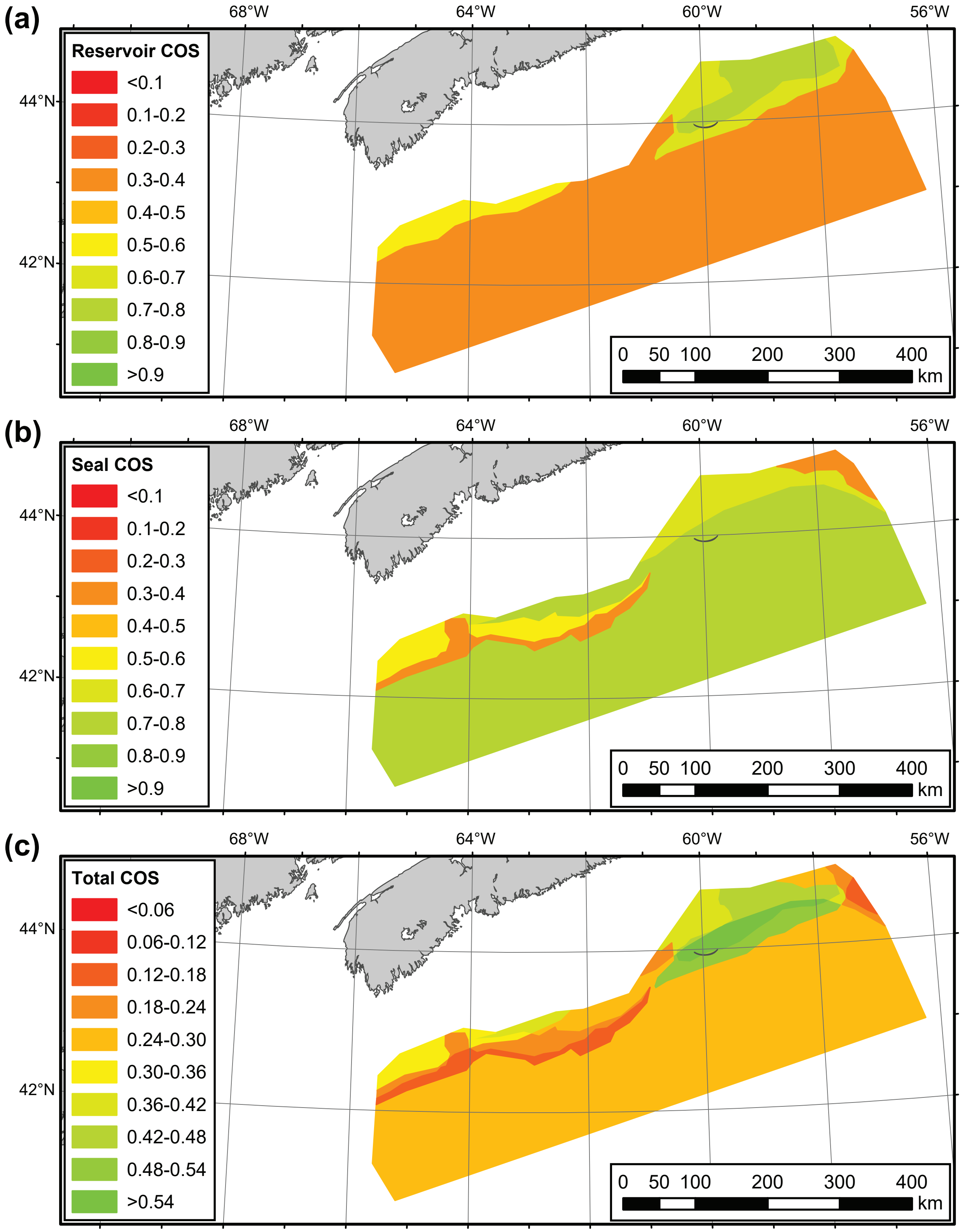

Figure 13. COS maps for the Bathonian to Kimmeridgian. (a) Reservoir COS, (b) Seal COS, and (c) Total COS.

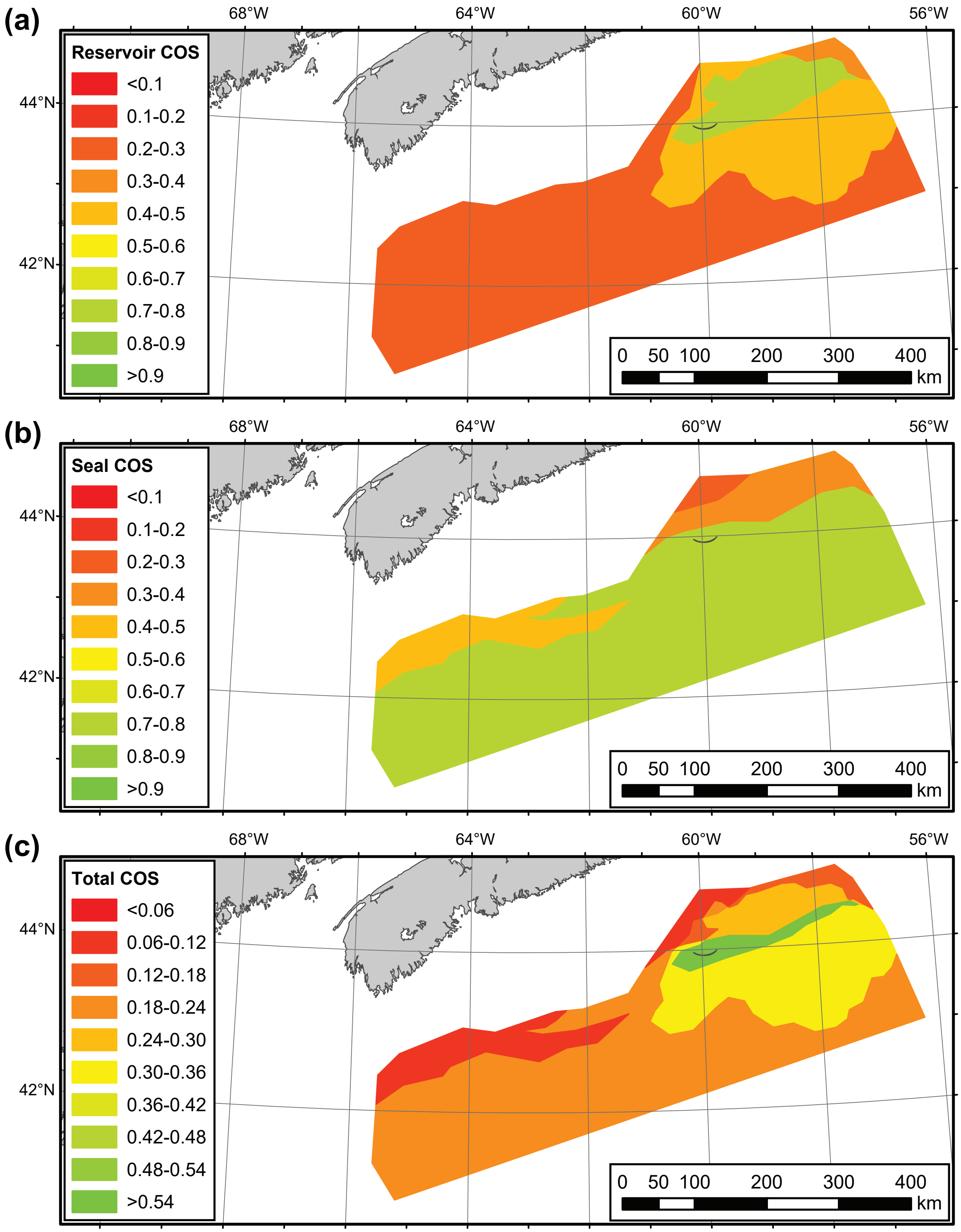

Figure 14. COS maps for the Tithonian to Berriasian. (a) Reservoir COS, (b) Seal COS, and (c) Total COS.

7.3.3.2 Tithonian to Berriasian

The Tithonian to Berriasian reservoir unit is the lower Missisauga Formation. The paleo-shoreline position was similar to the Bathonian-Kimmeridgian but did begin to (overall) move landward. There were more carbonate facies along the entire length of the shelf-edge as opposed to only the western end. Clastic sediments were deposited proximal to source, predominantly in the Sable Island region, with the onset of the (Missisauga) delta system, therefore this region has a higher COS then the rest of the reservoir (Figure 14a).

The Bathonian to Kimmeridgian seal unit is the Verrill Canyon, which had several transgressive/regressive cycles, resulting in repeating sequences of reservoir-seal pairs. However due to sea level rise and basin subsidence, accommodation space increased and significant hemipelagic shales were deposited in the basin and further landward than previously. The Verrill Canyon Formation was extensively deposited throughout the basin, resulting in a higher COS, except in areas where carbonate facies dominated and/or there was slope failure/erosion (Figure 14b).

The total COS map (Figure 14c), which combines the reservoir and seal COS maps, suggests that the best potential for carbon sequestration would be in the eastern side of the basin in the Sable Island region. The western and deeper parts of the basin have lower potential due to the presence of carbonates and reduced reservoir presence.

7.3.3.3 Valanginian to Hauterivian

The Valanginian to Hauterivian reservoir unit is the middle Missisauga Formation. Carbonate facies (carbonate reef, lagoon) were more abundant on the western side of the Scotian shelf, while clastic facies (prodelta, turbidite channel) predominated on the eastern side (resembling the Bathonian-Kimmeridgian). The paleo-shoreline position was similar to the Tithonian-Berriasian but moved slightly seaward during a maximum regressive period (forced regression). Clastic sediments were deposited with the ongoing development of the Missisauga delta system, which expanded west and east (Figure 15a). This was due to a significant increase in sediment supply and water flow. Based on this, the reservoir on the shelf and eastern side has a higher COS relative to the slope and western side.

The Valanginian to Hauterivian seal units are the Verrill Canyon formation and "O" marker interval. The "O" Marker records highstand conditions at the end of the Hauterivian, resulting in carbonate facies dominating the shelf and shales facies on the slope. This interval is widespread across the basin and is the main seal for the middle Missisauga reservoirs, accounting for a high COS throughout the area of interest (Figure 15b).

The total COS map (Figure 15c), which combines the reservoir and seal COS maps, suggests that the best potential for carbon sequestration would be in the shelf and eastern side of the basin. The western and deeper parts of the basin have lower potential but overall is higher than the Tithonian to Berriasian TCOS.

7.3.3.4 Barremian

The Barremian reservoir unit is the upper Missisauga Formation. The western side of the Scotian shelf was still more carbonate (carbonate reef, lagoon) and shale facies , but less so that during the Valanginian to Hauterivian because clastic sediments were being deposited by a small Shelburne delta system. The eastern side of the shelf was richer in coarse clastic facies but the sediment flow to the Missisauga delta was reduced relative to previous deposition volumes (Figure 16a). Therefore, reservoir on the shelf and eastern side of

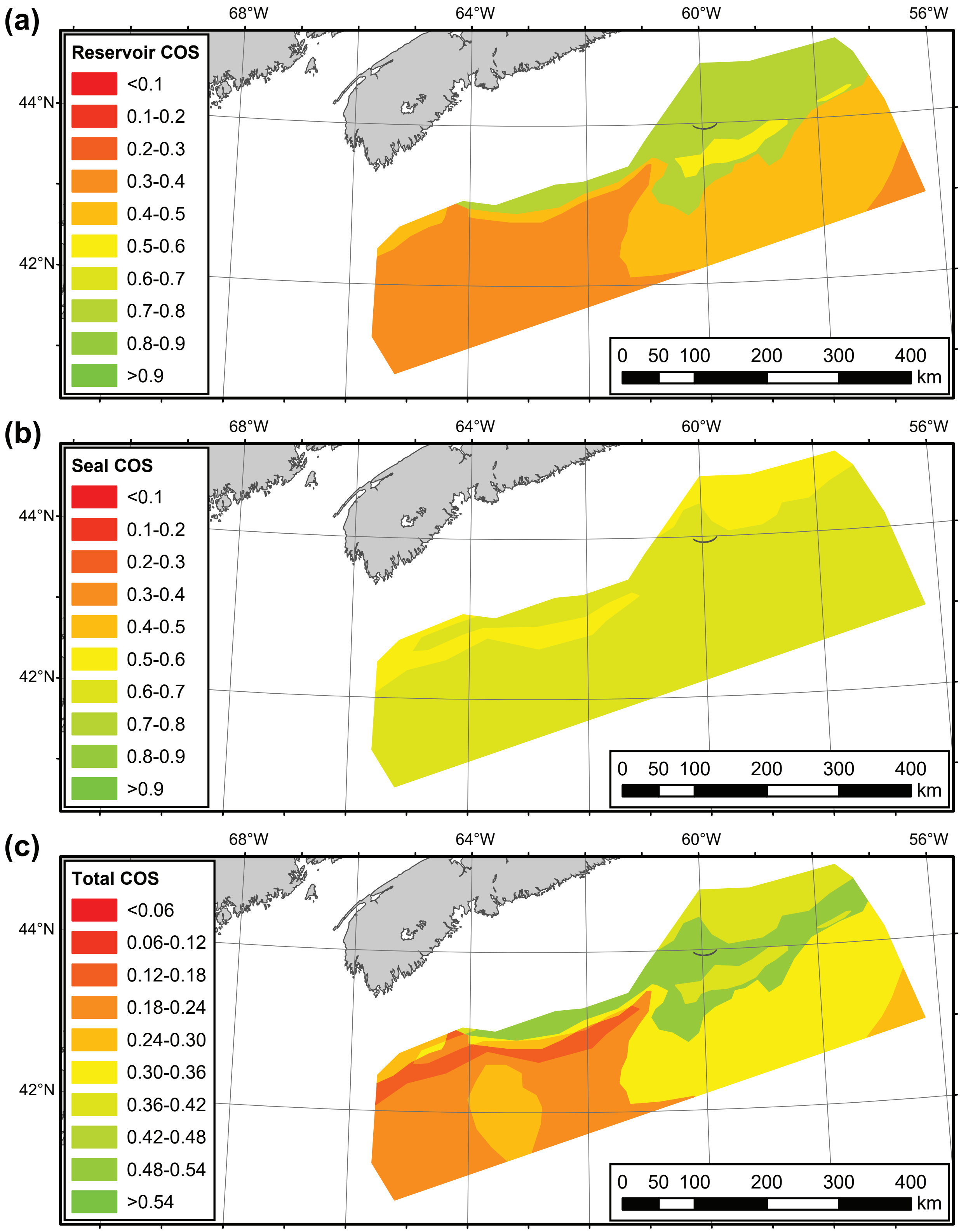

Figure 15. COS maps for the Valanginian to Hauterivian. (a) Reservoir COS, (b) Seal COS, and (c) Total COS.

the basin have a higher COS relative to the slope and western side.

The Naskapi Member provides a seal for Barremian reservoirs. There was a radical reduction in sediment supply, starving the deltas and basin of sand facies and allowing shale facies to dominate. Naskapi Member shales were deposited throughout the shelf and slope and form the regional seal for the upper Missisauga reservoirs (Figure 16b). The Naskapi Member has a high COS in most areas except where the Missisauga and Shelburne deltas were most active.

The total COS map (Figure 16c), which combines the reservoir and seal COS maps, suggests that the best potential for carbon sequestration would be the shelf and central to eastern side of the basin. The western basin has much lower potential.

7.3.3.5 Aptian to Cenomanian

The Aptian to Cenomanian reservoir units are the Logan Canyon and Cree formations. As a result of the Aptian maximum flooding event, clastic deposition becomes much more uniformly distributed along the shelf and carbonate sedimentation is highly localized. The shelf margin is dominated with clastic sand and shale deposits and the slope is dominated by turbidites. Between the Aptian and Cenomanian, there is an increase in shale content, therefore the sandier Logan Canyon Formation reservoirs (Figure 17a) have a higher COS than the shalier Cree Formation reservoirs (Figure 18a).

The Aptian to Cenomanian seal units are the Sable Member and Dawson Canyon Formation. The Sable Member is mostly shale (but does contain thin sandstones) and was deposited in the slope region (Figure 17b). The Dawson Canyon Formation is marine shales with chalks and limestones deposited extensively in the basin, therefore has a higher COS for seal throughout most of the basin (Figure 18b).

The Aptian to mid-Albian total COS map (Figure 17c), which combines the reservoir and seal COS maps, suggests that the best potential for carbon sequestration would be the shelf and central to eastern side of the basin. The western and deeper parts of the basin have lower potential. The mid-Albian to Cenomanian total COS map (Figure 18c), which combines the reservoir and seal COS maps, suggests that there is poor capacity and containment potential in these units.

7.4 Newfoundland Margin

7.4.1 Geological Setting

The broad continental margin extending to the southwest and southeast of Newfoundland is characterized by a series of sedimentary basins up to 20 km thick interrupted by continental platforms areas where Mesozoic and younger sediments are thin (*Grant and McAlpine*, 1990), such as the South Bank High, Flemish Cap, and Orphan Knoll (Figure 19). The best-known of these basins is the Jeanne d'Arc on the eastern Grand Banks, which is a prolific petroleum producer, but there are several other thick sedimentary accumulations on the margin (Figure 19). These include Whale Basin and Orphan Basin (Figure 19).

The initial history of the margin is similar to the Scotian Margin with rift initiation along NE-SW axes in the late Triassic in most of the basins (*Jansa and Wade*, 1975; *Sibuet et al.*, 2007; *Sinclair*, 1988; *Wielens et al.*, 2006), though it may not have begun until the mid-Jurassic in Orphan Basin (*Cawood et al.*, 2021; *Dafoe et al.*, 2017). The sediments deposited during this first phase of rifting were similar to those on the Scotian Margin and the same formation names are used (Figure 11). However, the rifting process stalled after shallow marine conditions were established and the area experienced renewed uplift and widespread erosion in the late Jurassic as the principle direction of extension reoriented to west-east (*Grant and McAlpine*, 1990; *Jansa and Wade*, 1975). This was followed by renewed subsidence as the Grand Banks separated from Iberia during the early Cretaceous, and deposition of the main petroleum reservoir sandstones: the Jeanne d'Arc,

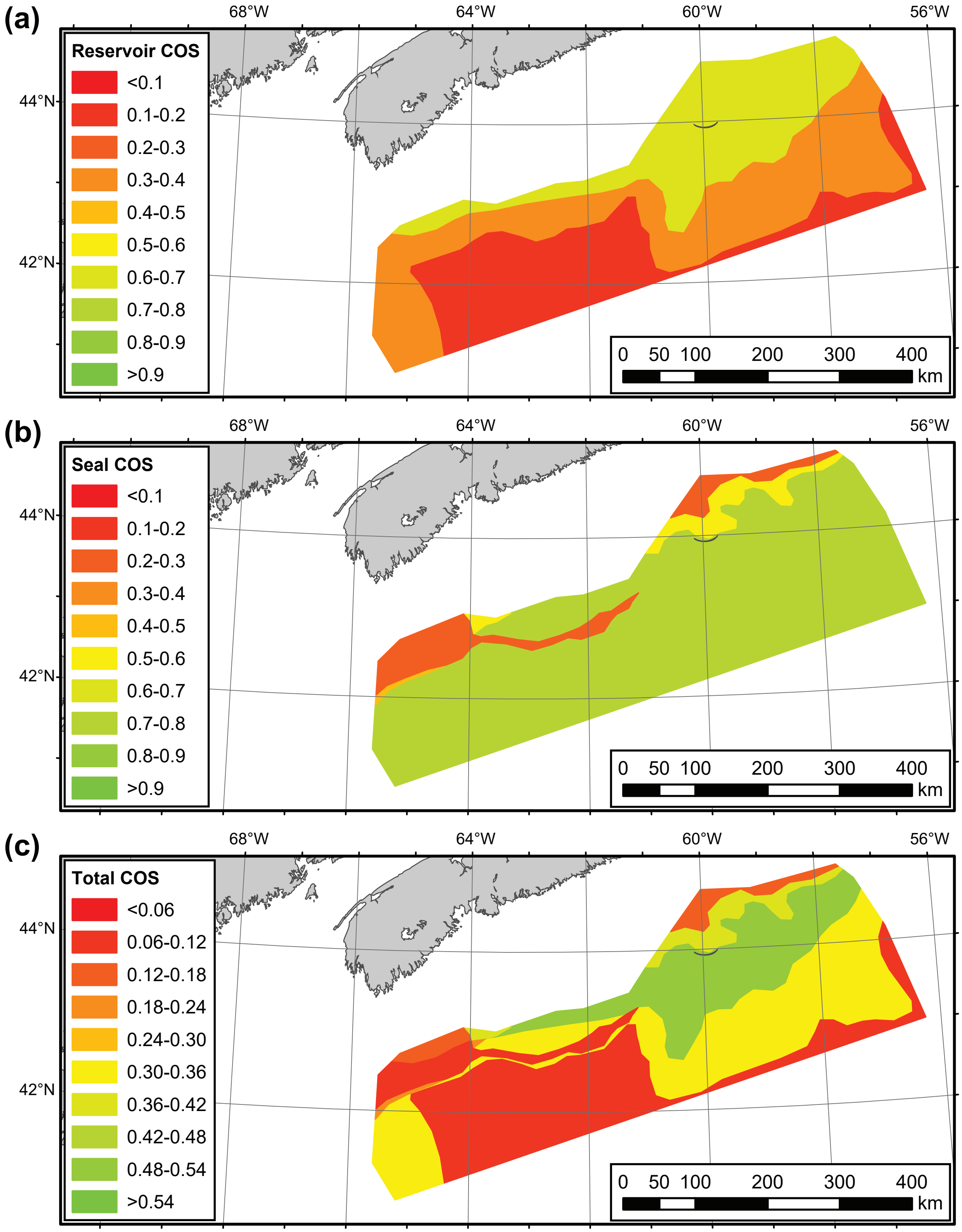

Figure 16. COS maps for the Barremian. (a) Reservoir COS, (b) Seal COS, and (c) Total COS.

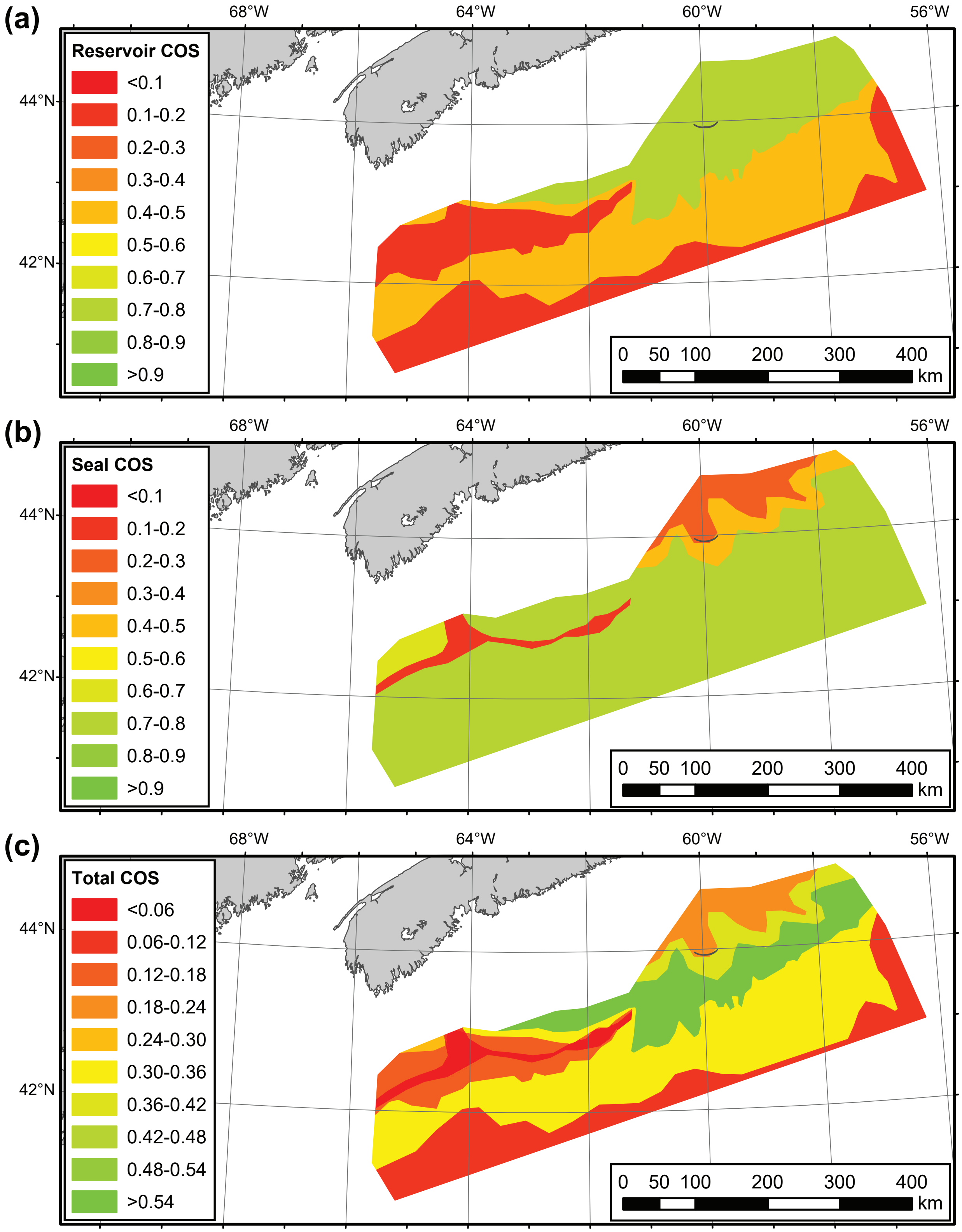

Figure 17. COS maps for the Aptian to mid-Albian. (a) Reservoir COS, (b) Seal COS, and (c) Total COS.

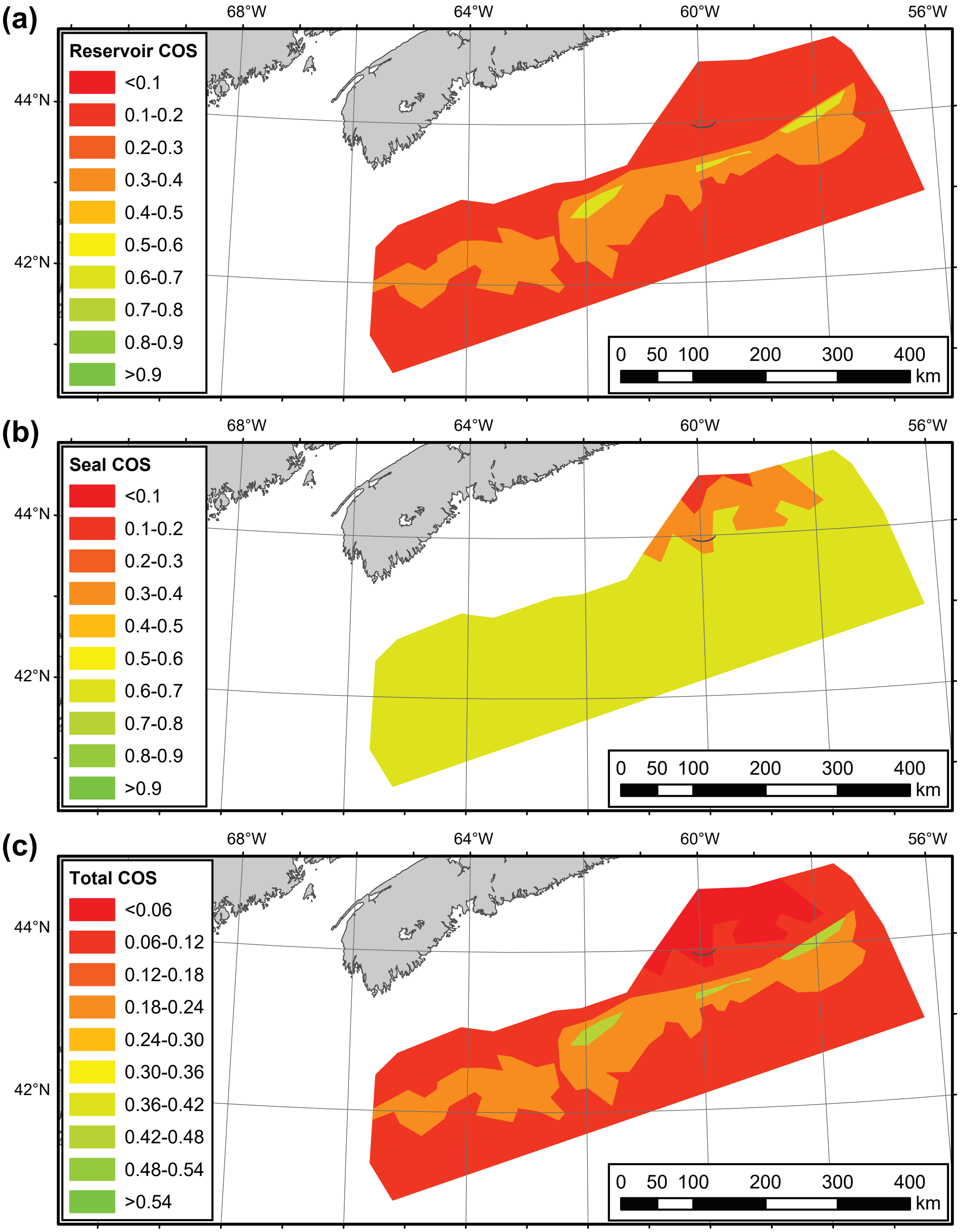

Figure 18. COS maps for mid-Albian to Cenomanian. (a) Reservoir COS, (b) Seal COS, and (c) Total COS.

Hibernia and Ben Nevis formations *Grant and McAlpine* (1990) and their sealing shale packages. Breakup of the margin and creation of oceanic crust progressed northward, reaching the Charlie Gibbs fracture zone by the Santonian (*Peace and Welford*, 2020), which is recorded as a breakup unconformity in Orphan Basin (*Dafoe et al.*, 2017). The post-Santonian Dawson Canyon and Banquereau Formations are predominantly marine shales, similar to these units on the Scotian Margin.

7.4.2 Carbon Sequestration Potential

The lower Cretaceous section contains several proven reservoirs for petroleum which could potentially host carbon dioxide. The coarse grained sands and conglomerates of the Jeanne d'Arc Formation have porosities of around 10%; the porosities in the Hibernia and Ben Nevis formations are typically 16-21% (*Grant and McAlpine*, 1990). These sandy intervals are overlain by the mud-dominated Fortune Bay, Whiterose and Nautilus formations should be effective seals for CO_2 injection as they have proven to be for petroleum systems. Sandstone members within the Dawson Canyon and Banquereau Formations are also potential reservoirs; *Deptuck et al.* (2003) report over 40 m of sand averaging 26% porosity in one interval. There was insufficient time to prepare COS maps of these basins for this report, but there is evidence of several high quality reservoir seal pairs. The Jeanne d'Arc Basin is the most likely target for future sequestration projects because of the abundance of geological and geophysical data, although there is likely high to excellent potential in all of these basins.

7.5 Labrador Margin

7.5.1 Geological Setting

The sedimentary basins of offshore Labrador extend for more than 1300 km along its shoreline and from the mid-shelf to beyond Canada's 200 nautical mile limit (Figure 9). Geologic investigations of the region began with seismic surveys in the 1960s followed by drilling on the shelf of 27 exploration wells between 1969 and 1984 (*Carey et al.*, 2020). The basic stratigraphic nomenclature (Figure 10) was developed by *Umpleby* (1979) and *McWhae et al.* (1980) and further refined by later workers (*Balkwill and McMillan*, 1990; *Dickie et al.*, 2011; *Dafoe et al.*, 2022). The sedimentary thickness exceeds 6 km over extensive areas of the outer shelf and upper slope within this region. The margin is commonly subdivided by the Okak Arch into Saglek Basin in the north and Hopedale Basin in the south (Figure 20; *Balkwill and McMillan*, 1990). South of the Cartwright Arch, the sedimentary cover on the shelf is thin, seismic data is limited, and there are no deep well penetrations of the Mesozoic-Cenozoic section (*Carey et al.*, 2020). Although a thick sediment deposit on the upper slope in "Hawke Basin" is known from regional mapping (*Grant*, 1990), this assessment is limited to the areas north of 54 N, the same cut-off used by *Carey et al.* (2020).

Regional crustal extension and thinning in Labrador began in the early Cretaceous, significantly later than elsewhere on the Canadian continental margin. Rifting of the margin resulted in a series of largely coastline-parallel grabens and half-grabens filled with syndepositional clastic sediments (Bjarni Formation) and volcanics (Alexis Formation; Figure 10) (*Balkwill and McMillan*, 1990; *Dickie et al.*, 2011; *Umpleby*, 1979). Bjarni Formation sediments were predominantly of terrestrial origin during the initial rifting phase, but deltaic to shallow marine rocks become more prominent by the Albian (*Dafoe et al.*, 2022). Subsequent rifting and thermal sag of the basin continued through the later Cretaceous resulting in deposition of the marine shale-dominated Markland Formation (*Dickie et al.*, 2011).

Breakup of the margin, peridotization of exumed mantle and seafloor spreading were initiated by latest Cretaceous time in central Labrador (*Keen et al.*, 2018). North of the Snorri Fracture Zone the margin evolved into a magma-dominated margin (*Keen et al.*, 2012). The early Paleocene was marked by a rapid sea level fall followed by deposition of the Gudrid Formation sandstones and the coeval Cartwright Formation shales (*Dickie et al.*, 2011) in the Paleocene (Figure 10). The thick, laterally extensive Gudrid sandstones

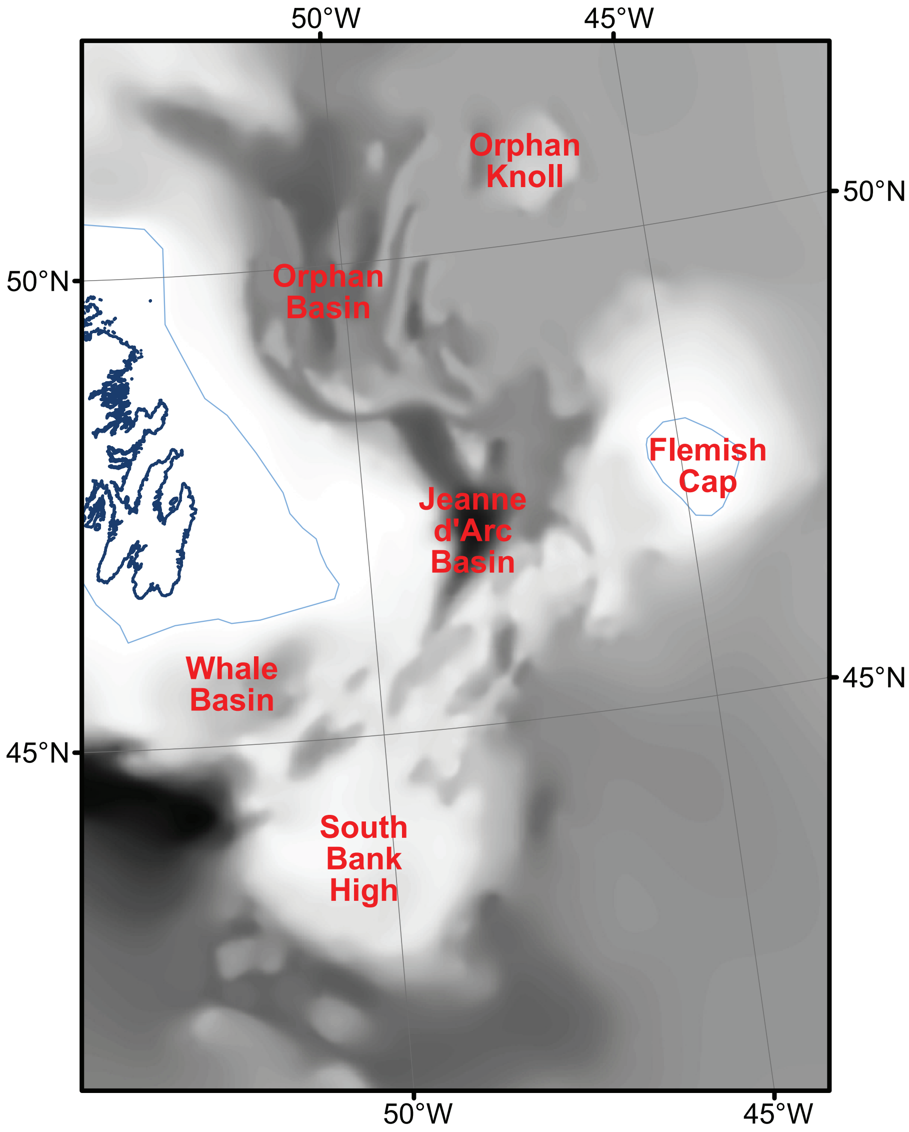

Figure 19. Sedimentary basins, platforms and major tectonic features of the Newfoundland margin. Depths estimated by interpolation from depth-to-basement contours from *Grant* (1990)

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have been interpreted as turbidites (*D'eon-Miller and Associates Limited.*, 1987), but more recent investigations have argued for a deltaic shoreline origin (*Dafoe et al.*, 2022).

As seafloor spreading continued, the margin was transgressed again near the Paleocene-Eocene boundary and the Kenamu Formation deposited in the Eocene (*Dickie et al.*, 2011). The Kenamu is predominantly composed of shales deposited in outer shelf water depths, but contains minor fine to medium grained sandstones that are likely deltaic to shallow marine known as the Leif Member (*Dafoe et al.*, 2022).

Crustal spreading slowed then ceased in the late Eocene (*Delescluse et al.*, 2015), which corresponds roughly to another unconformity followed by deposition of the Mokami Formation (*Dickie et al.*, 2011). The Mokami Formation is predominantly shaly and becomes coarser upwards (*Balkwill and McMillan*, 1990). The Mokami is overlain by the coarse-grained Saglek Formation which is marked by numerous strongly incised channel surfaces created during sea level falls (*Dafoe et al.*, 2022).

Carey et al. (2020) considered plays in six possible conventional hydrocarbon reservoirs on the Labrador Margin. We have chosen to limit our evaluation to the three most prospective (Bjarni, Gudrid, and Leif plays). Although there is reservoir rock in the Paleozoic, as noted earlier in this report, the difficulty in mapping its extent and its burial beneath more accessible reservoirs makes it an unlikely target. The Freydis Member of the Markland Formation appears to have very limited areal extent (*Carey et al.*, 2020). The Mokami Formation contains sands that are similar to the Leif Member of the Kenamu, but seal might be challenging owing to its dominantly coarsening upward character and the extensive erosion surfaces beneath the overlying coarse-grained Saglek Formation (*Carey et al.*, 2020; *Dickie et al.*, 2011).

7.5.2 Bjarni Play COS Mapping

The Bjarni Formation is a proven reservoir for hydrocarbons, hosting several significant discoveries, including the North Bjarni field which is estimated to contain more than 60 x 10^9 m^3 gas (*Canada-Newfoundland Offshore Petroleum Board*, 2023). Reservoir sandstones constitute more than 60% of the section in wells from central Hopedale Basin (*Carey et al.*, 2020). Typical sandstone porosities were 16-25% at a depth of 2000 m and decreased to an average of 10-16% at 3500 m (*Carey et al.*, 2020). Permeabilities of 1 to 100 mD were commonly reported from core analyses, but varied considerably with grain size and amount of interstitial clay and could exceed 1D (*Carey et al.*, 2020).

We used the reservoir COS values reported by *Carey et al.* (2020), reducing them only in the (rare) circumstances where the Bjarni might be too shallow for supercritical injection. This was determined using unpublished maps of the top Bjarni elevation prepared for the MCT program. Reservoir COS values were highest in mapped Bjarni half-grabens with well penetrations, and moderate to high in undrilled Bjarni half-grabens (Figure 21a). Low values were assigned in areas where no half-grabens were observed on seismic data.

The Markland Formation is predominantly shale and normally fills the upper part of half-grabens. The seal COS values from *Carey et al.* (2020) have high seal COS within these known structural basins and lower values in most other areas where the Markland Formation is thin or absent (Figure 21b).

Trap COS was evaluated based on the distance from subcrop edges and faulting. Due to the potential for fluid migration through extensive permeable and porous reservoirs, cutoffs of 10 km and 30 km from subcrop for low, moderate and high trapping potential. The Bjarni is extensively faulted, but the COS for trap was only reduced in areas where *Carey et al.* (2020) reported faulting in shallower horizons, as basement-related faults are unlikely to provide conduits to the surface. Trap potential for the Bjarni is excellent except in areas near the Labrador Margin trough and offshore areas where shallow faults were common (Figure 21c).

The Total COS map for the Bjarni Formation indicates good potential in the numerous half-grabens on the mid-shelf, particularly within Hopedale Basin (Figure 21d). Low potential generally reflects areas where the presence of Bjarni sediments is uncertain.

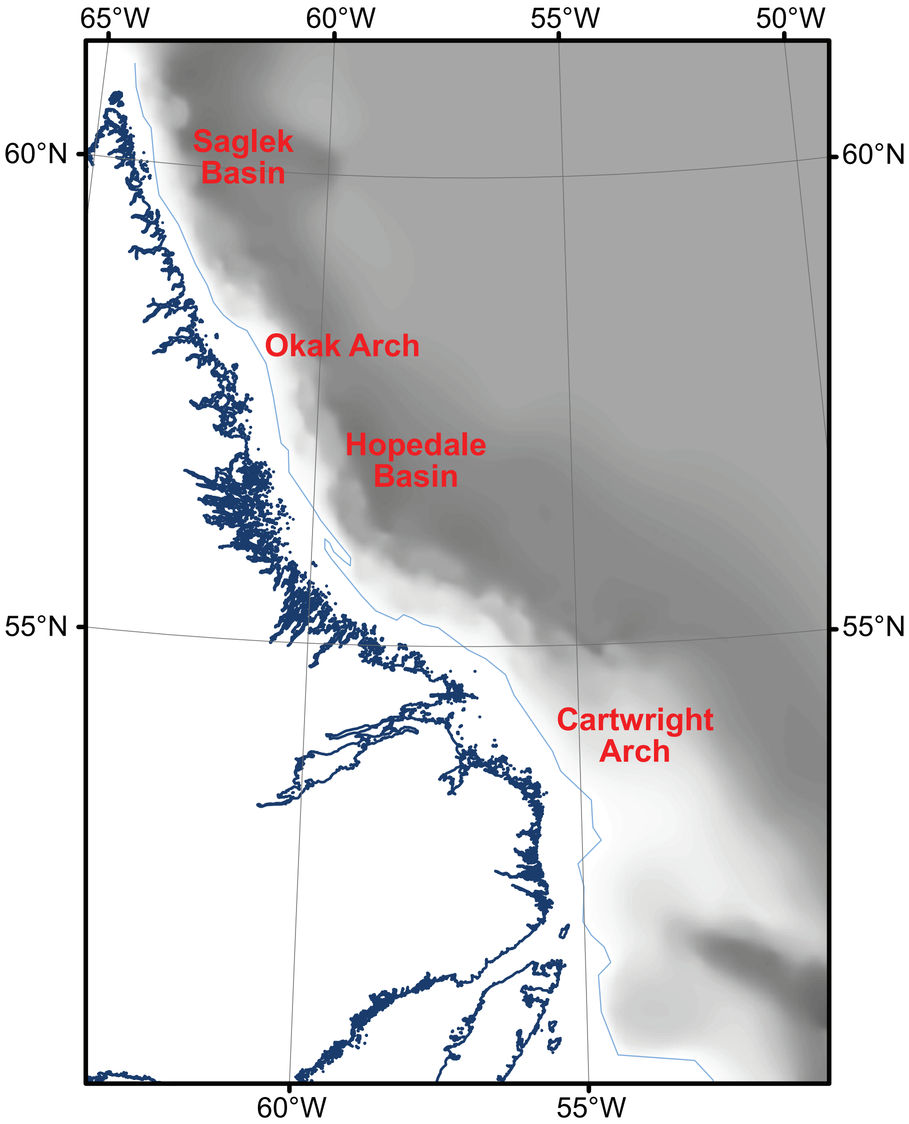

Figure 20. Labrador location map. Depths estimated by interpolation from depth-to-basement contours from *Grant* (1990).

7.5.3 Gudrid Play COS Mapping

The Gudrid Formation exhibits very high net-to-gross ratios and moderate to high porosities, at its best containing more than 200 m of medium to coarse-grained sandstone and conglomerate with porosities averaging 21-25% (*Carey et al.*, 2020). Reservoir COS for the Gudrid play was taken from *Carey et al.* (2020) except where it was anticipated to be at a depth of less than 800 m based on unpublished top Gudrid maps from the MCT program. The highest COS was where *Carey et al.* (2020) were able to map sand facies seismically from well control, which includes an extensive area of the southern Labrador shelf (Figure 22a). Moderately high potentials were assigned to areas of the undrilled continental slope downdip of known Gudrid sand accumulation. The northern shelf and more distal areas of the slope are expected to have low COS, as is the inner shelf where the Gudrid is shallow if present (Figure 22a).

The Gudrid Formation is overlain by the Kenamu Formation, an organic-rich shale typically hundreds of metres thick which should provide a good seal. Seal COS was derived verbatim from the mapping of *Carey et al.* (2020). COS for seal was high wherever Kenamu could be tied seismically to a thick shale package in the wells, which was most of the central and southern Labrador shelf (Figure 22b). The COS was lower in Northern Labrador where the lower Kenamu tends to be sandier, and on the slope, where the sedimentary facies present is uncertain (*Carey et al.*, 2020).

Trap COS was assessed in the same way as for the underlying Bjarni Formation. However, as it is shallower and not confined to structural basins, risk of migration to the subcrop edge in the Labrador Marginal trough was greater than for the Bjarni (compare Figure 21c and Figure 22c). Areas where the Kenamu and Cartwright sections were faulted were also deemed a potential seal risk, limiting the potential of the upper slope, but a large area of the shelf and slope remains with high COS for trap (Figure 22c).

Considering all three factors, the Total COS in the Gudrid is high for extensive areas of the middle to outer shelf in central and southern Labrador (Figure 22d). Potential on the slope is moderate, largely due to high uncertainty, and while the potential on the northern shelf and inner shelf is low (Figure 22d).

7.5.4 Leif Play COS Mapping

Core analysis data are limited for the Leif Member but existing information suggests excellent reservoir characteristics with samples ranging from 28 to 32% porosity and 65 to 250 mD of permeability (*Carey et al.*, 2020). Petrophysical analysis suggests that these porosities may be typical of sand bodies in the Leif Member, which commonly occur as relatively thin but widespread sheets (*Carey et al.*, 2020). Reservoir COS was characterized for the Leif Member in a similar fashion to the other plays, with use of the values from *Carey et al.* (2020) unless seismic mapping indicated that it was likely to be too shallow for supercritical injection. COS for reservoir was highest where well control indicated the presence of significant sand bodies (Figure 23a). Reservoir COS was inferred by *Carey et al.* (2020) to be less on the slope, with the exception of an area of thick Kenamu-equivalent sediments downdip of the best developed shelf sands (Figure 23a).

The Leif Member sands fall within a thick shale-dominated package and are, therefore, generally associated with good seals. *Carey et al.* (2020) assigned high values for seal almost everywhere for the Leif Member except the inner shelf (Figure 23b).

COS for trap was assigned in a similar way to the underlying plays and the resulting map bears a close resemblance to that for the Gudrid play (compare Figure 22c and Figure 23c). The principal difference is that the subcrop edge is estimated to be a little farther seaward making inner to mid-shelf traps slightly riskier.

The Leif Member is estimated to have moderate to high sequestration potential through most areas of the shelf where well and seismic data are plentiful (Figure 23d). It is seen as less prospective for the slope, except in the far southwest (Figure 23d).

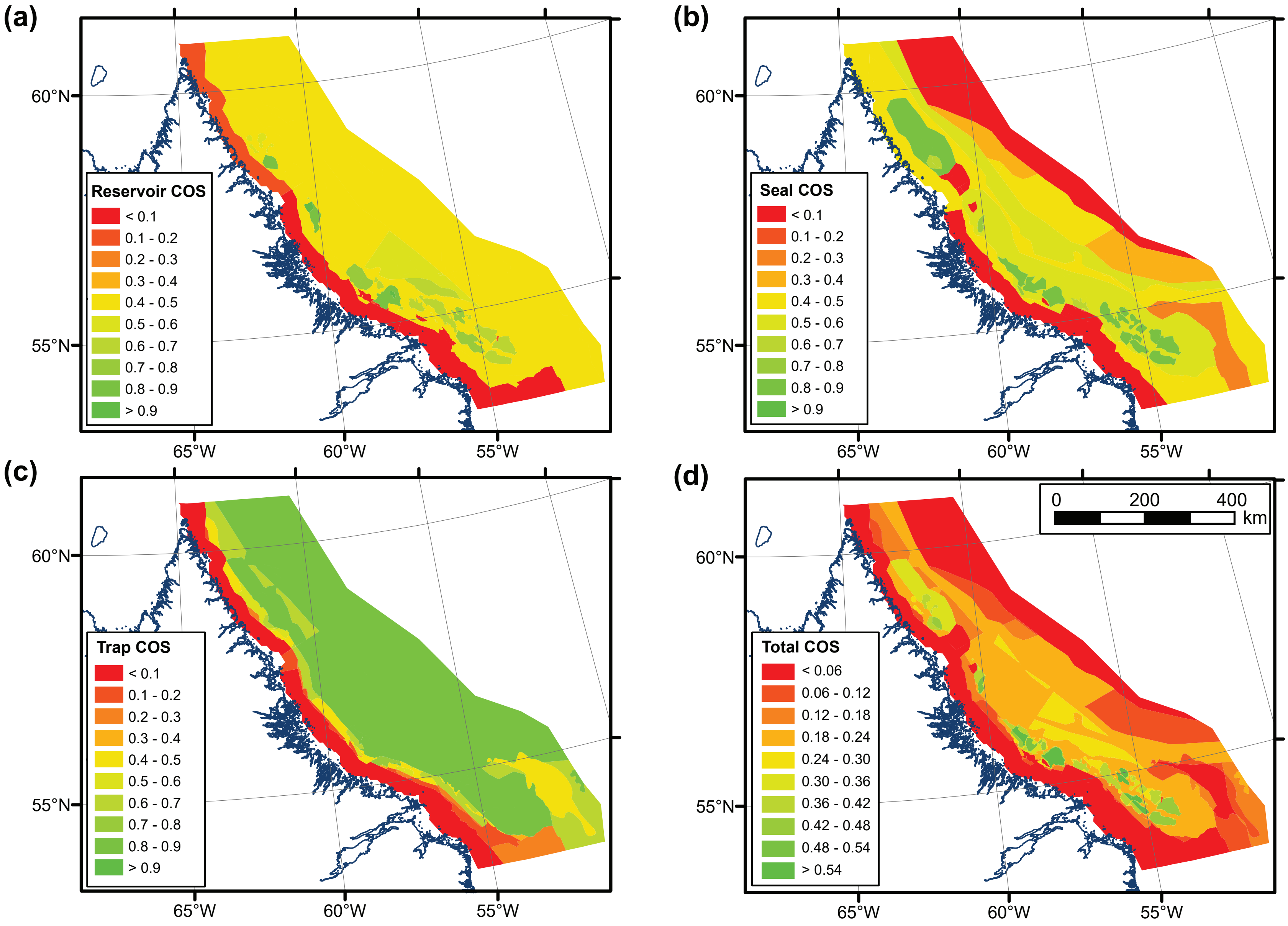

Figure 21. COS maps for the Bjarni play.

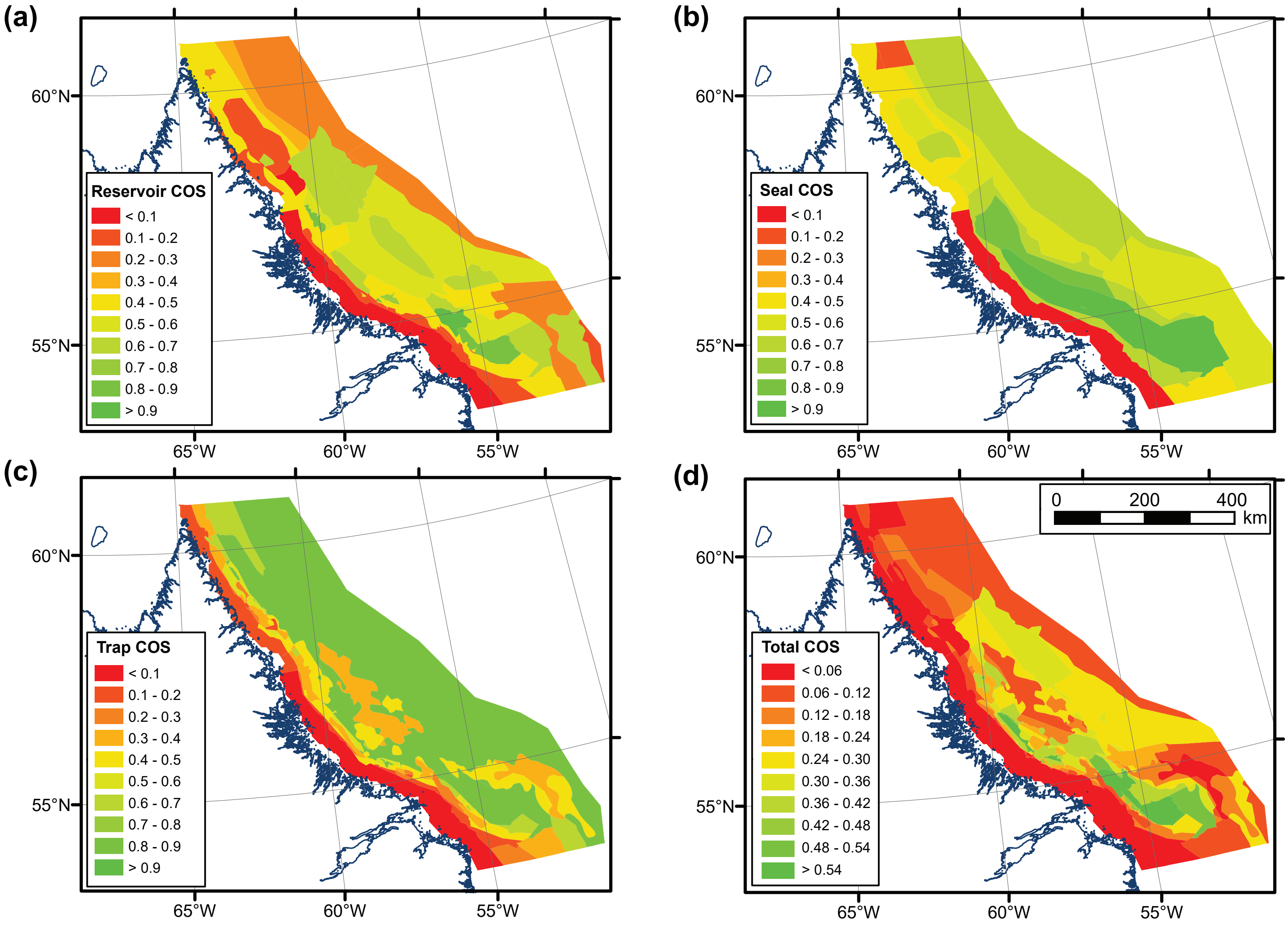

Figure 22. COS maps for the Gudrid play.

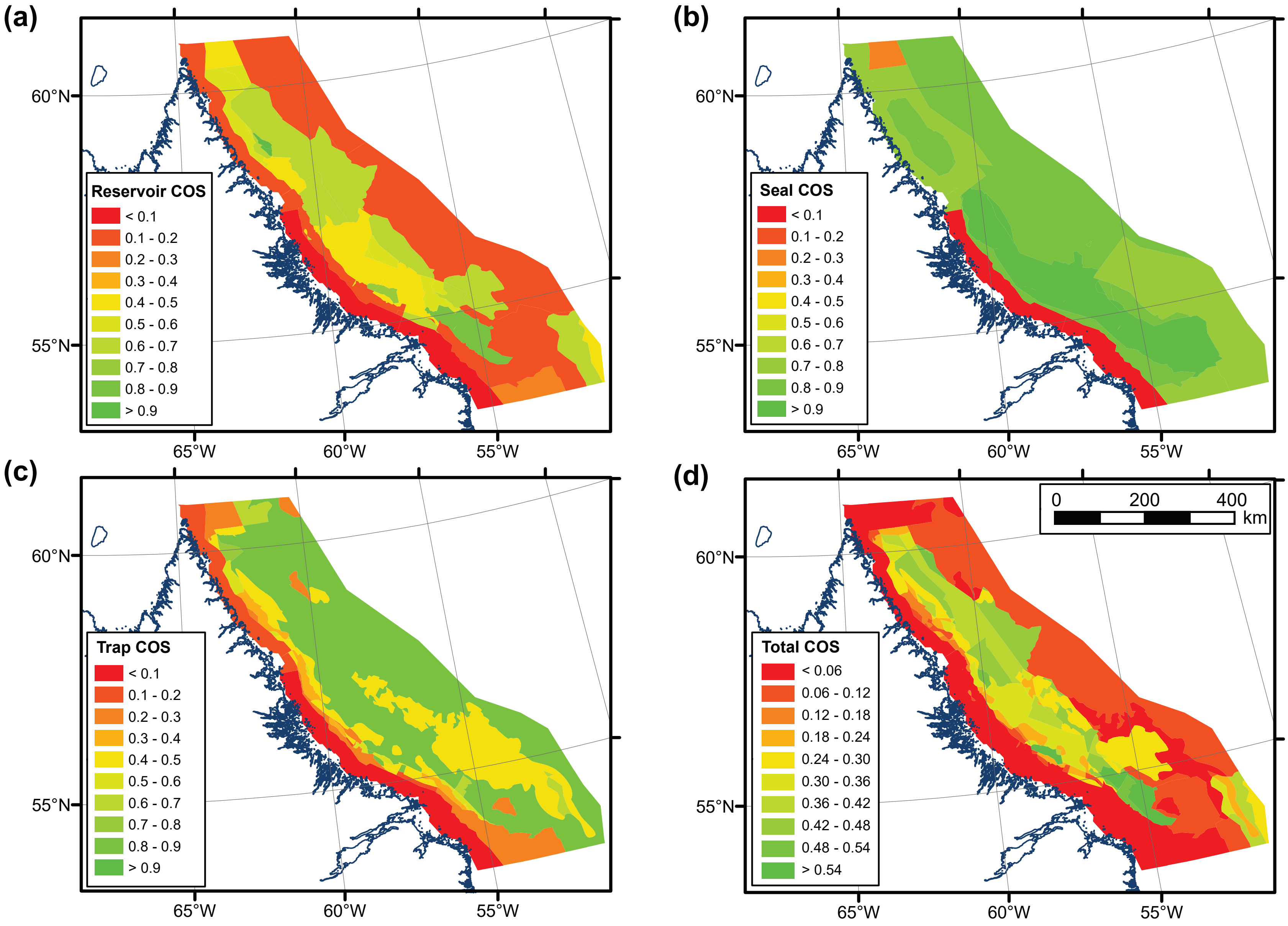

Figure 23. COS maps for the Leif Member play.

8 Basalt in the context of CCUS

Discussion surrounding the use of basalt as a GCS reservoir has grown significantly in recent years. The major advantage of basalt, compared to most sedimentary rocks, is that the $(Ca,Mg,Fe)^{2+}$-rich minerals common to mafic (and ultramafic) rocks readily react with CO_2 to form carbonate minerals, potentially mineralizing the vast majority of injected CO_2 in just a few years (*Matter et al.*, 2016). Mineralization of the CO_2 mitigates the risk of leakage to the surface, lessening the importance of long-term monitoring at injection sites. Some of the advantages, as well as challenges, of basaltic reservoirs for GCS are reviewed by *Raza et al.* (2022).

The modest scale of most basaltic reservoirs, their relatively limited porosity and permeability, as well as a relative paucity of available data on these critical properties (and how they are affected by CO_2 mineralization), all pose challenges to potential basalt-GCS projects. To date, the most significant basalt-GCS operation is the CarbFix pilot project in southwest Iceland (*Gunnarsson et al.*, 2018), which currently stores $\sim$12 kt y^{-1} of CO_2 (*Snæbjörnsdóttir et al.*, 2020). In 2013, there was also a smaller pilot project, in Wallula, Washington, USA, that injected nearly 1 kt of CO_2 into the Columbia River flood basalts (*McGrail et al.*, 2014). Technical aspects of these operations will not be discussed here—instead we refer to the review by *Snæbjörnsdóttir et al.* (2020) and references therein—but we note that their injection rates are orders of magnitude smaller than those at the largest GCS operations in sedimentary reservoirs, which are $\sim$1 Mt y^{-1}. In part because of this discrepancy, this report only briefly tabulates basalt formations found throughout in the Maritimes Basin to facilitate future investigations, should they become warranted. We also note that there is speculative interest in using ocean-floor pillow basalts, i.e. Layer 2A, as a reservoir for GCS (e.g. *Goldberg et al.*, 2018; *Columbia World Projects*, 2021). However, in Atlantic Canada, the several-kilometres-thick sedimentary sequences overlying the nearest oceanic crust, as well as the long transit distances just to reach the continental margin, make ocean floor basalts an impractical target reservoir for GCS, so we disregard them in this report.

Basalts, and other mafic rocks, may be relevant to CO_2-mitigation strategies outside the context of direct GCS. In particular, there is growing interest in the use of pulverized basalt as agricultural fertilizer or soil conditioner, accelerating natural CO_2-adsorption through enhanced rock weathering (ERW, *Beerling et al.*, 2020; *Lehmann and Possinger*, 2020; *Goll et al.*, 2021). Evaluating the suitability of the mafic rocks in Atlantic Canada for agricultural application is beyond the scope of this report; it would require the determination of 1) their effectiveness as a fertilizer, 2) their potential for causing heavy metal contamination (*Choi et al.*, 2021), and 3) the overall carbon budget of pulverization and application (versus that of traditional fertilizers). However, because of this potential application, we will briefly summarize smaller basalt formations even if they have no potential to be a conventional GCS reservoir.

8.1 Basalts in Atlantic Canada

Figure 24 maps known occurrences of volcanic rocks within the Maritime provinces, and Figure 25 indicates stratigraphic position of the Devonian and Carboniferous units, notably excluding the much younger (Jurassic, $\sim$200 Ma) North Mountain Basalts (*Kontak*, 2008). In this section, we identify the stratigraphic intervals in which basalts have been noted, even where their lateral extent may be limited or unknown, and briefly comment on their potential CCUS applications.

This section ignores Newfoundland and Labrador almost entirely. Although mafic and ultramafic rocks are relatively common in Newfoundland (*Colman-Sadd et al.*, 2000), they are mainly older—Neoproterozoic to Ordovician—and less therefore likely to have significant porosity. Likewise, Labrador contains a variety of Precambrian mafic rocks, and neither region has sufficient agricultural activity to warrant discussion of ERW application in this report.

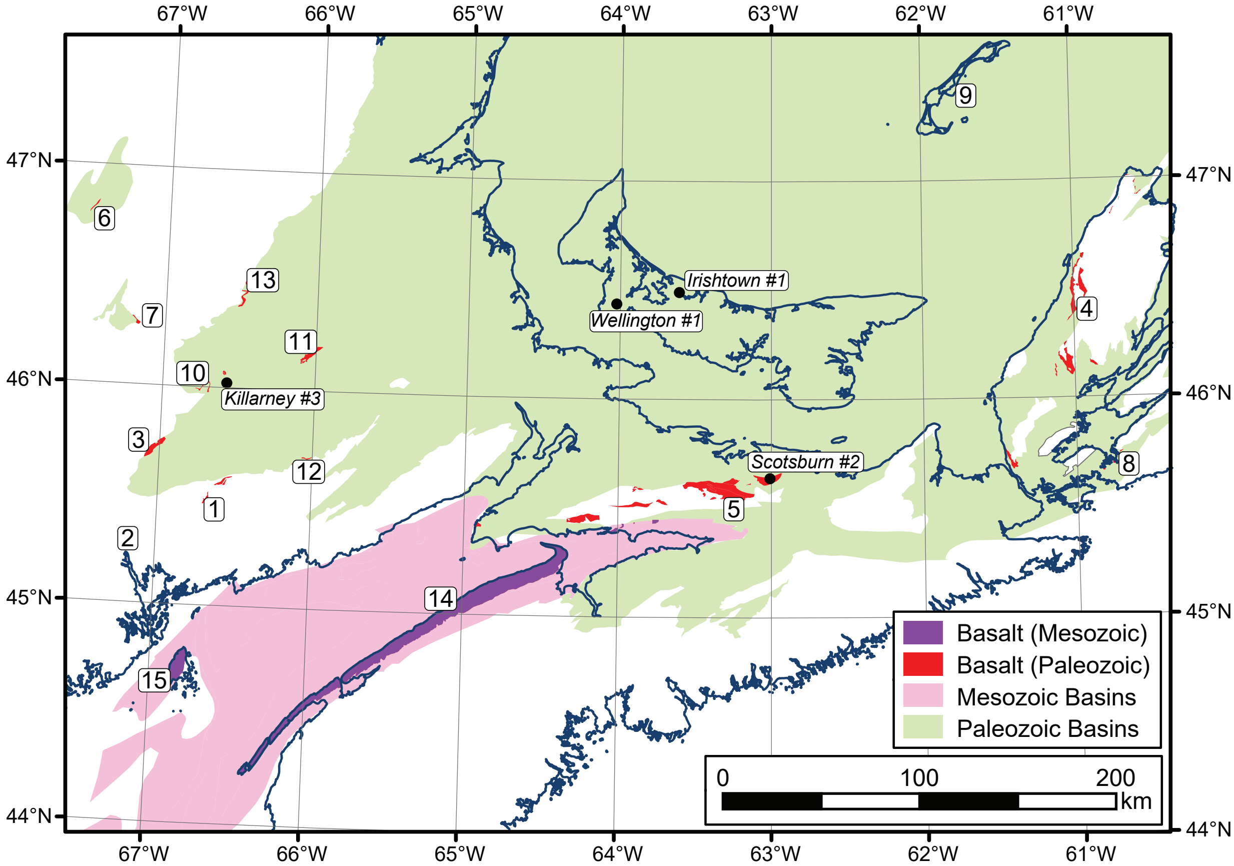

Figure 24. Map of known occurrences of volcanics within the Maritimes and Fundy basins. 1: Piskhegan Group, 2: Perry Formation, 3: Harvey Group, 4: Fisset Brook Group, 5: Fountain Lake Group, 6: Gladwyn Mafic Flow, 7: Carlisle Basin, 8: St. Peter's Gabbro, 9: Îles-de-la-Madelaine Basalts, 10: Royal Road Mafic Flow, 11: Hardwood Ridge Mafic Flows, 12: Queenston Mafic Flows, 13: Boiestown, 14: Grand Manan Island, 15: North Mountain Formation.

8.1.1 Fisset Brook Formation (Fountain Lake Group)

Bimodal volcanic rocks interbedded with red siltstones and sandstones characterize the Fisset Brook Formation. They lie unconformably on pre-Carboniferous rocks and are overlain in contiguous sections by Horton Group strata (Figure 25). They occur in two outcrop belts in western Cape Breton Island, extending more than 30 km from the Cheticamp vicinity towards the southwest, reaching Lake Ainslie (Figure 24). Fisset Brook volcanics, including basalts reaching 20 m in local thickness, are also known from the western shores of St. Georges Bay, in the Cape George area, where their distribution is much more limited. The total thickness of mafic volcanics is $\lesssim$400 m, with $\lesssim$100 m of younger, felsic volcanics. The mafic rocks were estimated to be late Famennian in age by miospore assessment (*Martel et al.*, 1993). However, with U–Pb dating (*Dunning et al.*, 2002) estimated slightly older ages of 374–370 Ma, with one younger rhyolite reported at 365 Ma, indicating an age span of early-to-late (but not latest) Famennian.

CCUS Assessment: Low GCS potential due to relatively limited thickness of closely spaced basalts and very limited understanding of their subsurface distribution. Modest potential may exist for agricultural ERW applications, although there is little agriculture in western Cape Breton.

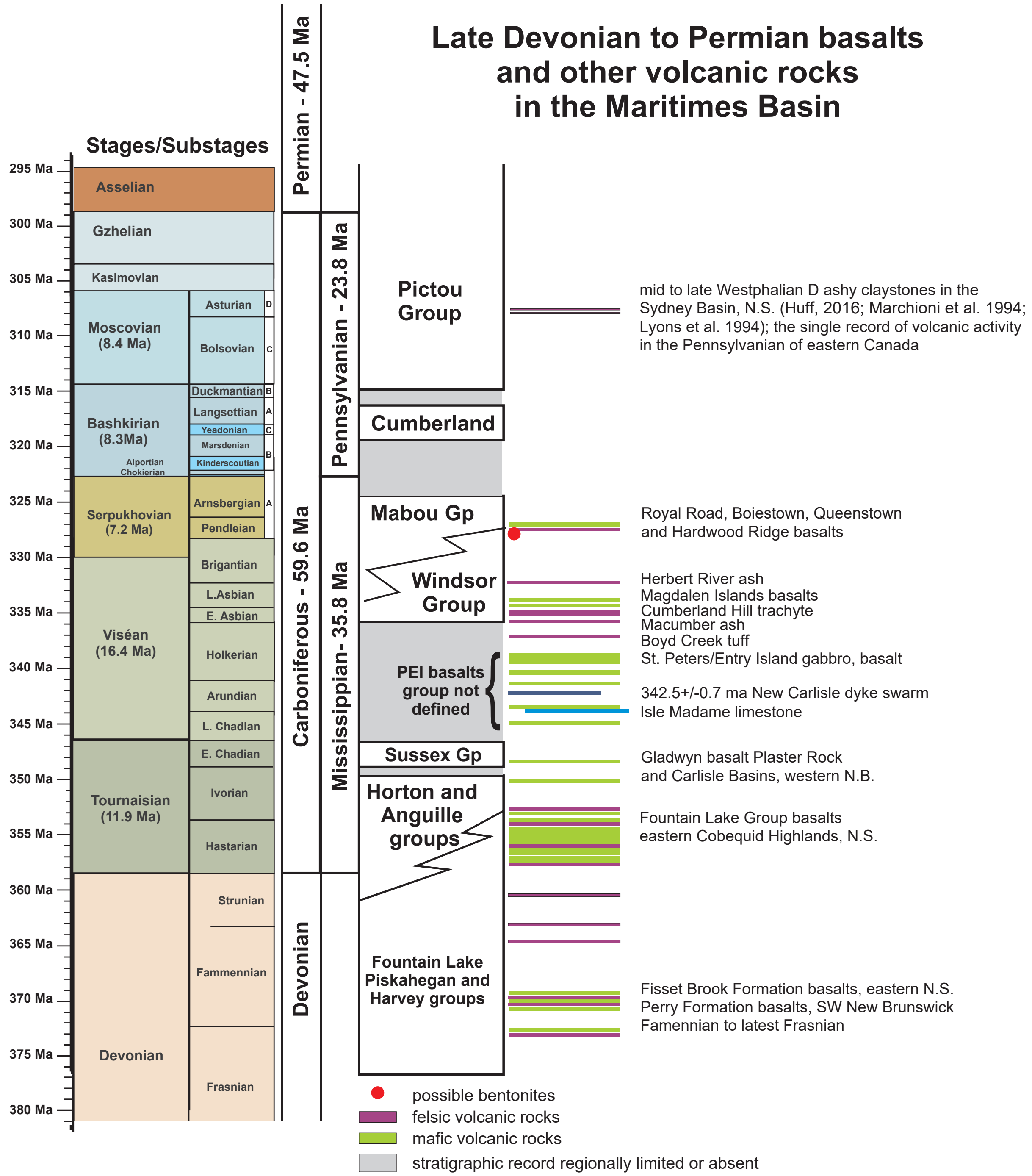

Figure 25. Simplified Devonian–Carboniferous stratigraphy of the Maritimes basin with volcanic units highlighted.

8.1.2 Diamond Lake and Byers Brook Formations (Fountain Lake Group)

Volcanic rock units, with relatively minor associated sedimentary rocks, outcrop in the eastern Cobequid Mountains of Nova Scotia and were drilled in the Scotsburn #2 well (*Utting et al.*, 1989, Figure 24). Mafic volcanics cover 100 km^2 and have a minimum thickness of 2000 m, and there is an additional $\leq$200 m of felsic volcanics in aggregate thickness. The Scotsburn #2 well sits in the center of an anticline, such that although it encounters the top of the basalts near-surface, seismic reflection surveys indicate that that top of the volcanics deepens in all directions, and reaches almost 6 km depth under at the Northumberland Strait shoreline, 20 km to the northeast (*Durling*, 1997, 2023). The upper Diamond Lake Formation is interbedded with gray to black shales bearing miospore assemblages comparable to those of the middle Horton Bluff Formation (middle Tournaisian, Ivorian, *Utting et al.*, 1989). Ages for rhyolites outcropping with associated basalts from both formations found no material older than the lowest Tournaisian (circa 358 Ma, *MacHattie*, 2018) although *Martel et al.* (1993) have alluded to possible Famennian miospore assemblages in the Diamond Lake Formation. If accepted, the latter ages would be inconsistent with the oldest U–Pb dates from the Byers Brook Formation (358 Ma and still within the Tournaisian, *MacHattie*, 2018) which underlies the Diamond Brook. Only the upper part of the Byers Brook Formation has been dated, so a Famennian age is possible for lower volcanic rock units at that stratigraphic level.

In western Newfoundland, recent work has identified a basalt in the Tournaisian Anguille Group comparable in age to those of the Fountain Lake Group (*Hinchey et al.*, 2022). The basalt is reported from a single locality in the Deer Lake Basin. Minor basaltic tuffs are associated. These volcanic rocks have very uncertain lateral extent and are less than 10 m in thickness. To date they are the only volcanic rocks identified within the entire Carboniferous succession in western Newfoundland.

CCUS Assessment: The thickness and depth extent of these basalts in the eastern Cobequid Mountains makes them potentially suitable for GCS. Further assessment of GCS potential, including porosity and permeability analyses, is currently lacking. There is a significant industrial CO_2 emitter—a cement plant at Brookfield, Nova Scotia— approximately 20 km from the main basalt location and the Scotsburn #1 wellhead. Use for ERW is plausible, although there is limited nearby agricultural activity due to the relatively poor and thin soils in the area of the Cobequid Mountains.

8.1.3 Gladwyn Basalt (Sussex Group)

A single basalt flow, 20 m thick, is observed in outcrop in western New Brunswick, near the communities of Carlisle and Plaster Rock (Figure 24). Its surficial extent is unknown, but probably limited. No subsurface occurrences have been documented. It lies uncomformably on lower Paleozoic rocks in the Plaster Rock basin. We interpret its age to be late Tournaisian and assign it to the Sussex Group.

CCUS Assessment: No GCS potential as it is extremely limited in extent and thickness. Its volume is potentially sufficient for modest, local ERW applications.

8.1.4 PEI basalts (Viséan Succession, group unidentified)

As many as nine basaltic flows are intersected in the Wellington #1 and Irishtown #1 wells in western Prince Edward Island (Figure 24). The top five flows are form an 80% basalt, 20% sedimentary interval with a thickness of 175-195 m, whereas the total basalt-bearing interval approaches 1500 m in thickness *Giles and Utting* (1999). Seismic reflection signatures suggest the basalts are laterally continuous between the two wells and further westerly within bounding fault traces; otherwise the volcanic rock distribution is unknown. The youngest basalts are interpreted as middle Viséan in age (probably 339–340 Ma) and comparable to basalts exposed at St. Peters on Cape Breton Island. Ages were estimated by scaling the thickness of the basalt-bearing section to the time represented from the base-Windsor (at the beginning of the late Viséan) to the top of the underlying Sussex Group set (at the start of the Viséan).

CCUS Assessment: Modest potential for GCS, although there are no obvious CO_2 point sources on western Prince Edward Island that might motivate further investigation. No ERW potential given that there are no confirmed surface exposures.

8.1.5 St. Peters gabbro and basalt (Viséan Succession, group unidentified)

Gabbro is exposed at St. Peters, at Corbetts Cove, and in the Chapel Island area of southern Cape Breton Island (Figure 24); associated basalts much more poorly seen. The gabbros are briefly described by *Barr et al.* (1994), with emphasis on radiometric dating, and are basalts noted but no stratigraphic details are provided. Stratigraphic relationships indicate an unconformable relationship between the gabbro, dated at 339 ± 2 Ma, and the basal Windsor limestone. A similar age is reported from I'sle d'Entrie in the Magdalen Islands (M.C. Williamson, personal communication) where a small gabbroic body supposedly was emplaced by salt diapirism. Since this age predates deposition of the thick lowest Windsor Group salts, concurrent diapiric involvement of Sussex Group evaporites (late Tournaisian) with Windsor Group diapiric salt movements could explain the presence of this gabbro body on the Magdalen Islands beside Windsor Group diapiric-remnant stratigraphy (see below).

CCUS Assessment: Most of the occurrence is gabbroic; there is little information available on the thickness or extent of basalt, but we expect it to be very limited, and as such there is no significant GCS potential. Its location on Cape Breton Island is not favourable for any extensive ERW application.

8.1.6 Magdalen Island basalts (Windsor Group)

Two intervals of basalt outcrop on L'Isle Harvre aux Maison in the Magdalen Islands (Les Îles-de-la-Madelaine, Quebec, Figure 24), each >200 m thick and interbedded with fossiliferous marine rocks of late Viséan age. Their distribution is limited, and they have been extensively quarried for local aggregate. Their chemistry is well documented (*Barr et al.*, 1985; *La Flèche et al.*, 1998), and their age is biostratigraphically constrained by miospores and conodonts to be late Viséan, with assignment to the B Macrofaunal Subzone (*Giles*, 2008). However, extensive alteration has hindered attempts to date these rocks radiometrically, and they are structurally complex due to emplacement by diapiric salt.

CCUS Assessment: Low GCS potential; although extent of basalt at depth is unclear, the scale of the basalt outcrop at the surface is not substantial. They conceivably have potential to be used as a local source of basalt for ERW application on the Magdalen Islands.

8.1.7 Royal Road basalts (Mabou Group)

The Royal Road basalts are best seen at the Royal Road quarries NNW of the city of Fredericton, New Brunswick (Figure 24). Their total thickness there is uncertain, but at the Killarney #3 well drilled just ∼10 km to the east, >180 m of aggregate thickness of basalt was intersected with minor interbedded red sedimentary rocks, to a maximum depth of ∼280 m . Their age is biostratigraphically constrained by miospores to be latest Viséan to early Namurian, although no radiometric dating has been attempted. The basalts are underlain by a thin felsic tuff at Hardwood Ridge which has been dated at 327.7 Ma (*Jutras et al.*, 2018). The basalts seen at the Royal Road quarries are also exposed at Boisetown, Queenston, and Hardwood Ridge in southern New Brunswick. The widespread distribution and possible lateral correlations suggest that a considerable body of volcanic rock may be associated at this stratigraphic level.

CCUS Assessment: The basalts have low GCS potential as their subsurface extent may insufficient, and in particular they are unlikely to extend to sufficient depth for GCS. However, given their relatively widespread surface distribution near agricultural areas of New Brunswick, they may have potential utility in ERW applications.

8.1.8 North Mountain Basalt (Fundy Group)

The North Mountain Basalt (NMB) is unique in this report both because it is far younger than all the other units we discuss—having been dated at 202 ± 2 Ma (*Hodych and Dunning*, 1992)—and because it has a significantly larger aerial extent. It is best exposed at surface on the southern flanks of the Bay of Fundy, in Nova Scotia, stretching more than 80 km from SW of Digby easterly and northeasterly to Cape Split (Figure 24). The basalts along this coast have been described in detail by *Kontak et al.* (2002) and *Kontak* (2008), who divide them into three main units: the lower (East Ferry) member, the middle (Margaretsville) member, and the upper (Brier Island) member. Whereas the lower and upper units are massive, the Margaretsville Member is highly vesicular—it is rich in zeolite amygdules and known to local mineral collectors for its agate and amethyst, typically found in the uppermost flows. The Margaretsville member has maximum observed thickness of ∼170 m out of a aggregate NMB thickness of ∼500 m, although the local NMB thickness averages only 250 m along its strike length (*Kontak*, 2008).

Structurally, the NMB sits in a large, SW-plunging syncline, which produces the hook shape ridge at Cape Split, Nova Scotia (*Withjack et al.*, 2009). Seismic profiles allow us to follow the NMB offshore, to the NW from western Nova Scotia, down the syncline to depths of ∼1 km under much of the central Bay of Fundy (*Wade et al.*, 1996). The northwestern arm intersects the the Cobequid-Chedabucto fault system, and smaller scale folding, producing much more complex structure and variable NMB depth in the western Bay of Fundy. Seismic reflection surveys and borehole intersects indicate an NMB depth of ∼200 m near Saint John, New Brunswick, but a depth of ∼2 km near Salmon River, New Brunwsick, 60 km to the NE (*Wade et al.*, 1996).

CCUS Assessment: The lateral extent, thickness, and depth of the NMB under the Bay of Fundy an attractive target for further investigation into its potential as a GCS reservoir. To our knowledge, no porosity or permeability measurements of NMB exist, but the middle, Margaretsville Member may have sufficient porosity and permeability for GCS applications despite the infilling of vesicles with zeolites. There is also a nearby point-source CO_2 emitter in the major oil refinery of Saint John, New Brunswick.

The greatest potential of the NMB may be for ERW applications, as they parallel the Annapolis Valley, which is host to a significant portion of the agriculture in Nova Scotia. Notably, Kings County, which contain the eastern portion of the NMB, has the most agricultural land and the highest rate of arable land use for agricultural production in Nova Scotia (*Devanney*, 2010). *Prime* (2008) have previously discussed the potential benefits of using NMB rock dust as a fertilizer. Bulk and trace chemical analyses of the NMB may be warranted, in order to determine its suitability for agricultural ERW application, including the CO_2-adsorption potential.

9 Conclusions

GCS is projected to play a significant part in Canada's carbon emission reduction goals (*Environment and Climate Change Canada*, 2022). Although all currently active Canadian GCS projects are located in Western Canada, this report highlights the potential for GCS in deep saline aquifers and basalts in Atlantic Canada. In view of the limited capacity for GCS in nearby Ontario and Quebec, which are major carbon emitters, GCS in Atlantic Canada could play an important role in Canada's drive to achieve its climate goals.

The Paleozoic sedimentary rocks onshore in Atlantic Canada tend to have modest permeability and porosity, which will limit their capacity and ability to support high injection rates. Nevertheless, potential reservoir targets for smaller projects to store carbon emissions from local industries in Atlantic Canada were identified through COS mapping of late Paleozoic basins in the Maritime Provinces. These include the Horton Group in southeastern New Brunswick and south of the Minas Basin in Nova Scotia, the Cumberland Group in northern Nova Scotia and western Prince Edward Island, and the Pictou Group in parts of Prince Edward Island. COS mapping was not completed for onshore Newfoundland in this study, but some potential likely exists there, as well, particularly in the early Paleozoic rocks of western Newfoundland.

Mesozoic-Cenozoic basins underlie a vast expanse of Atlantic Canada's offshore area. COS mapping completed indicates potential for the Wolfville Formation beneath parts of the Bay of Fundy, and several reservoir-seal targets on the Scotian Shelf and Labrador Margin. The Sable Sub-basin on the central Scotian Shelf is particularly attractive because its geology is comparatively well understood due to past seismic surveys and drilling for petroleum exploration and production. Six intervals were evaluated for this study; the middle Missisauga, upper Missisauga and Logan Canyon Formations are prospective over a large part of the central Scotian margin. COS maps were not made for the basins around Newfoundland for this study, but most of the offshore basins likely have significant GCS potential. Reservoirs with high permeability and porosity overlain by marine shales to trap CO_2 are common in Atlantic Canada's offshore basins. The Mesozoic-Cenozoic basins have the capacity and injectivity to sequester a significant portion of eastern Canada's future carbon emissions.

Late Paleozoic and Mesozoic basalts in the Maritime provinces also have potential for GCS. The most promising sites for GCS through injection are the North Mountain Basalt north of the Annapolis Valley and the Fountain Lake Group basalts in the eastern Cobequid Highlands, both in Nova Scotia. Agricultural application of crushed basalt can result in passive sequestration of atmospheric CO_2 through the creation of carbonate minerals by weathering. The most promising rocks for this purpose in Atlantic Canada are the North Mountain basalt in Nova Scotia and Mabou Group basalts in New Brunswick because of their widespread lateral extent and proximity to agricultural regions.

This study highlights the geological suitability of several GCS "plays" in Atlantic Canada but considerably more work is required to assess their viability and identify prospects. Geological uncertainty is considerable due to limited subsurface data information for much of the region. Further work is required to determine the likely capacity and injectivity of onshore saline aquifers and basalts, and geochemical characterization of the basalts would be needed to assess their suitability for agricultural application. More detailed mapping, modeling work, and seismic risk assessment are needed to evaluate the long-term safety of GCS reservoirs in the region. In addition, assessment of the geographic variation in factors such as drilling costs and distance from infrastructure and CO_2 sources is necessary to establish the economic viability of potential projects.

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Appendix: Upper Paleozoic COS Mapping by AOI

This appendix summarizes the data sources and assumptions used for generation of COS maps for subregions of the Maritimes Basin outside the Magdalen AOI, which was mapped and discussed in detail by *Atkinson et al.* (2020). The AOIs are discussed in alphabetical order (Figure 5) except for the Windsor AOI, where more detail is provided as an example to illustrate our approach. Detailed maps of each AOI, including the features used to determine their boundaries, are not presented here; the reader is referred to the geological literature for their definition and description. Regional scale COS maps are presented in Figures 6 and 7. The objective of this study was to provide a broad regional picture of GCS potential for Atlantic Canada. Therefore, large-scale maps focused on individual AOIs are not presented, for they would imply a greater level of certainty and precision than intended. Additional details of how individual polygons values were assessed are also available in the attached shapefiles. For details on the locations of faults, geologic mapping and structures described in the text, the reader is directed to the published sources cited.

The current COS evaluation relies on a very simplified view of the stratigraphy. However, given the paucity of well control and limited quantity and quality of seismic, any more sophisticated treatment of the basin fill would need to rely on conceptual models, except in parts of the Moncton AOI. Table A-1 summarizes the size of the AOIs and available well control for assessing reservoir and seal quality at the depths required for supercritical injection of CO_2. The ”wells per township” value is reported to assist readers familiar with Western Canada to evaluate well density in Atlantic Canada. For comparison, there are approximately 459,000 wells drilled in Alberta, which is divided into 7098 townships, approximately 64 wells per township.

Where available, time structure maps from published and unpublished sources were compiled to assess reservoir depth for the various group-level reservoirs evaluated during this study. The time structure maps were converted from time to depth using the depth conversion function in Kingdom Suite software. The specific velocity functions used in different structural basins are described within the sections on the relevant AOIs. In other cases, depths to prospective reservoirs were estimated from published cross-sections or the outcrop patterns from the geologic maps combined with descriptions of the thicknesses of the mapped formations. Provincial geologic maps for Nova Scotia (*Keppie*, 2006) and New Brunswick (*Langridge*, 2008) were used for these assessments. For Prince Edward Island, a map was created by combining subsurface geologic mapping (*Giles and Utting*, 1999) with bedrock geology and dip attitudes (*van de Poll*, 1989).

A-1 Windsor AOI

The Windsor AOI is bounded to the north by the Minas Basin and Cobequid Bay (headwaters of the Bay of Fundy) and to the south by the Roulston Corner Fault and an inverted basement block named the Rawdon Block (*Waldron et al.*, 2010; Figure A-1). It is bounded to the east by the Shubenacadie AOI and the west by pre-Carboniferous basement. The AOI consists of a structural basin filled largely with Horton and Windsor Group strata, although up to 600 m of Cumberland Group strata are present near the centre of the basin (*Waldron et al.*, 2010). The Horton Group in the area is subdivided into the Horton Bluff Formation and an overlying Cheverie Formation (*Martel and Gibling*, 1996).

Depth mapping

Bianco (2013) mapped the top of basement and a seismic marker near the top of the lower Horton Bluff Formation (Horton Group). The basement structure is deepest in the north achieving calculated depths near 3500 m. At the southeast margin of the basin, the Rawdon Fault separates basin strata from the Rawdon block where basement and Horton Group occur at the surface. *Waldron et al.* (2010) interpret the Rawdon Fault as a steep reverse fault, and seismic indicates that the fault is associated with a syncline that affects

Table A-1. Area and well control of Upper Paleozoic AOIs.

Area of Interest	Area (km^2)	Deep Well Penetrations ($>$800 m sedimentary)	Wells per Township (Township ≈ 93.24 km^2)
Antigonish	1733	1	0.05
Bay St. George	2729	6	0.2
Carlisle	180	0	0
Central Cape Breton	1794	1	0.05
Cumberland-Sackville	5168	20	0.36
Deer Lake	1705	2	0.11
Magdalen	97755	32	0.03
Moncton	4341	203	4.36
Musquodoboit	272	0	0
New Brunswick Platform	22356	4	0.02
Plaster Rock	689	0	0
St. Anthony	28261	0	0
St. Mary’s	2491	1	0.04
Shubenacadie	1299	4	0.29
Southeast Cape Breton	1543	2	0.12
Stellarton	924	2	0.20
Sydney	49802	3	0.01
Western Cape Breton	1214	2	0.15
Windsor	1486	9	0.56
TOTAL	225742	292	0.12

the basement surface and overlying basin fill (*Bianco*, 2013). Immediately northwest of the Rawdon Fault occurs a series of relative basement highs that trend southwest to northeast. Depth structure maps were computed from the time maps using the time-depth relationships for various wells presented in (*Bianco*, 2013). The average velocity function for well number 132 was used for depth conversion and is shown below.

$$\text{Depth} = 1000 * (0.18 * \text{TWTT}^2 + 2.087 * \text{TWTT}), \tag{A-1}$$

where TWTT is two-way travel time (in seconds) from the time structure maps and depth is measured in metres. The resulting depth map for Basement is shown in Figure A-2.

Based on the analysis of well data and seismic reflectivity, *Bianco* (2013) subdivided the Horton Bluff Formation into a coarse-grained lower interval and a fine-grained upper interval. The boundary between these two intervals produced a seismic event that could be mapped throughout the Windsor AOI (*Bianco*, 2013). A depth map for the Horton Bluff marker (Figure A-3) was computed using the time-depth relationship described above. Similar to the top of basement structure, this surface is deepest in the north and shallows to the south. The top of the coarse-grained interval is approximately 1400 m depth where it is draped over the basement highs described above. A potential structural trap has more than 50 m of vertical closure with an area roughly 7 km long by 2 km wide.

A time-structure map of the base of the Windsor Group was available through the *Nova Scotia Department of Natural Resources and Renewables* (2017). This map was extended at the basin margins using the results of *Waldron et al.* (2010) and surface geological maps. The latter shows Horton Group at surface

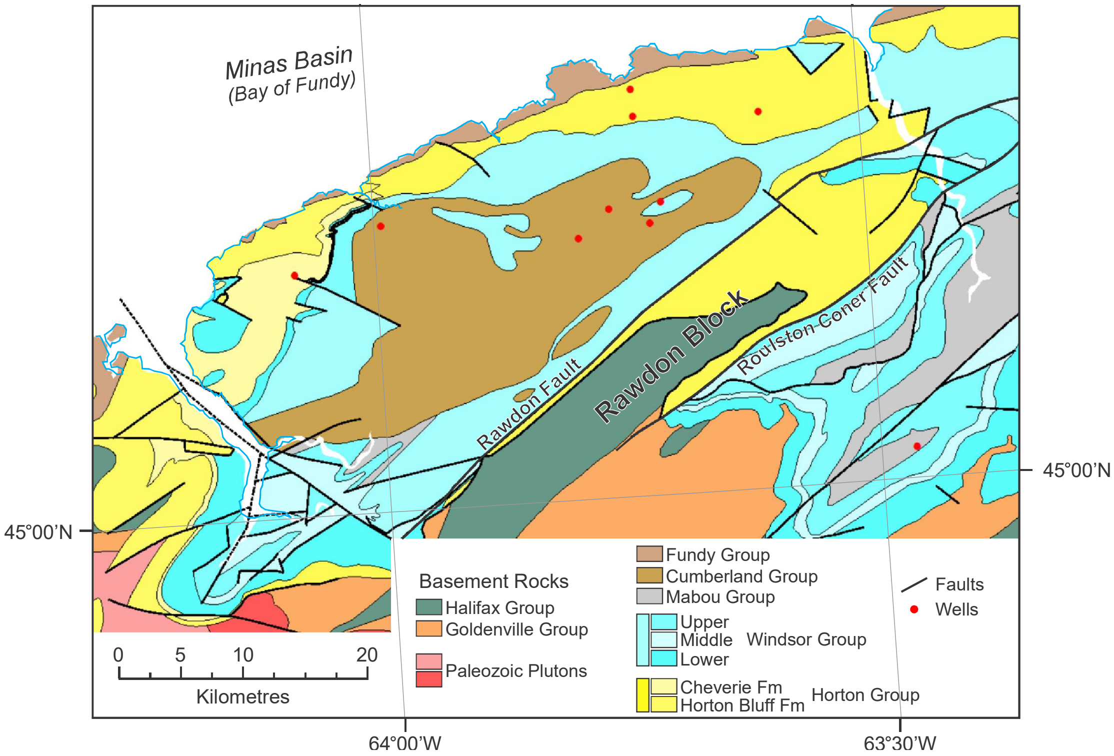

Figure A-1. Geologic map of Windsor AOI and surrounding area depicting bedrock geology and major structures. Modified from *Keppie* (2006).

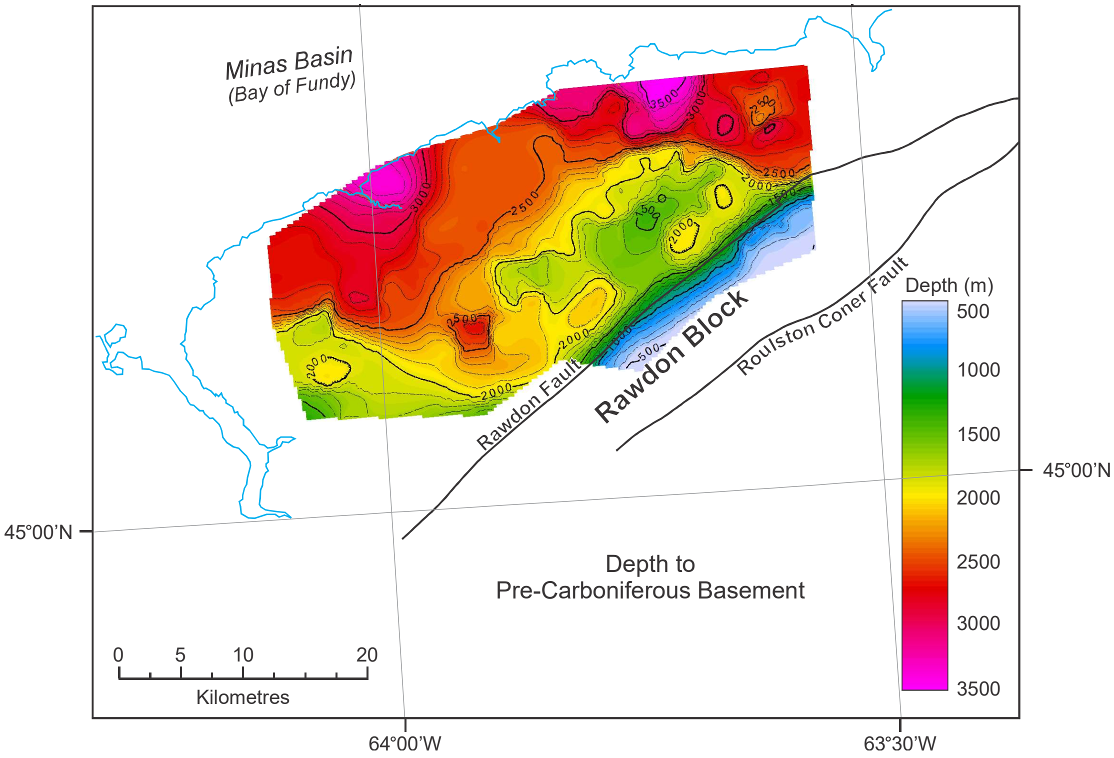

Figure A-2. Depth to pre-Carboniferous basement in the Windsor AOI.

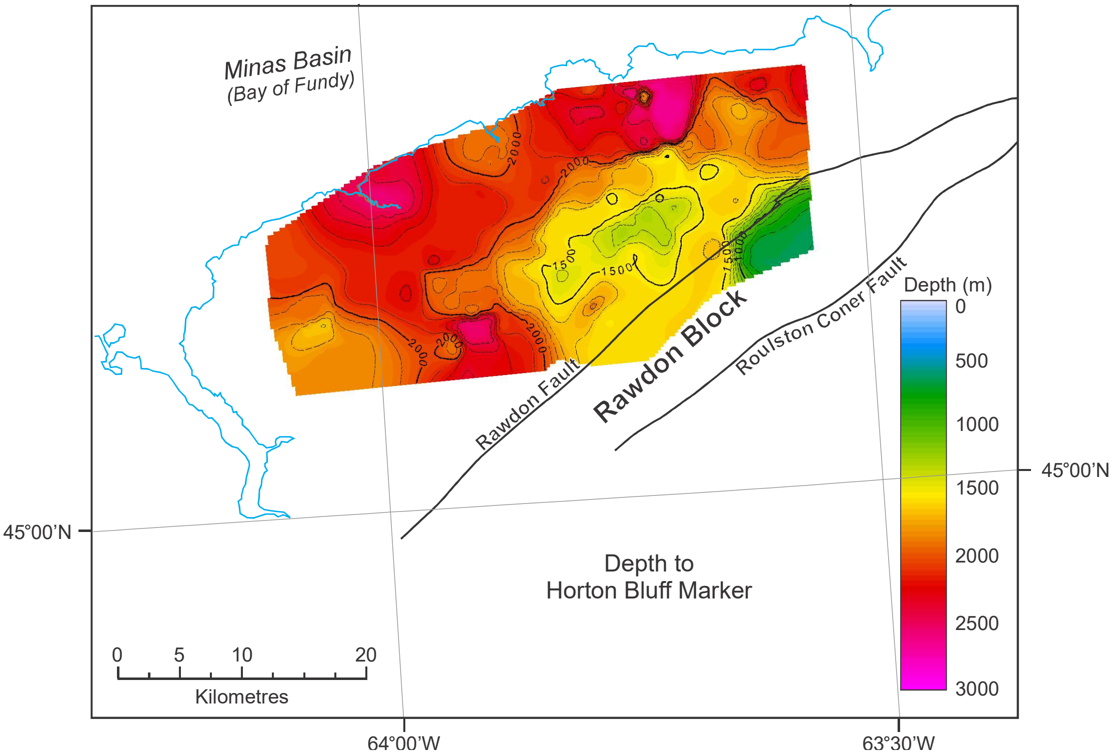

Figure A-3. Depth to the Horton Bluff marker in the Windsor AOI.

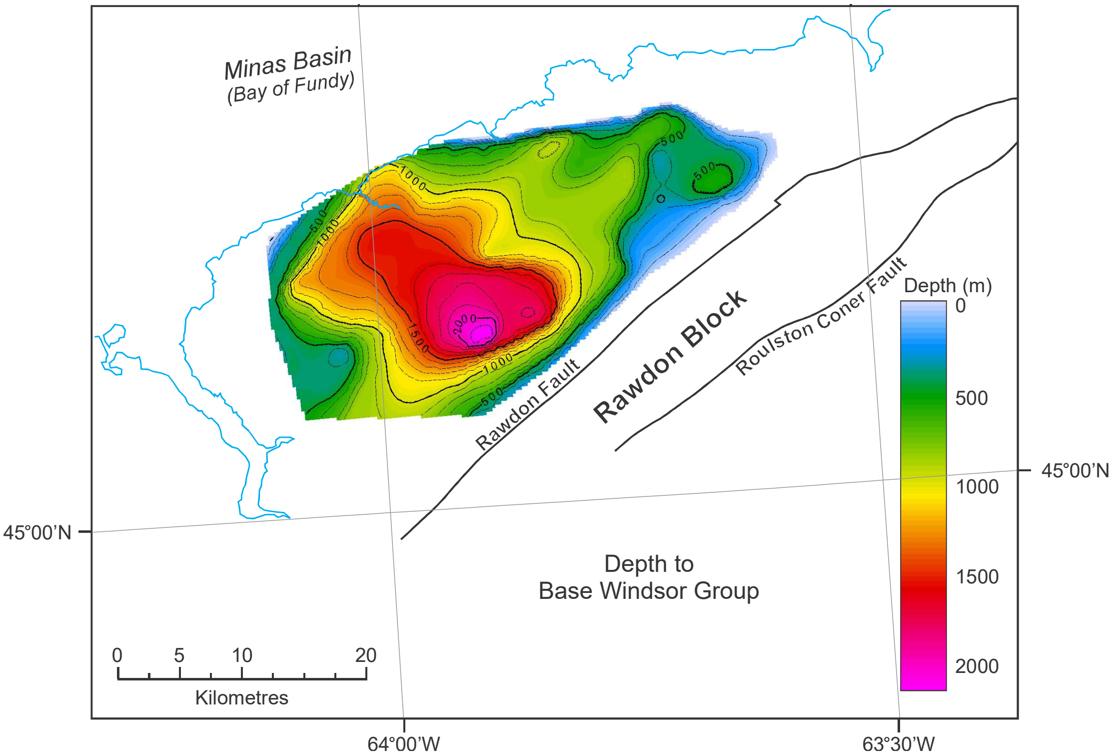

Figure A-4. Depth to the base of the Windsor Group in the Windsor AOI.

along the coastline of the Minas Basin and Cobequid Bay. *Waldron et al.* (2010) used seismic data to show that the surface exposures of the Horton Group occur in relatively horizontal thrust sheets emplaced on the Windsor Group evaporite rocks. The Cheverie No. 1 well drilled through a thrust sheet where Horton Group occurs at surface. The well intersected Windsor Group strata at 404 m and encountered Horton Group at 890 m before reaching total depth at 1410 m (*Waldron et al.*, 2010). Based on the seismic interpretation (*Waldron et al.*, 2010) and the well results, we estimate the depth of the Windsor Group at 400 m on the northwest side of the basin (Figure A-4). The deepest Windsor Group occurs in the south-central part of the basin and shallows gently to the east where Horton Group occurs at surface.

COS mapping

Martel and Gibling (1996) subdivide the Horton Bluff Formation into four members. Although sandstones occur in all four members, the uppermost (Hurd Creek Member) and lowermost (Harding Brook Member) are more sand-prone and of particular interest for GCS. Sandstones in the Hurd Creek Member are interpreted as lacustrine shoreline sands and are particularly quartzose and well-sorted, which has permitted them to be exploited as sands for glassmaking (*Martel and Gibling*, 1996). They are conspicuous on gamma ray logs, commonly having counts lower than 30 API, and are sometimes picked as "Glass Sand" (*Nova Scotia Department of Energy*, 2017). Typical porosities of sands in the upper Horton Bluff are ∼9% overall and can locally exceed 15% based on preliminary well log analysis. These sands are commonly 5-10 m thick.

Outside of the uppermost sands, porosities in clean sands in the Horton Bluff Formation are relatively poor (average ∼6%). Although the lowermost part of the Horton Bluff contains the coarsest-grained clastics in the interval (*Martel and Gibling*, 1996), the porosity is likely to be relatively poor, particularly given the deep burial of these sediments in much of the area.

The younger Cheverie Formation is an interval of interbedded red and brown clastics that are interpreted as fluvial in origin (*Utting et al.*, 1989). Well logs from the Cheverie Formation examined indicate that it is predominantly shaly, but clean sandstones within the interval typically show moderate effective porosities averaging ∼10%. However, these reservoir intervals are typically only a few metres thick and of uncertain lateral extent.

Given the cursory review of the Horton Group reservoirs described above, the COS was assessed as follows. The highest COS for reservoir was assigned to areas where the base Windsor depth was 800 to 1600 m. Areas where the base Windsor was deeper than 1600 m were assigned lower COS, as were those where it was shallower than 800 m. The lower COS in the latter case was assessed because the stratigraphically lower Horton Bluff rocks are much less prospective than those in the overlying Hurd Creek Member. If the total thickness of the Horton was less than 800 m, a near zero COS was assigned due to no potential for supercritical injection. The resulting map shows a ring of high reservoir COS with low COS inside and outside that ring due to excessive or insufficient reservoir depth, respectively (Figure A-5)

The Lower Windsor group typically includes significant thicknesses of evaporites (*Giles*, 2009) and is likely to provide an excellent vertical seal for any underlying reservoirs. The Cheverie Formation is also rich in mudstones and would limit upward migration from a Horton Bluff reservoir. Therefore, the COS for seal was excellent wherever the Windsor Group is present, and moderate elsewhere (Figure A-5).

A low COS for trap was generally assigned to areas within 5 km of Horton Bluff Formation outcrop or basin bounding faults, and a moderate value for those where the distance was greater than 5 km. A high COS was assigned to the mapped area of closure due to the probable structural trap (Figure A-5).

The combined COS for a Horton GCS play is depicted in A-5. The best COS is in the east-central part of the basin where the Hurd Creek member is likely at a favorable depth, overlain by evaporites in the Windsor Group and within a potential structural closure over a basement high.

The foregoing discussion summarizes our approach to assessing the COS for reservoir, seal and trap for each AOI based on published information. This provides a consistent methodology for a broad regional

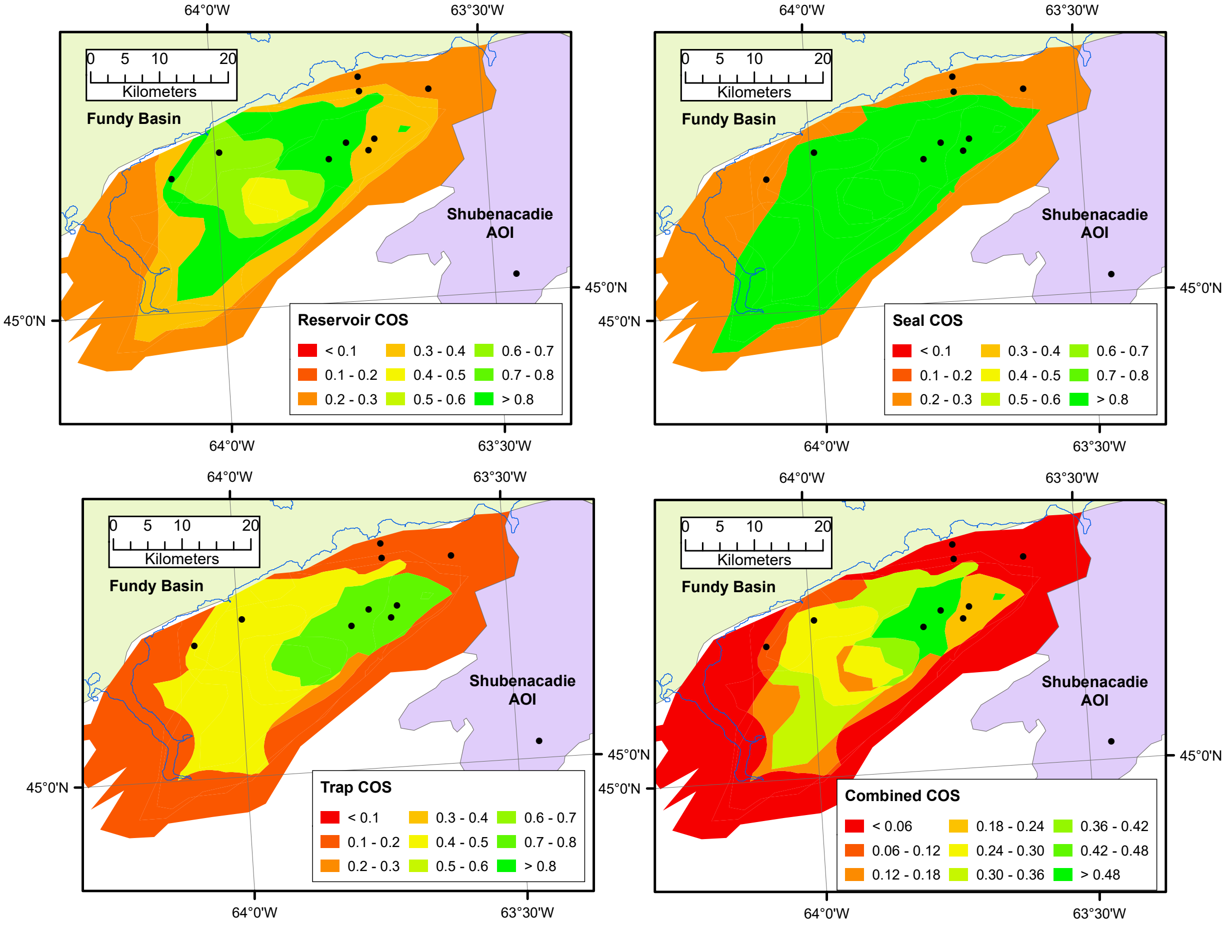

Figure A-5. COS maps for the Windsor AOI. Black dots are locations of deep (>800 m) drill penetrations.

picture of GCS potential.

A-2 Antigonish AOI

The Antigonish AOI consists of a large area of eastern Nova Scotia north of the Chedabucto Fault (see Figure 1 in *Ténière et al.*, 2005) and east of the Silurian and older rocks that outcrop in the Antigonish Highlands (Figure 5). The AOI excludes the offshore area beneath St. George's Bay, which is described within the Magdalen AOI. COS mapping for this AOI was only undertaken for the Horton Group (Figure 6) because the Cumberland Group and younger rocks are largely absent in the onshore areas. Subsurface data is limited in this AOI. The only petroleum well drilled within it to date is the VPCI Beech Hill (*Nova Scotia Department of Natural Resources and Renewables*, 2017), which penetrated 1006 m of Mabou and Windsor Group rocks. Results of seismic studies of the Antigonish Basin were reported by *Durling et al.* (1995) and *Thomas* (2019). Most of the data interpreted by *Durling et al.* (1995) was offshore within the Magdalen AOI, whereas the work of *Thomas* (2019) provides insight into the structure of this AOI.

Horton Group rocks are present at the surface in most of this area except for the Antigonish Basin which lies between the Morristown and Glenroy Faults (*Boehner and Giles*, 1982; *Thomas et al.*, 2003). Areas where Horton is at the surface were assigned low potential for reservoir; any rock deep enough for supercritical CO_2 injection would be in the lower Horton section which is typically composed of coarse-grained alluvial deposits in contact with older bedrock (*Martel and Gibling*, 1996) that are typically mineralogically and texturally immature. A further reduction in reservoir COS was applied to the southeastern part of the AOI because of the impact of low-grade metamorphism (*Ténière et al.*, 2005). Within the onshore Antigonish Basin, seismic interpretation by *Thomas* (2019) suggests that upper Horton Group rocks should be present at suitable depths for injection (∼800 to 2500 m). Therefore, a fairly high COS for reservoir was assigned within the central part of the Antigonish Basin (Figure 6a).

Seal COS for parts of the AOI south of the Glenroy Fault was judged generally low, as the Windsor Group is absent and upper Horton Group is typically dominated by terrestrial red bed successions where the presence of a continuous shale horizon is uncertain. However, within the central Antigonish Basin, seal potential is assessed very high because the Horton Group is overlain by anhydrite and halite of the Bridgeville and Hartshorn Formations, respectively (Windsor Group; *Thomas et al.*, 2003).

Trap COS in the Antigonish AOI is moderate at best (Figure 6). Horton Group rocks outcrop at the surface in much of the area and the Antigonish sub-basin is intensely faulted (*Durling et al.*, 1995), which might provide leakage paths to surface.

In summary, the Antigonish AOI has very low GCS potential, except within the Antigonish sub-basin where potential is moderate.

A-3 Bay St. George AOI

Although the stratigraphic nomenclature used for the upper Paleozoic rocks of southwestern Newfoundland differs from that elsewhere in the Maritimes Basin, the sedimentary succession is broadly similar to that seen regionally in the Maritimes Basin (*Utting and Giles*, 2008; *Waldron et al.*, 2017). Six petroleum wells concentrated in the northern part of the AOI penetrated at least 800 m into the sedimentary succession (*Newfoundland and Labrador Department of Industry Energy and Technology*, 2023). Several hundred kilometres of 2D seismic data have been collected in the northern part of the AOI.

The Anguille Group is time-equivalent to the Horton Group (*Waldron et al.*, 2017). The lowermost unit (Kennels Brook Formation) is predominantly composed of coarse-grained fluvial sediments, similar to other basal Horton successions elsewhere (*Martel and Gibling*, 1996). It is overlain successively by a mud-prone lacustrine unit (Snakes Bight Formation), a more-sand-prone lacustrine deltaic interval (Friars Cove Formation), and capped by red fluvial sands with minor siltstones (Spout Falls Formation; *Knight*, 1983). This is a succession is similar succession to Horton Group successions in areas such as the Windsor-Kennetcook and Moncton Basins (*Martel and Gibling*, 1996).

The overlying Codroy Group is composed of a basal limestone (Ship Cove Formation) overlain by the evaporite-bearing Codroy Road Formation, the clastic dominated Robinson River Formation, and capped by the clastic Highlands Formation (*Knight*, 1983). This is a similar pattern to the time-equivalent Windsor Group rocks seen elsewhere in the Maritimes Basin (*Waldron et al.*, 2017).

The Barachois Group consists of a lower unit dominated by coarse-grained multistory, fluvial sandstones (Searston Formation) and an upper unit with finer grained sandstones, shale and minor coal (*Utting and Giles*, 2008). Although time-equivalent to the Mabou Group (*Waldron et al.*, 2017), the lithologies are more similar to the Cumberland Group.

No COS mapping was done in this AOI and no subsurface mapping was reviewed for this study. However, Anguille Group reservoirs should be moderately prospective where overlain by the Codroy Group (a good potential seal) at moderate depths. The Barachois Group is estimated as 1500–2300 m thick (*Knight*, 1983), so it is possible that there could be Searston Formation reservoir at sufficient depth for supercritical CO_2 injection. However, it is not clear that the upper Barachois Group would be a continuous seal, because it is not as rich in coal as the coal-rich formations of the Cumberland Group in Nova Scotia (*Utting and Giles*, 2008). There might also be risk of migration up dip to nearby outcrop.

A-4 Carlisle AOI

The Carlisle AOI is a small (∼230 km^2) remnant Carboniferous basin (*van de Poll et al.*, 1995) in western New Brunswick (Figure 5). It is subdivided into two predominantly coarse-grained formations, the Carlisle Formation and the Mountain View Formation (*van de Poll et al.*, 1995) with a combined thickness of approximately 300 m (*St. Peter*, 1982). With insufficient depth for supercritical injection and no clear potential seal rock, it has no potential for GCS.

A-5 Central Cape Breton AOI

This AOI is centered on Bras d'Or Lake and largely separated from the adjacent AOIs by the crystalline rocks of western and eastern Cape Breton Island; it does not correspond exactly to a specific geologic structure. Much of this AOI is submerged and its geology is poorly known (*van de Poll et al.*, 1995). The subsurface is largely known from a series of drill holes on the west side of Bras d'Or Lake defining the Malagawatch salt deposit (*Giles*, 2003).

The reservoir COS for the Horton Group was judged to be low in the southern half of the area where Horton Group outcrop is limited and the Windsor Group is often in contact with basement rocks, suggesting it may largely lie outside Horton depocenters. Farther north, the potential for Horton reservoir was deemed moderate. A high COS for seal was assigned wherever Windsor Group rocks are present, low COS where Horton outcrops at the surface (Figure 6). The COS for trap was judged low throughout due to short distances to outcrop and faults, though local structural traps could exist where the faults act as seals. The total potential for GCS central Cape Breton is estimated as very low in the south and in areas of Horton outcrop, and low in the northern area where it is buried by the Windsor Group. Localized areas of Cumberland Group outcrop exist, but no COS map was prepared for them as they are unlikely to lie at sufficient depth for supercritical injection.

A-6 Cumberland-Sackville AOI

This region consists of the Sackville Basin of southeastern New Brunswick and the Cumberland Basin in northern Nova Scotia between Chignecto Bay and the Northumberland Strait (Figure 5). Structurally, the Sackville-Cumberland basin may be described in terms of four synclinal areas: the Sackville Basin in the north, the Amherst Syncline in the middle, and the Athol and Tatamagouche synclines in the south (see Figure 2 in *Allen et al.*, 2013). The structurally deepest parts of the Cumberland-Sackville AOI underlie the Athol and Tatamagouche synclines. The Amherst Syncline is underlain by an elevated basement block known as the Hastings Uplift (*Howie*, 1986). This AOI was evaluated for both Horton Group and Cumberland Group targets (Figures 6 and 7).

Depth estimates for the Cumberland AOI were provided by structure maps of the base of the Windsor Group and the base of the Boss Point Formation (basal Cumberland Group). These maps were based on time structure maps from *Durling* (2023) for the Cumberland Basin, and *Martel* (1987) for the Sackville Basin. The latter were modified using recent interpretations of modern seismic data in the Sackville Basin (*Eggleston*, 2017) and surface geological maps (*St. Peter and Johnson*, 2009).

Structure contours of the base Windsor Group follow *Martel* (1987) in the NW part of the Sackville Basin. These contours were truncated to the north at the Dorchester Fault, and to the south at the Harvey Hopewell Fault. The location of these faults was based on interpreted seismic profiles presented in (*Eggleston*, 2017). The Harvey Hopewell Fault is a gently, north dipping fault that places Horton Group and younger rocks in the hanging wall over Windsor Group and older rocks in the footwall (*Eggleston*, 2017). Southeast of this fault, the basal Windsor Group structure contours were manually blended with those in the Cumberland Basin (*Durling*, 2023).

The map of the base of the Boss Point Formation was based on time structure contours from *Martel* (1987) in the northeast part of the Sackville Basin in the vicinity of the Port Elgin wells. In the northwestern part of the Sackville Basin the seismic interpretations of *Eggleston* (2017) were used to establish the magnitude of the time structure contours. The trend of the contours was guided by formation contact boundaries on surface geological maps (*St. Peter and Johnson*, 2009). Near the Nova Scotia-New Brunswick border the contours were manually blended with those of *Durling* (2023).

The following time-depth relationships were used to depth-convert the time-structure contours:

$$\text{Depth (base Boss Point)} = 1000 * (0.508 * \text{TWTT}^2 + 1.557 * \text{TWTT}) + 75, \tag{A-2}$$

$$\text{Depth (base Windsor)} = 1000 * (0.292 * \text{TWTT}^2 + 1.542 * \text{TWTT}), \tag{A-3}$$

where TWTT = two-way travel time (in seconds) from the time structure maps and depth is measured in metres.

Horton Group outcrop is uncommon in the area and is known only from the northern Sackville Basin and around the Scotsburn anticline in the east; it may be thin or absent in most of the basin. Therefore, the COS for reservoir is low for most of the area, except for the Sackville Basin. Where present, the seal chance is very high throughout, due to the overlying Windsor Group evaporites. Trap chance was reduced near the major faults that define the subregions of the area, but is assessed as high within the Athol and Tatamagouche synclines. Moderate COS for trap was assigned to the tectonic wedges on the northern edge of the AOI where the risk of leakage along the faults was judged low. The resulting combined COS for the Horton Group is very low, except in northern Sackville Basin (Figure 6).

Within the Cumberland Group, there are several formations containing sandstones that could be potential reservoirs. The estimate of reservoir COS was based upon which of these formations was expected to be deep enough for supercritical injection (> 800 m depth), but not so deep that good porosity was unlikely. This determination was made using the base Boss Point Formation depth structure map and the typical thicknesses of the formations within the Cumberland Group as described in outcrop (*Allen et al.*, 2013; *Calder et al.*, 2005; *Rygel et al.*, 2015). The Boss Point Formation is a sandstone-dominated interval that can exceed 1000 m in thickness (*Rygel et al.*, 2015), characterized by multi-storey cross-bedded fluvial channel sandstones (*Browne and Plint*, 1994; *Rygel et al.*, 2015). A moderate reservoir COS was assigned where the base of the Boss Point was 2000–3000 m below the surface, and a good chance where it was 800–2000 m below the surface. This leads to high COS in much of Sackville Basin, the Amherst and Tatamagouche Synclines, and the outer part of the Athol Syncline. In deeper parts of the Tatamagouche Syncline and moderately deep parts of the Athol Syncline, the Boss Point was assumed too deep and the overlying Joggins and Springhill Mines Formations were the assumed targets. While there are fluvial channels throughout these intervals, they are characteristically smaller and would provide smaller, less continuous reservoirs. The deepest parts of the Athol Syncline have a fairly high chance of reservoir success, as the comparatively sand-rich Ragged Reef and Malagash formations are in the depth range where GCS success is most likely.

For the Boss Point Formation, seal COS is rated high, though less than for the Horton Group. The relative abundance of mudstones and coal within the thick Joggins and Springhill Mines formations should form an adequate barrier. Seal risk was estimated as considerably greater for the younger formations because the overlying sections are predominantly coarse-grained.

Trap risk was judged high near faults or Cumberland Group surface outcrop. The combined COS for the Cumberland Group was highest in the centre of the Amherst Syncline, the northeastern part of Sackville Basin, and the central part of the Tatamagouche Syncline (Figure 7).

Pictou Group rocks are found within the AOI, but are likely too shallow for supercritical injection and no obvious seal rock is present. Therefore, the Pictou COS was not evaluated for this AOI.

A-7 Deer Lake AOI

The Deer Lake AOI is a sedimentary basin with an area of 2200 km^2 in western Newfoundland (Figure 5) that formed as a result of strike-slip motion along the Cabot Fault Zone between the Humber and Dunnage crustal blocks (*Hyde et al.*, 1988). The basin has a central flower structure with two sub-basins on either side of it (*Hyde et al.*, 1988). Two stratigraphic groups are recognized within the basin, the Anguille Group (a name also applied in the Bay St. George AOI), and the Deer Lake Group (*Hyde and Ware*, 1981; *Waldron et al.*, 2017). The latter consists of terrestrial sediments (*Hyde and Ware*, 1981) with an age range overlapping the Codroy and Barachois Groups in the Bay St. George AOI. Three modern (post-1990) wells have been drilled in the area (two >800 m, one reaching only 442 m depth), all in the northern part of the basin, where a small number of seismic surveys have been conducted (*Hogg and Enachescu*, 2015). The deepest of these, Western Adventure #2, penetrated 1879 m into the subsurface.

No COS mapping was completed for the Deer Lake AOI. *Hogg and Enachescu* (2015) view the coarse-grained alluvial fan and braided stream deposits of the North Brook Formation within the Deer Lake Group as the best reservoir target, reporting 7–9% porosity and permeabilities of up to 10 mD. This formation lies at depths of 1–3 km beneath both lateral sub-basins and could be a potential GCS target where overlain by muddy lacustrine sediments of the Rocky Brook Formation (*Hogg and Enachescu*, 2015). Leakage to outcrop could be an issue due to the small size of the basin, as could leakage along faults. Our preliminary assessment is that the Deer Lake AOI has relatively low potential for GCS.

A-8 Moncton AOI

The AOI is centered on the Moncton sub-basin but contains some peripheral areas such as the Cocagne sub-basin, a parallel feature to the north separated by an intervening uplifted area known as the Indian Mountain Deformed Zone (*Wilson and White*, 2006). The limits of the AOI are the Keirstead Mountain Fault on the northwest, the Dorchester Fault on the southeast, the Magdalen AOI on the northeast and uplifted basement blocks elsewhere (Figure A-6). The Moncton AOI is richer in subsurface information than any other AOI in this report, due to its long history of petroleum production dating back to 1895 (*New Brunswick Department of Energy and Mines*, 2023). The McCully field is currently the site of the only onshore petroleum production in Atlantic Canada.

The AOI is structurally complex and dominated by NE-trending faults. The basin formed in a transtensional to extensional setting, with up to 5 separate sub-basins developing (*Durling*, 1997; *St. Peter*, 1993) during deposition of the Horton. Subsequently the basin underwent repeated cycles of basin inversion and significant compression along a NW-SE axis (*Wilson and White*, 2006).

The reservoir interval for petroleum is the Hiram Brook Member in the upper Albert Formation of the Horton Group. Sedimentation during Horton time was strongly controlled by synsedimentary faulting, with fluvial sediments predominating in the axial parts of the basins and lacustrine sediments in the southern area (*St. Peter and Johnson*, 2009).

As the sole modern petroleum producing region onshore in Atlantic Canada, the Moncton AOI has been the subject of numerous seismic surveys. COS mapping for this AOI was supported by depth conversion of time structure maps from several sources, based on the interpretation of seismic reflection data acquired between the 1980s and the early 2000s. No original seismic interpretation was completed during this study. A regional seismic grid that covers most of the Moncton AOI was collected between 1980 to 1984. This widespread grid of seismic lines is complimented by site-specific seismic surveys acquired in the early 2000s in the southwestern (McCully Field) and northeastern (Stoney Creek Field) parts of the Moncton Basin proper (Figure A-6).

An interpretation of the early 1980's seismic data was completed by *Durling* (1997). A component of that work involved the preparation of time structure maps for the base of the Horton Group (top basement),

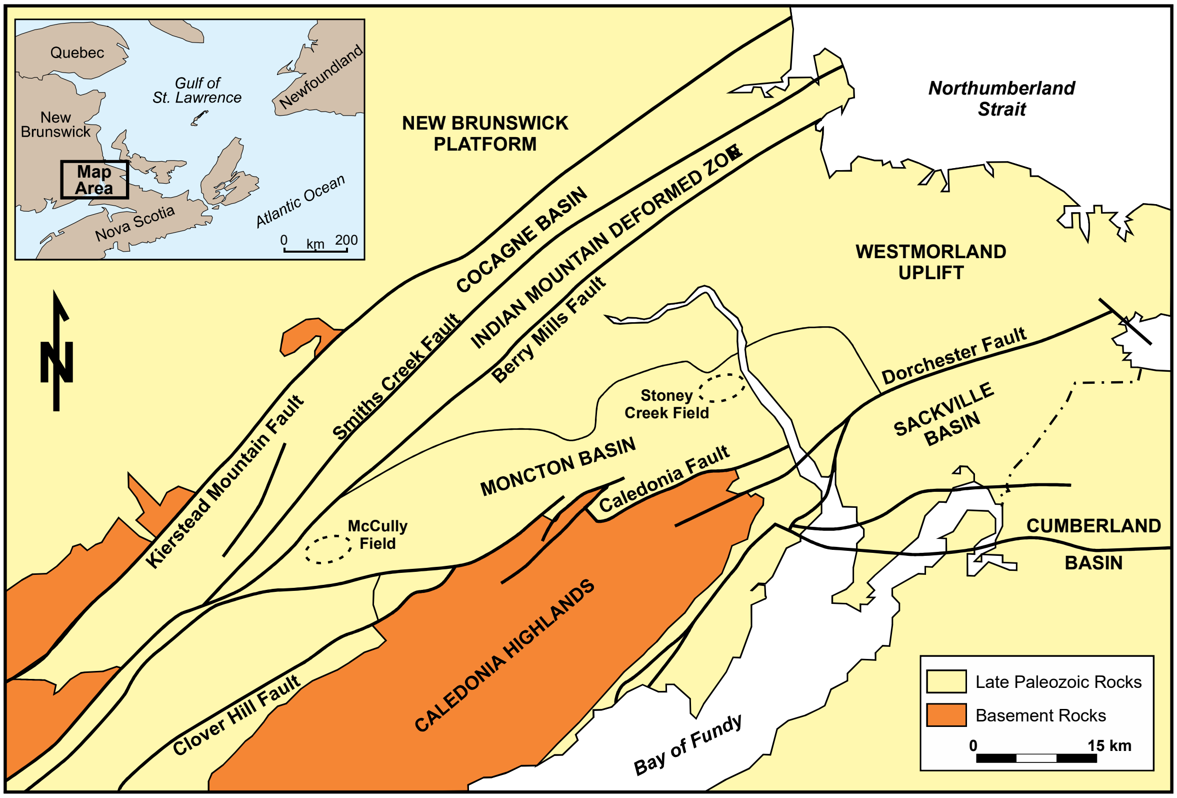

Figure A-6. Location map of the Moncton AOI and surroundings showing key features mentioned in text.

and the base and top of the Windsor Group. The map of the base of the Windsor Group is presented in *Durling* (1997); however, the base Horton and top Windsor group maps are unpublished work.

The unpublished time structure map of the base of the Horton Group underlies a structure described by *Durling* (1997) as the Riverview half-graben. The southeastern part of the contour map defines contours on an interpreted listric normal fault (*Durling*, 1997), whereas the structure contours on the northern part of the map defines the ramp side of the half-graben. Interpretations of more recently acquired seismic data published by *Kugler et al.* (2020) and *Eggleston* (2017) were incorporated into the base Horton Group map. The composite map shows two structural lows in the Moncton AOI; a southwestern low where the McCully Field is located and a northeastern low that includes the Stoney Creek Field (Figure A-6). The depth to basement in the southwest is up to 7000 m and up to 5500 m in the northeast. The intervening high between the two structural lows is up to 3500 m depth. Cross sections presented by *Durling* (1997), in concert with the results of *Wilson and White* (2006), *Eggleston* (2017), and *Kugler et al.* (2020), provide an overview of the structural relationships in the Moncton AOI.

An estimate of the Sussex Group isopach was made by contouring thickness information of the Sussex Group from limited boreholes listed in the New Brunswick borehole database (*New Brunswick Department of Energy and Mines*, 2023). The term ‘Sussex Group’ was introduced in the early 2000s to include continental clastic rocks that unconformably overlie the Horton Group and underlie the Windsor Group (*St. Peter and Johnson*, 2009). The stratigraphic assignment for many of the boreholes described in the NB borehole database was made prior to the Sussex Group being recognized as a unit distinct from the Horton Group. Consequently, the thickness of the Sussex Group was estimated by adding together the thickness of units such as the Weldon Formation and the Moncton Group (term no longer used). Although not considered part of the Sussex Group in New Brunswick (*St. Peter and Johnson*, 2009), the Hillsborough Formation (Windsor Group) was included in the Sussex isopach estimate for this report to be consistent with legacy seismic interpretation. The clastic rocks of the Hillsborough Formation are generally indistinguishable on seismic reflection data from the underlying Sussex Group. The basal Windsor Group seismic marker (*Durling*, 1997) denotes the contact between carbonate and evaporite rocks of the Windsor Group and the underlying Hillsborough Formation. Selected wells were used to estimate the regional Sussex Group isopach. This isopach was added to the depth map of the base Windsor or the seismic datum (as the case may be) to give an estimate of the depth to the base of the Sussex Group for GCS assessment.

A time structure map of the base of the Windsor Group for the Moncton Basin was published by *Durling* (1997). This map was converted to depth using the velocity function presented below. The base Windsor is deepest (estimated up to 3100 m) adjacent to the Berry Mills Fault and thins to zero thickness near the Caledonia Highlands and the Westmorland Uplift (Figure A-6).

The equation below is based on the time depth relationships in the Irving Chevron Hillsborough No. 1 well and was used to convert all surfaces to approximate depth.

$$\text{Depth} = 1000 * (0.48 * \text{TWTT}^2 + 1.77 * \text{TWTT}), \tag{A-4}$$

where TWTT = two-way travel time (in seconds) from the time structure maps and depth is in metres.

Horton reservoir COS was largely evaluated on the basis of depths estimated from the depth maps. Through much of the basin, the depth to top Horton is in the range of 800 to 3000 m. A high COS was assigned for this depth range because Horton reservoirs have been proven adequate for petroleum production, despite relatively low permeability and porosity. The top Horton was chosen for COS assessment because the best reservoir quality is typically in the Hiram Brook Member, near the top of the Horton succession. A moderate reservoir COS was given to the deepest parts of the basin because lower porosities are anticipated at greater depths. These areas are mainly northeast of the McCully Field, south and southwest of the Stoney Creek Field, and adjacent to the Berry Mills Fault. In areas where the sedimentary section was less than 2 km thick a moderate value of reservoir COS was assigned because in these areas the Hiram Brook Member may be too shallow for GCS injection. Examples of these areas occur west of the Westmorland uplift or adjacent to the Caledonia Fault on the southern margin of the AOI. A very low COS for reservoir was assigned to the eastern part of the AOI over the Westmorland uplift, as the Horton Group is likely absent (*Eggleston*, 2017; *St. Peter and Johnson*, 2009).

Seal COS was highest where Windsor Group evaporites were present (*Durling*, 1997), as in most of the Moncton Basin proper (Figure A-6). A moderate COS was assigned for areas where the Windsor Group was absent, but where mud-prone lower Mabou Group or Sussex Group rocks were mapped at surface. Areas that were assessed as having low seal COS were areas where Horton Group was present at the surface, such as in the southwestern part of the AOI, or where the Horton was directly overlain by the Cumberland Group or by a thin Mabou section, such as the area east of the Stoney Creek Field.

Areas near Horton Group outcrop (within 5 km) were assigned the lowest COS for trap due to risk of up dip migration. Notable areas include the southwest part of the AOI, an area east of the Stoney Creek Field, and the north-easternmost part of the Indian Mountain deformed zone. A slightly higher COS was assigned to an area southeast of the Cloverhill Fault because the fault might impede migration to the Horton Group outcrop on the northwest side of the fault. Moderate trap COS was assigned to areas 5–15 km from Horton outcrop, and high COS to areas more than 15 km from any Horton Group outcrop. Areas with the highest trap COS are in the central part of the Moncton Basin and adjacent to the northern portion of the Belleisle Fault.

The distance-from-outcrop method of assessing trap COS, although practical for the current regional GCS assessment, has its limitations. For example, a detailed review of the results presented in this report will reveal that the McCully Field is located less than 5 km from Horton Group outcrop. It is a natural gas field that is contained clearly within a good trap. However, being located within 5 km of Horton Group outcrop we must assign a moderate value in keeping with our methodology. This example illustrates that detailed studies are warranted to assess fully the GCS potential in the onshore Carboniferous basins.

The total COS map implies that the best potential for GCS within the Horton Group lies west of Stoney Creek or in the eastern part of the Cocagne Basin (Figure A-4), with generally low potential in the southwest and the Westmorland uplift area.

The Cumberland Group rocks of the area are predominantly coarse-grained clastics interpreted as braided stream deposits (*St. Peter and Johnson*, 2009) that could form a reservoir. However, in most of the AOI these are at or near the surface. Reservoir COS was assessed as high in a narrow band southeast of the Berry Mills Fault (Figure A-6) where the basin is deep (Figure 7a). Elsewhere, the Cumberland Group is either likely shallower than 800 m or not present at all.

Cumberland Group rocks are not known to include abundant coals and terrestrial floodplain rocks equivalent to formations like the Joggins and Springhill Mines formations in Nova Scotia (*St. Peter and Johnson*, 2009). However, there are few wells in the area southeast of the Berry Mills Fault, so a moderate COS for seal was assigned in view of the uncertainty (Figure 7b). Elsewhere, seal COS is expected to be very low.

Trap COS for the Cumberland Group was determined through evaluation of the distance to outcrop. Much of the northeastern part of the AOI is more than 5 km from the nearest Cumberland Group outcrop and assigned a moderate COS (Figure 7c), with a high COS in the northeastern area closest to the Berry Mills Fault (Figure A-6). Elsewhere the COS for trap was judged low.

The combined COS for the Cumberland Group in the Moncton AOI indicates very low GCS potential through most of the region (Figure 7d). Southeast of the Berry Mills Fault (Figure A-6), there is a narrow bend with low to moderate potential, improving toward the northeast (Figure 7d).

A-9 Musquodoboit AOI

The Musquodoboit AOI is a small sub-basin nearly surrounded by Meguma group rocks. The geology is known from shallow boreholes and surface outcrops. There is very little Horton Group preserved in the area and most of the exposed outcrop belongs to the Windsor Group (*Jutras et al.*, 2006). No COS maps were constructed for this AOI. Even if a localized Horton Group or lower Windsor Group reservoir were to exist, the small size of the basin suggests there would be a high risk of leakage to nearby outcrops. The potential for GCS in this AOI is extremely low.

A-10 New Brunswick Platform AOI

This AOI encompasses all the late Paleozoic sedimentary rocks north of the Keirstead mountain fault (Figure A-6) and outside of the Magdalen AOI (Figure 5). The area has seen limited petroleum exploration with only a few deep wells drilled and very little published seismic interpretation. Seismic surveys were completed in the early 2000s but these data remain confidential. Gravity and magnetic data, along with the limited amount of available seismic information indicates that the sedimentary cover in most of this area is less than 1000 m thick (*Kingston and Steeves*, 1979) and consists of Mabou, Windsor and Pictou Group rocks (*Jutras et al.*, 2007). Localized thicker sections are inferred to be extensional basins likely filled with Horton and Windsor Group rocks (*Kingston and Steeves*, 1979).

COS mapping for this AOI was completed for the Horton Group based on the depth to magnetic basement maps of (*Kingston and Steeves*, 1979). The deepest parts of the basement depth map were inferred to have Horton Group present based on the identification of Horton Group basins on the offshore extension of the New Brunswick platform in the Magdalen AOI (*Atkinson et al.*, 2020). Two large areas and one small area (Figure 6) were identified. The COS for reservoir was judged moderate in these areas to reflect the potential for Horton Group reservoirs below 800 m depth. These reservoirs may be thin, however. Elsewhere, the COS was judged very low as the Horton Group is likely absent outside the inferred thickest areas. A low to moderate chance of seal was assigned in the inferred thick areas, with higher values assessed where the depth to basement was greatest (*Kingston and Steeves*, 1979). The presence of Windsor Group evaporite rocks, which would provide a good seal in these basins, is uncertain but more likely in deeper areas. Outside the inferred thick areas, a very low chance of seal was assigned, as the Cumberland and Pictou Group rocks are predominantly coarse-grained sediments (*St. Peter and Johnson*, 2009) with limited seal potential. Trap COS was assigned a high value for the inferred thick areas as the reservoir rocks do not outcrop. The resultant total COS is virtually zero for most of the New Brunswick Platform, and low to moderate within the inferred thick areas.

COS mapping was not completed for the Cumberland or Pictou Groups as they are unlikely to be deep enough for supercritical injection. Further, it is unlikely that there is a suitable seal in the predominantly coarse-grained New Brunswick platform section.

A-11 Plaster Rock AOI

The Plaster Rock AOI consists of a remnant basin of approximately 825 km^2 in northwestern New Brunswick (*van de Poll et al.*, 1995). No published seismic interpretations or deep wellbores are available for this AOI. The sedimentary section is subdivided into a lower coarse-grained clastic unit known as the Arthurette Redbeds overlain by lacustrine limestones and gypsum (Plaster Rock Formation) and capped by shale (*St. Peter*, 1979).

The total stratigraphic thickness of sedimentary rocks in the basin is at least 940–1090 m, so it is possible that the Arthurette Redbeds could provide a reservoir deep enough for supercritical injection in the central part of the basin. The fine-grained limestone and gypsum of the Plaster Rock Formation should provide an adequate seal. However, updip leakage would likely be an issue, as the distance to up dip Arthurette Redbed outcrop would be less than 10 km. Therefore, the GCS potential of the Plaster Rock AOI is judged to be very low, and COS maps were not constructed.

A-12 St. Anthony AOI

This AOI encompasses an extensive area north of Newfoundland underlain by upper Paleozoic rocks (Figure 5). This area can be subdivided into two sub-basins, Notre Dame and Belle Isle (see Figure 4.13 in *Bell and Howie*, 1990). The Notre Dame sub-basin underlies Notre Dame Bay and appears to be related to NE-oriented faults parallel to the Cabot fault zone, while the Belle Isle sub-basin lies beneath the outer continental shelf and strikes NW-SE. The geology is known largely from shallow boreholes and seismic data. The Verrazzano L-77 well was drilled to a depth of only 460 m. Farther east, the Hare Bay E-21 well penetrated upper Paleozoic rocks beneath the Mesozoic section that likely belong to the Belle Isle sub-basin (*Bell and Howie*, 1990).

The age and geologic history of the AOI appears similar to other parts of the Maritimes Basin. The lowermost section is predominantly terrestrial clastics that are age-equivalent to the Anguille and Horton groups (*Haworth et al.*, 1976b). An overlying unit records a marine transgression that deposited carbonates and evaporites similar in age and character to the Windsor and Codroy groups (*Haworth et al.*, 1976a). The youngest rocks observed are terrestrial clastics, as seen in the Hare Bay E-21 well (*Bell and Howie*, 1990), and are broadly similar to the Cumberland or Pictou groups.

The St. Anthony AOI describes a large, deep sedimentary basin similar to the Magdalen and Sydney AOIs. No COS mapping was attempted in this study due to the paucity of published information. It likely has at least moderate potential for GCS, with similar reservoir-seal plays to those seen elsewhere in the Maritimes Basin. However, due to its remote, offshore location and the presence of nearby younger sedimentary basins that likely have better reservoir quality, it is unlikely to be a significant target.

A-13 St. Mary's AOI

The St. Mary's AOI is a swath of central Nova Scotia bounded by the Chedabucto and St. Mary's Faults to the north and south, respectively, and the Guysborough County fault to the east (*Murphy*, 1998). To the southwest, the boundary with the Shubenacadie AOI is defined where younger (Windsor Group) rocks are mapped. Elsewhere, it is bounded where overstepped by Mesozoic rocks or by the Bay of Fundy. Structurally, this AOI consists largely of the St. Mary's Basin (*Murphy et al.*, 1994), but also includes Paleozoic rocks in a structurally complex zone between the north shore of the Bay of Fundy and the Cobequid Highlands. The Camden 100/G40-A/11-E-06 well penetrated 1463 m of Horton Group rocks in the western part of the AOI (*Nova Scotia Department of Natural Resources and Renewables*, 2017).

The St. Mary's AOI was evaluated for GCS potential within the Horton Group. Elsewhere in the Maritimes Basin, the best reservoir quality in the Horton Group is typically in the lacustrine sands in the middle-upper part of the section, rather than in the coarse, mineralogically immature deposits at its base. However, Horton rock outcrops at the surface throughout most of the St. Mary's Basin and the upper Horton Group comprises largely red beds that are doubtful as seals. The lacustrine muds of the Lower Stewiacke Formation (*Murphy*, 1998) could provide a seal, but only for the underlying lower Horton Group. Therefore, the reservoir COS was assessed as moderate in most of the AOI, and high only in the northeastern part where Windsor Group and younger rocks seal the more reservoir-prone upper part of the Horton section.

Seal COS is dependent on the presence of the Lower Stewiacke Formation or Windsor Group rocks and is therefore assessed as high in the north, but low in the south where the Lower Stewiacke Formation is inferred to be absent (*Murphy*, 1998). Trap COS is assessed as low for most of the AOI because of the proximity to basin bounding faults (within 5 km) but moderate in the central part. The total COS map indicates very low to low GCS potential for the AOI overall, with a small area with fair potential in the west-central part.

A-14 Shubenacadie AOI

The Shubenacadie AOI is a small SW-NE oriented structural basin largely surrounded by Meguma terrain. It is separated from the adjacent Windsor AOI by the Roulston Corner Fault (Figure A-1) to the northwest and a more arbitrary boundary with the St. Mary's AOI to the northeast. Many boreholes have been drilled into the basin targeting base-metal deposits in Windsor Group bioherms.

COS mapping was undertaken only for the Horton Group within this AOI. The Scotch Village Formation (Cumberland Group) is present in the east-central part of the AOI (*Waldron et al.*, 2010), but burial is unlikely to be sufficient for supercritical injection. Furthermore, the minor mudstone interbeds within this sandstone-dominated formation seem unlikely to form an adequate seal.

The Horton Group is largely limited to narrow valley fills within this AOI (*Jutras et al.*, 2006). While these might provide reservoirs, the COS for reservoir is dependent on their uncertain presence, so the reservoir COS was assessed as moderate. Seal COS is high almost everywhere due to the presence of thick Windsor Group carbonates and evaporites. The small size of the basin increases the risk that CO_2 injected would be able to migrate and escape along basin-bounding faults. Therefore, trap COS was assessed as low, except in the central part of the basin. The resulting total COS is low except within the central basin where it is fair.

A-15 Southeast Cape Breton AOI

This AOI covers the upper Paleozoic rocks of southern and eastern Cape Breton (Figure 5) and was discussed together with central Cape Breton by *van de Poll et al.* (1995). It does not correspond to a specific geologic feature and includes several small sub-basins such as the Loch Lomond Basin and Glengarry Graben (*Boehner and Prime*, 1993). Two exploration wells have been drilled to depths greater than 1000 m in the area: the Port Malcolm and North Glen wells. These wells encountered Cumberland, Mabou and Windsor Group rocks (the reader is referred to the online Nova Scotia Drillhole Database).

Only Horton Group reservoir plays were assessed for this study. Cumberland Group rocks are mapped at the surface in the Loch Lomond area and southeast of Bras d'Or Lake, but the presence of sufficient burial depth and the presence of an overlying seal is doubtful.

A low reservoir COS was assigned to this AOI for the Horton because its presence is unknown in the Loch Lomond area (*Boehner and Prime*, 1993) and indications of low-grade metamorphism in some Horton outcrop in the AOI (*Force*, 2006). As in most other areas, seal COS was judged to be high in areas where surface rocks were Windsor Group or younger, and low where Horton outcropped at the surface. The COS for trap was similarly low through most of the area due to short distances (less than 5 km) to Horton outcrop and faults. A moderate COS for trap was assigned to a small area southwest of Bras d'Or Lake and east of Port Hawkesbury, which is characterized by a syncline relatively far from the nearest Horton outcrop. Our assessment indicates a very low potential for GCS in this AOI.

A-16 Stellarton AOI

The Stellarton AOI is a region bounded by the axis of the Scotsburn Anticline on the west, the Magdalen AOI on the north (Figure 5), the Antigonish Highlands on the east and the Chedabucto Fault on the south (see Figure 1b in *Waldron*, 2004). Structurally, it can be subdivided into several regions, one of which is the Stellarton Basin, a pull-apart basin formed between the Hollow and Cobequid faults (*Naylor et al.*, 1989; *Waldron*, 2004). North of the Stellarton Basin lies the Trenton Syncline, most of which lies within the Magdalen AOI; to the south lies an area with Windsor and Mabou group rocks at the surface between the Stellarton Basin and Chedabucto fault (Figure 1b in *Waldron*, 2004).

Horton Group reservoir was not evaluated for this AOI. Horton Group rocks are exposed in the western part of the Trenton syncline, but elsewhere in the AOI, Horton outcrop is largely absent and Windsor or Mabou group rocks are in contact with older rocks. While Horton reservoir could exist in the western region, there would be a high risk of up dip migration to the Horton outcrop on the Scotsburn anticline.

Cumberland Group rocks are present within the Stellarton Basin and the deeper parts of the Trenton Syncline. Reservoir COS was judged high in the Stellarton Basin and in the areas immediately to the west and south because there are typically coarse-grained rocks in the lower Cumberland Group. The depth of these strata was estimated to be 1–3 km based on the work of *Waldron* (2004). A high COS was assigned for seal in these areas as well due to the abundance of coal and organic-rich shales in the middle members of the Stellarton Formation (*Naylor et al.*, 1989). However, any injection site in this AOI would be less than 5 km from a fault, so a low COS for trap seems likely. As a result, the overall evaluation of the Stellarton AOI for GCS is low and restricted to the Cumberland Group within the central area.

A-17 Sydney AOI

The Sydney AOI is a large region underlying Cabot Strait and part of eastern Cape Breton Island. It is separated from the Magdalen AOI by the Cabot Fault Zone (Figure 5). Only two wells have been drilled in the offshore area, both in the southern part, but a substantial number of 2D seismic surveys have mapped its offshore extent. Most of these date from the 1970s and 1980s but a more recent survey was conducted by Husky in 2010 (*Kendell et al.*, 2017). The onshore area is known primarily from outcrop and two exploration wells. A third well drilled in 2011 represents the sole attempt at onshore GCS in Atlantic Canada (*Schlumberger*, 2015). However, the well did not encounter the anticipated Horton reservoir; the Windsor Group was underlain by volcanic rocks at 1140 m depth (*Schlumberger*, 2015). This should not be viewed as a significant deterrent to future interest in the AOI for GCS however. The well was spudded more than 1.5 km from the nearest of the two seismic lines that were examined, due to restrictions in where they were permitted to drill (*Schlumberger*, 2015). The failure of the project illustrates the need for better seismic and subsurface control before attempting to inject CO_2 in the complex Maritimes Basin.

As in much of the Maritimes Basin, the Horton Group is found within discrete fault-bounded extensional basins within the AOI (*Kendell et al.*, 2017; *Pascucci et al.*, 2000). The Grantmire Formation is a conglomerate-dominated interval with some reservoir potential; permeabilities of up to 7 mD were reported by *Oakes* (1999) from the PE83-1 well. The Horton Group is up to 800 m thick where observed in outcrop but not present throughout the AOI (*Boehner and Giles*, 2008).

Reservoir COS for the Horton was estimated using depths from *Kendell et al.* (2017) for the offshore region of the following criteria: high COS where the Horton is present and the base of the Windsor Group was 1–2.5 km below the surface; moderate COS where base of the Windsor Group was between 2.5 and 4 km depth; and low where deeper than 4 km. In areas beyond the limit of Kendell's mapping (closer to Newfoundland), trends were extrapolated but areas near the edge of the basin were assumed to have insufficient depth and therefore assigned a low COS. The distribution of the Horton Group for the present study is generalized based on the complex pattern mapped by *Kendell et al.* (2017). High COS was only assigned where the Horton was mapped continuously or nearly so, lower COS in areas where the Horton was intermittently present, and a low COS in areas where no mapped Horton was known. Onshore reservoir COS was assessed moderately high in areas where Mabou or younger rocks were present at the surface (sufficient depth for supercritical injection); elsewhere the Horton Group was assumed too shallow, if present at all. The Windsor Group was assumed to provide a good seal throughout the area, and distance to basin edges and Horton outcrop was used to assess the trap COS, consistent with other AOIs. The total COS for the AOI was moderate at best in the onshore area due to the limited area where Horton was sufficiently deep and proximity to outcrop. Total COS was high in much of the offshore area and moderate in the deeper central offshore area.

Within the Cumberland Group, the South Bar Formation is a potential reservoir. Predominantly composed of sandstones deposited in braided fluvial environments, the formation is up to 1000 m thick (*Rust and Gibling*, 1990). The South Bar Formation is overlain by the Sydney Mines Formation, a terrestrial deposit rich in coal and shale that should provide an adequate seal. A high COS for reservoir was assigned for most of the offshore AOI except in the deepest central area, but onshore COS was viewed as low because the South Bar Formation is likely to be too shallow for supercritical injection. A high seal COS was assumed throughout. A high COS for trap for most of the AOI was assigned, with the exception of areas near the mapped salt diapirs, the Cabot Fault Zone or the basin edge. The resulting total COS indicates a high GCS potential for much of the offshore area but low around the margins of the AOI, including the onshore area.

A-18 Western Cape Breton AOI

This AOI coincides with the extension of sedimentary basins seen in the Antigonish and Magdalen AOI's onshore onto Cape Breton (*Allen et al.*, 2014; *Durling et al.*, 1995). Carboniferous rocks in the area are separated by uplifted basement blocks but the structural relationships are poorly understood (*Durling et al.*, 1995). Horton and Windsor Group rocks were likely deposited in a sedimentary basin that extended into the Central Cape Breton AOI as depicted by *van de Poll et al.* (1995), but subsequently deformed by blind thrust faults through the Horton Group that are accommodated through salt deformation in the Windsor Group and folding in the overlying Mabou Group (*Durling et al.*, 1995). Two exploration wells were drilled into a feature known as the Mull River Syncline.

In the absence of seismic mapping of the region, the map outcrop pattern was used to evaluate COS for reservoir and seal. Reservoir COS for the Horton was assigned low values where the Craignish Formation outcropped, as it is the lowermost formation indicating that there would be insufficient burial depth. A moderate COS was given to areas with younger Horton Group rocks at surface, assuming some potential for the Craignish Formation to provide a reservoir beneath the more mud-prone Strathlorne Formation (*Ham-*

blin, 1992). The COS for reservoir was deemed high where Windsor and younger rocks were present at the surface, as this would allow the upper Horton Group rocks, which are generally more prospective, to be sufficiently buried for supercritical injection. For seal, high values were assigned for COS where the Windsor Group is present and moderate where a seal within the Horton Group (likely the lacustrine sediments of the Strathlorne) would be needed. Trap COS was viewed as low throughout the AOI due to the extensive faulting, although local trapping could exist. Overall the AOI has low to moderate potential for GCS, with the more prospective areas being where the Horton is buried by Windsor Group and younger rocks.

Cumberland Group rocks are present in the area. The Port Hood Formation in the lower Cumberland Group is a potential reservoir unit. However, the reservoir COS throughout most of the area was judged low through most of the area, and moderate only for a small area near the coast in the northern part of the AOI where it is buried by younger rocks. The seal COS in that area was also moderate; it was negligible elsewhere because the Port Hood is at the surface. Trap COS was low throughout the AOI due to the short distance that would be required to reach outcrop and would only be feasible in local structural traps. Overall, the total COS for GCS in the Cumberland Group was low for a small region in the northern part of the AOI and negligible elsewhere.