Natural Resources Canada
Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE XXXX

Geological model of parameters relevant for offshore wind energy infrastructure in Atlantic Canada

G. Philibert, J. Eamer, E.L. King, M. Li

2024

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE XXXX

Geological model of parameters relevant for offshore wind energy infrastructure in Atlantic Canada

G. Philibert, J. Eamer, E.L. King, M. Li

2024

Permanent link: https://doi.org/10.4095/xxxxxxx

Recommended citation

Philibert, G., Eamer, J., King, E.L. and Li, M. 2024. Geological model of parameters relevant for offshore wind energy infrastructure in Atlantic Canada; Geological Survey of Canada, Open File xxxx, xxx p. https://doi.org/10.4095/xxxxxxx

ISSN 2816-7155
ISBN xxxxxx
Catalogue No. xxxxxx

TABLE OF CONTENT

TABLE OF FIGURES

TABLE OF TABLES

ACKNOWLEDGEMENTS

The authors thank

AUTHORS' ADDRESS

Natural Resources Canada, Geological Survey of Canada (Atlantic), Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, NS, B2Y 4A2

1. INTRODUCTION

1.1. CONTEXT AND OBJECTIVES

The interest in the development of offshore wind energy (OWE) projects is rapidly growing in Canada. The Marine Renewables Program, funded by the Government of Canada and led by Natural Resources Canada (NRCan), is focused on collecting data and developing knowledge products to support decision-making for future OWE projects in eastern Canada's offshore areas. Crucial to this effort are data on surficial and shallow subsurface geology in shallow areas of the continental shelf. This mapping and analysis effort is crucial for government-led marine regional planning, as it provides essential baseline data on the seafloor. Such data will enable informed decisions regarding the impacts of marine activities and the sustainable use of the seabed. Understanding the composition, morphology, and stability of the seabed is essential for effective ocean management (Collie et al., 2013), assessing the cumulative impacts of human activities and natural events (Syvitski et al., 2020), and ensuring the sustainable, long-term development of marine renewables throughout all stages of the project lifecycle (Velenturf et al., 2021). The Geological Survey of Canada conducts seabed characterization to develop a regional geological understanding before development occurs. This information is essential for guiding regulatory decisions and establishing the conditions necessary for the safe, economical and long-lasting design, placement, and operation of OWE infrastructure.

The current study focuses on evaluating the suitability of eastern Canada’s continental shelf that includes portions of the Scotian Shelf and Newfoundland Shelf. The objective is to identify areas of the shelf where OWE development may be considered and to assess the relevant and available geological data for those areas. This study aims to provide guidance for future site specific and higher-resolution data collection campaigns and studies. It serves as an initial, regional-scale investigation of the geology of Atlantic Canada’s offshore for OWE development and builds upon earlier literature reviews and desktop studies on the topic (Eamer et al., 2023, 2021, 2020; MacKillop et al., 2023). In this work, geological criteria are integrated into a regional scale geological suitability model catered to conditions appropriate for 3 different types of OWE turbine foundations (i.e. gravity, pile, and caisson).

Specifically, the objectives of this study are to:

- Assemble existing geoscience data related to bathymetry, surficial geology, sediment thickness, stability, and geohazards.
- Combine all the geoscience layers and assign a weight to each geological factor integrated in the model.
- Assess the spatial patterns associated with the model results and integrate those results into a broader framework of geological and geographical knowledge.

To fully assess the potential impacts of OWE infrastructure development on a site, comprehensive and interdisciplinary studies will be indispensable. Factors such as wind conditions, marine protected areas, habitats, fisheries, marine traffic, oceanography, as well as many others (Kilpatrick et al., 2023) would need to be merged with the geological data presented here.

1.2 STUDY AREA

The study area was selected based on a) its relevance to governmental mandates in the region, and b) the availability of crucial regional datasets needed to assess geological conditions of the area potentially hosting OWE infrastructure. As water depth plays a significant role in determining the suitability of OWE turbine installation, the study area is confined to the continental shelf. The study area covers approximately 660 000 km^2 and extends from the eastern shore of Nova Scotia To the southern tip of Labrador and to the shelf break. The depth within the study area varies approximately between 30m to 100m on the banks and reaches up to 500m in the Laurentian Channel (figure 1).

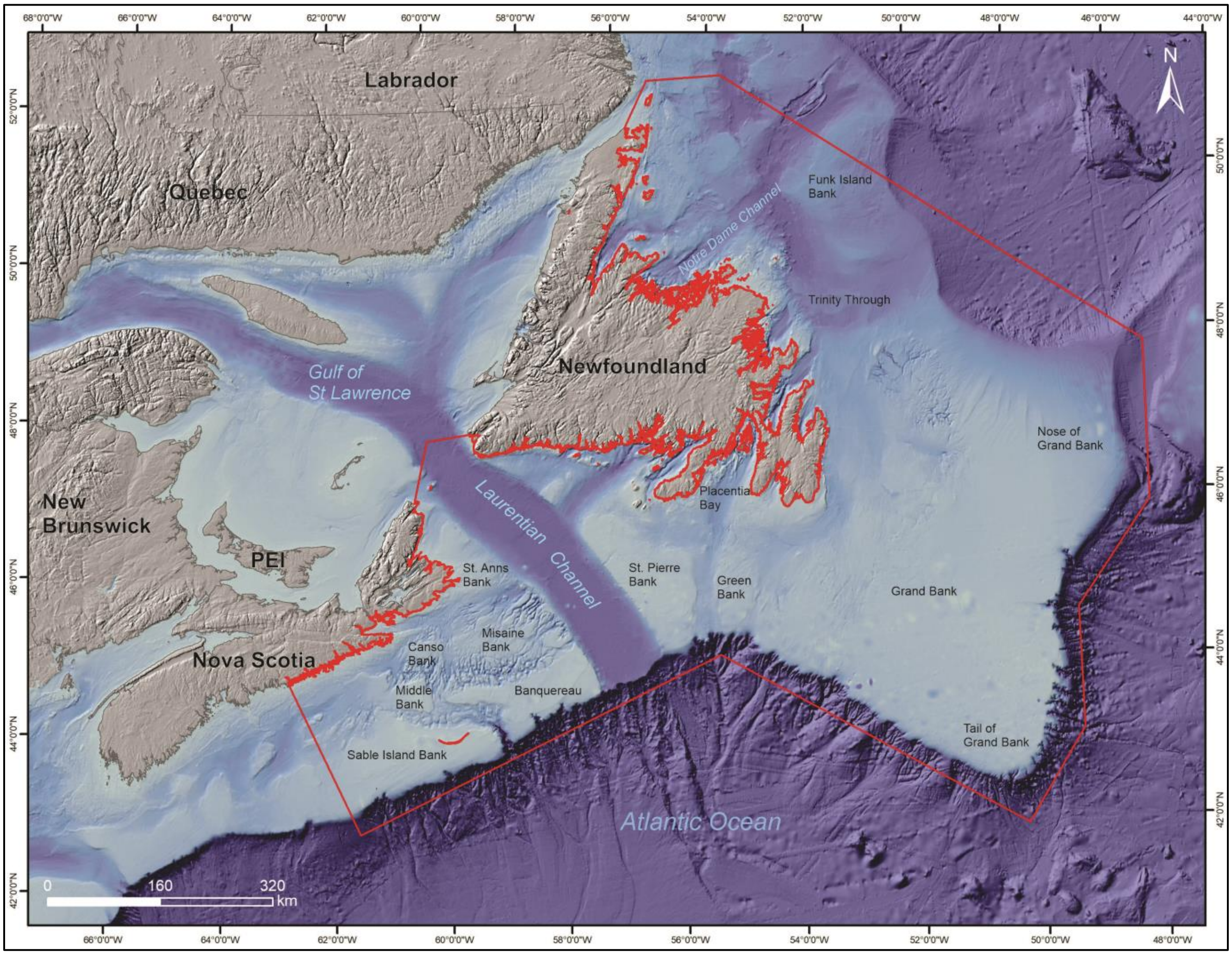


Figure 1: Regional study area with toponyms and hydronyms.

2. TYPES OF FOUNDATION

OWE turbines differ from their terrestrial counterparts primarily in size, power output and foundation design (Figure 2i). OWE turbines are subject to different and generally more extreme loading conditions than those on land (Eamer et al. 2022). Consequently, the foundation and the underlying soil must be capable of absorbing and dissipating these increased loads effectively. The type of foundation for OWE turbine is dependent primarily on seabed geology and water depth. For the model developed in this study, the three most common foundation types were parameterized – gravity base, piled, and caisson (Figure 2ii (a, b, c), respectively). Floating OWE turbines were not included in the development of this model for several reasons:

a) Although the floating OWE industry is rapidly expanding (e.g., Musial et al., 2023), it currently represents only a small portion of the existing or planned OWE capacity (Williams and Feng, 2023).

b) The levelized cost of energy for floating OWE is higher than fixed base OWE (Westwood Global Energy Group, 2023), making it likely that the industry will prioritize lower-cost options first.

c) Since floating OWE is still largely in the developmental stage, there are numerous anchoring, mooring, and platform configurations that require different geological conditions (ABSG Consulting, 2021). This diversity makes it challenging to establish restrictive conditions for floating OWE technologies in model development at this stage.

Gravity-based foundations (Figure 2ii, a) consist of large, heavy structures made of concrete or steel that rest directly on the seabed, relying on their weight to remain stable. These foundations are best suited for shallow waters (< 30 m) with a firm seabed and shallow subsurface geology that can support the weight without significant or differential settlement.

Pile foundations (Figure 2ii, b, d) involve driving or drilling long, slender steel tubes (piles) deep into the seabed. This method is versatile and can be used in various geological conditions, including soft sediments, clay, sand, and even harder soils and rock. Piles provide strong lateral and vertical support, making them suitable for deeper waters (up to 70 m).

Suction caissons (Figure 2ii, c) are cylindrical and hollow steel structures that are embedded into the seabed by creating a vacuum inside the caisson that drives it into the ground. This foundation type is particularly suitable for finer sediments, such as silt and fine sand in intermediate water depths (20 – 70 m).

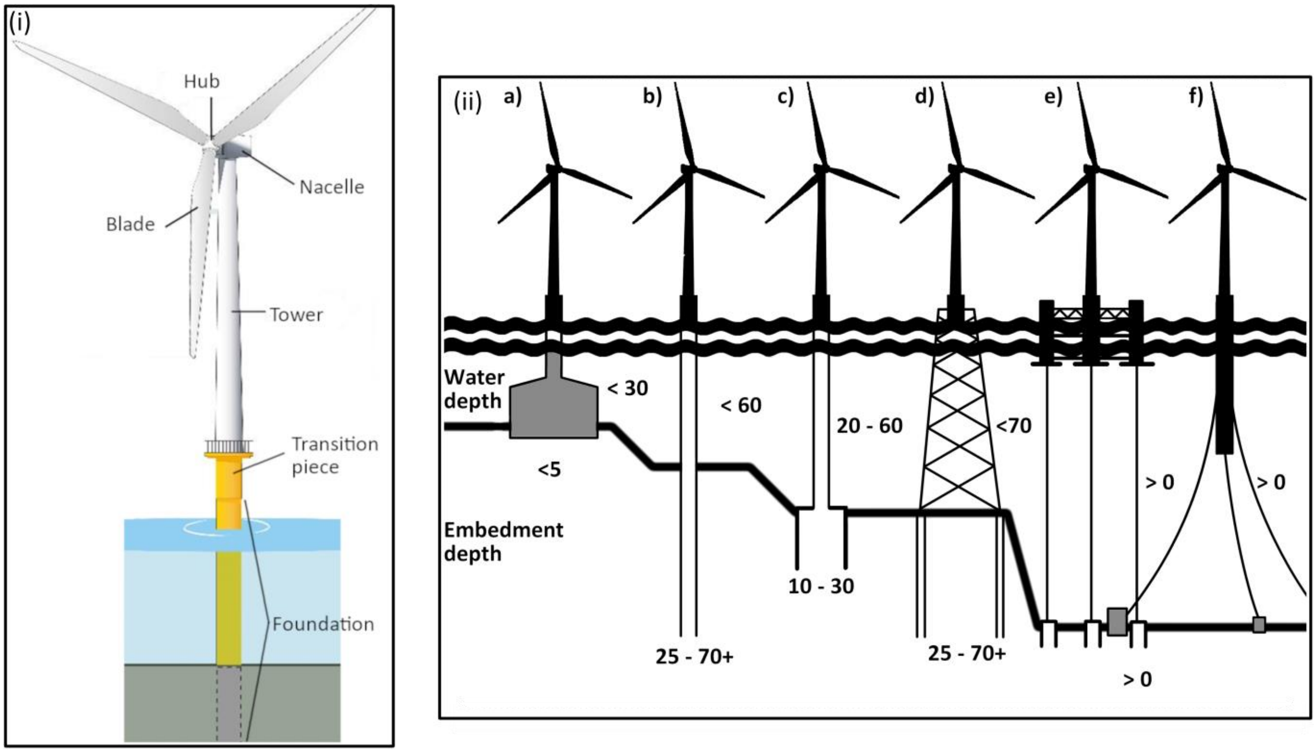


Figure 2: Components and foundation types of OWE turbines. (i) the various components of a turbine, including the foundation which represents the structure below the transition piece and the structure on or below the seabed, which together supports the entirety of the turbine. (ii) various foundation types and their respective parameters, which are continuously evolving as technology is developed (modified from Eamer et al., 2021). (a) Gravity base, (b) driven and/or drilled monopile, (c) suction caisson on a monopile, (d) driven/drilled piles with a jacket substructure (note caissons may also be used as the subsurface component of a jacket structure), (e) floating semi-submersible platform with tension leg moorings and caisson anchors, (f) floating spar platform with catenary moorings and gravity based anchors. Note that (e) and (f) represent a small sample of the multitude of combinations possible for floating OWE turbines.

3. DATA AND METHODOLOGY

The input layers used to build the model were selected based on data availability within the study region and their relevance to OWE development. These factors were selected through those identified in other regions globally where OWE turbine installation is already a well-established practice (Fischer et al.,2020). Therefore, a total of 9 input layers were included in our model : 1) water depth, 2) slope, 3) surficial geology, 4) Quaternary or unconsolidated sediment thickness, 5) buried channels, 6) sediment mobility index, 7) areas exposed to postglacial sea-level lowstand, 8) the presence of subsurface salt diapirs and 9) gas. Each layer was considered using a weight (surficial geology), threshold (depth, slope, sediment thickness), or presence/absence (sediment mobility, lowstand sediments, salt) for input into the model.

3.1 DEPTH

The bathymetric data, sourced from GEBCO 2023, was categorized into classes based on the specific depth requirements of the different types of foundations. The table below (Table 1) outlines the optimal depth ranges needed for each foundation type. The depth values were used as a threshold – those within the parameters in Table 1 were included, and those outside the parameters were excluded from the model.

Table 1 - Suitable depth range per foundation type *(Musial et al., 2016.; Osezua Akeme, 2018)*

	Type of Foundation		
	Gravity	**Pile**	**Suction caissons**
Depth (m)	0 - 30	0 - 70	20 - 70

3.2 SLOPES

Slopes were derived from the bathymetric dataset, and a threshold of 5° was applied for all three types of foundation. Slopes were categorized into two groups: slopes ≤5° were included, whereas slopes >5° were excluded from the model (Coughlan et al., 2020). Figure 3 illustrates the distribution of the computed slopes.

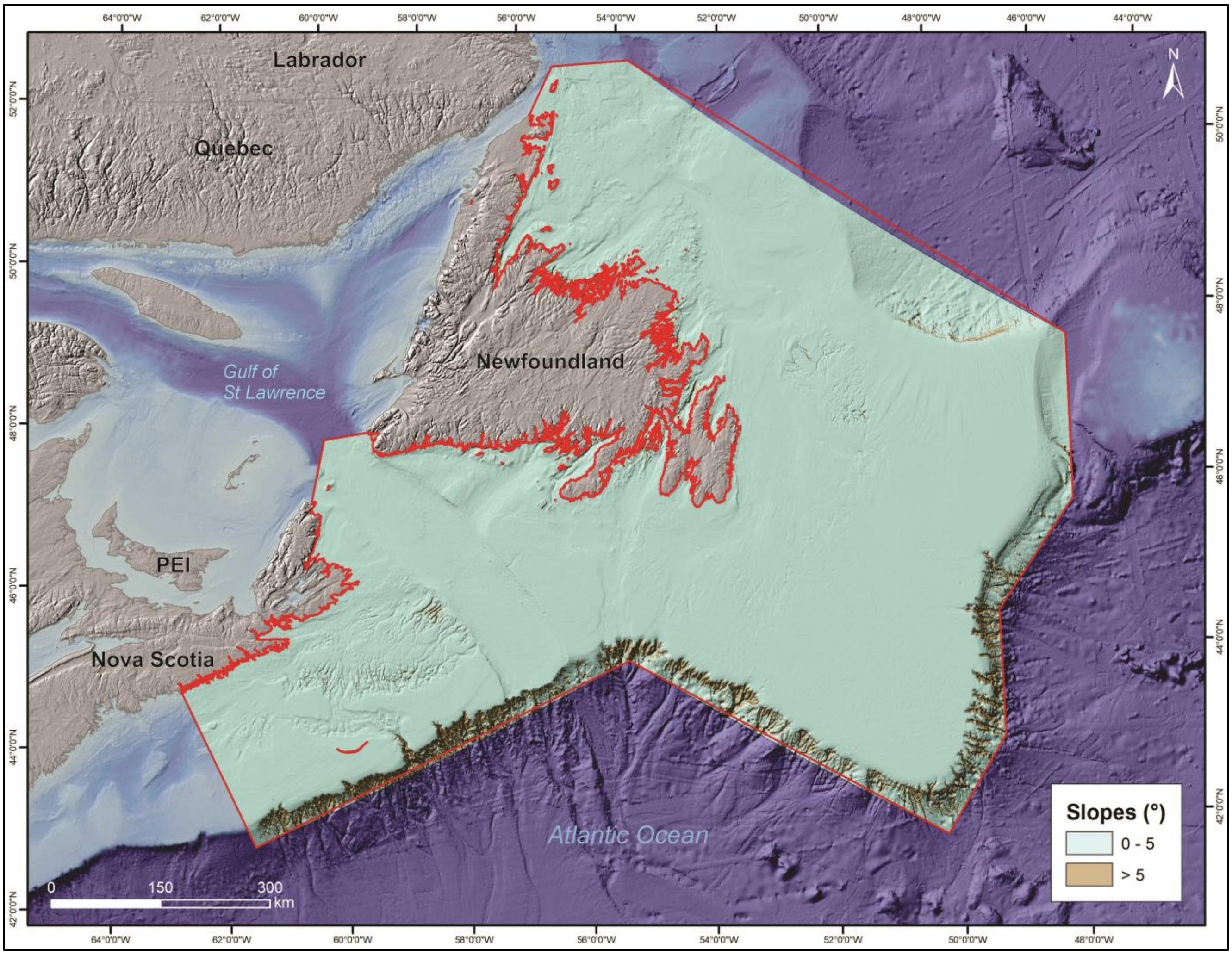


Figure 3: Computed slopes in the study area. Light blue areas indicate suitable slopes (ie. ≤ 5°), while brown areas indicate unsuitable slopes (ie. > 5°).

3.3 SURFICIAL GEOLOGY

Three sources were used for surficial geology: Philibert *et al.* (2024) on the Scotian Shelf, Cameron and King (2010) on the Southwestern Shelf of Newfoundland and Grand Banks areas and King (2014) on the Northeast Newfoundland Shelf. The spatial distribution of these layers is shown on figure 4. Due to the diverse origins and geological focuses of the surficial geology layers used in this study, efforts were made to standardize the geoscience language by adhering to a consistent and comparable terminology from one layer to another by using a language that provides information related to texture (e.g., sand, gravel, mud, etc.) and depositional environment or process (e.g., glacial, postglacial, marine, etc.) only.

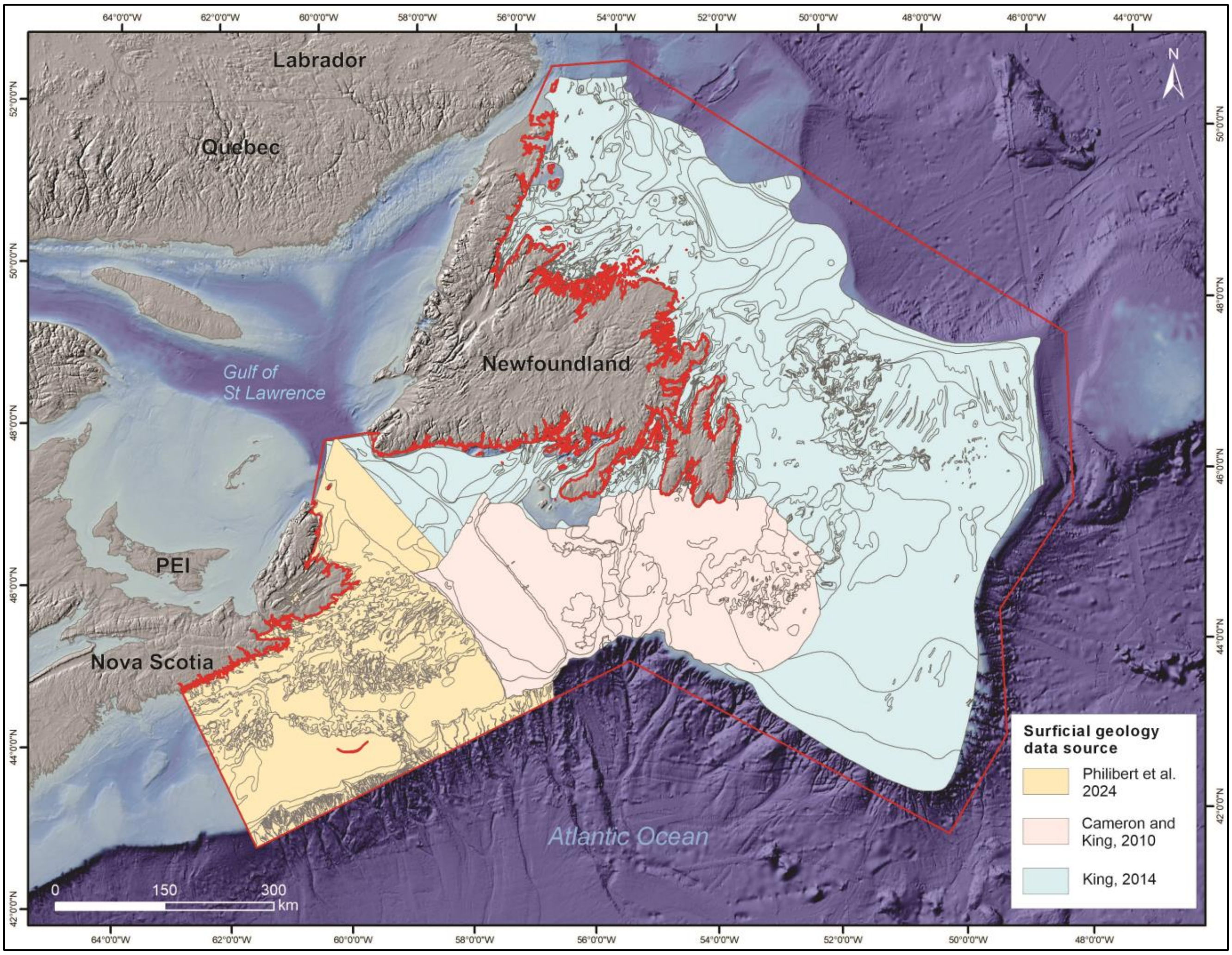


Figure 4: The distribution of the 3 surficial geology layers used in the suitability model. The yellow polygons are from Philibert et al. (2024), the pink polygons from Cameron and King (2010) and the blue polygons from King (2014).

A suitability index has been assigned to each standardized surficial geology category based on each type of turbine foundation. The indexes range from 1 to 3, with 1 being the lowest suitability and 3 being the most suitable. The index for a particular sediment category may vary for each foundation type, as each foundations have different geological requirements. For example, the optimal substrate for gravity foundations consists of low relief bedrock and/or stiff, overconsolidated mud or diamict. For pile foundations, sand and gravel are ideal, while suction caissons perform best in either sand, glaciomarine or postglacial mud deposits. The table below lists the indices assigned to each sediment classes (table 2).

Table 2 – Surficial geology suitability ranking per type of foundation.

Surficial Geology	Suitability ranking (1-3)		
	Gravity base foundations	Piled foundations	Suction caissons
Glacial Diamict	2	1	1
Post-Glacial Sand and Gravel	3	3	2
Post-Glacial Marine Mud	1	2	3
Glacial Marine Mud	1	2	3
Bedrock	2	1	1
Hemipelagic Mud	1	1	2
Overconsolidated Mud to Diamict	2	1	1
Glacial Sublittoral Sand	3	3	3
Pro-Glacial Sand and Gravel	3	3	2
Mass Transport Deposit	1	1	1
Interbedded Sand and Mud	1	2	2
Interbedded Silt and Mud	1	2	2
Overconsolidated Diamict	2	1	1
Undifferenciated Post-Glacial Sediments	2	2	2
Pro-Glacial Sand	3	3	3
Undifferenciated Bedrock or Glacial Diamict	2	1	1

3.4 QUATERNARY SEDIMENT THICKNESS

Two different datasets were used for Quaternary sediment thickness. In King (2014), seismic profiles were interpreted and spot thicknesses were extracted (using available in-house software ; Courtney, 2013) to cover the sector across the Grand Banks of Newfoundland and the Northeast Newfoundland shelf (green points on figure 5) while a dataset derived in a similar manner to King (2014) was developed for the Eastern Scotian Shelf (orange points on figure 5 ; King, unpublished). For both datasets, the thickness of Quaternary unconsolidated sediments was compiled into a GIS geodatabase. The data is derived from existing studies such as (Staal and Fader, 1997) on the Scotian Shelf but, where possible, it also differentiate a stacked sequence of various stratigraphic units based on their origins. This includes sub-glacial, proglacial, sub-littoral, littoral, and open marine paleo-environments. These analyses utilize an extensive grid of high and mid-resolution seismic reflection profiles collected over more than 40 years by the Geological Survey of Canada. These points consist of spot thickness measurements along the available survey tracks.

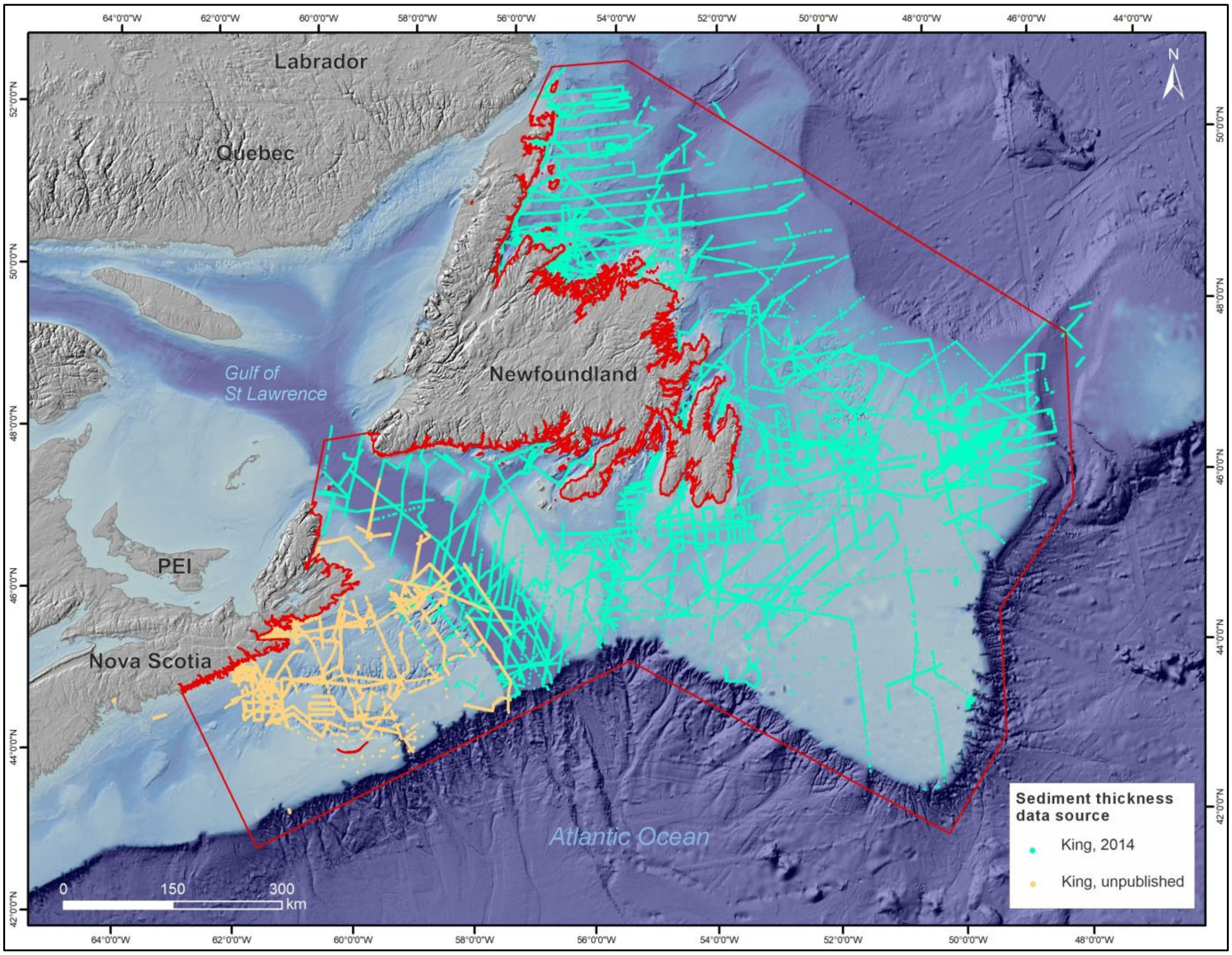


Figure 5: Spatial distribution of sediment thickness data inside the study area. The green points are from King (2014) and the light orange points are from King (unpublished).

The optimal sediment thickness required by each type of foundations are listed in the table below (table 3). Sediment thickness values within the optimal ranges were included in the model, while values outside of these ranges were excluded.

Table 3 – Optimal Quaternary sediment thickness required for each type of foundation.

	Type of Foundation		
	Gravity	**Pile**	**Suction caissons**
Sediment thickness (m)	≥ 0	> 25	> 10

3.5 BURIED CHANNELS

While sediment thickness and geotechnical suitability are crucial variables for offshore wind energy (OWE) projects, subsurface geology is often more complex than represented by thickness maps due to the spatial variability provided by geomorphic systems. One significant factor is the presence of buried channels—valleys with little or no surface expression yet filled with diverse sediment types commonly characterized by lateral and vertical heterogeneity. A common example on the Eastern Scotian Shelf are "tunnel valleys," which are formed sub-glacially by a mix of ice and meltwater flow under high hydraulic pressure. The seismic signatures of these infills are often insufficient to accurately identify sediment types or depositional environments, making it difficult to infer their geotechnical properties. Additionally, a single channel fill can exhibit highly variable seismic signatures. Currently, survey grids with sufficient resolution to trace these buried channels are rare.

Figure 6 illustrates the points where seismic tracks intersect individual channels. On the Grand Banks of Newfoundland, the outer boundary forms a broad arc, with its shoreward edge loosely defined by the presence of buried hard rock types that resisted sub-glaciofluvial erosion. The outer arc follows the most glacier-distal traces of tunnel valleys, cut primarily into more erodible Mesozoic and Cenozoic strata. In contrast, the pattern on the eastern Scotian Shelf is less uniform because nearly all offshore bedrock is subject to having been eroded by subglacial rivers.

One limitation is that individual channels on the Scotian Shelf, with the exception of Sable Island Bank, were not specifically targeted during database compilation. At Sable Island Bank, apparent channel widths and thalweg elevations have been documented, with widths ranging from several hundred meters to a few kilometers, and thalweg depths between 100 and 350 meters below sea level (bsl). Elsewhere, an arbitrary infill thickness of 180 meters was used as a proxy for buried channel infill. A broad area, geologically similar to the Sable Island Bank valleys, spans French Bank, Middle Bank, and eastern Banquereau. Although Banquereau also contains subsurface valleys, these have not been documented.

Another buried valley system rings the Misaine area, near the edges of a radiating pattern of tunnel valleys visible at the seabed. In this region, the 180-meter infill threshold is rarely met, despite thick, mud-rich channel deposits. An anastomosing or distributary tunnel valley pattern is typical where it can be imaged, with infill often reaching the depth range of OWE pile foundations. However, data gaps and the inability to map buried tunnel valley routes prevent these channels from being fully integrated into this suitability analysis. Nevertheless, they need to be considered as they may complicate future infrastructure siting decisions.

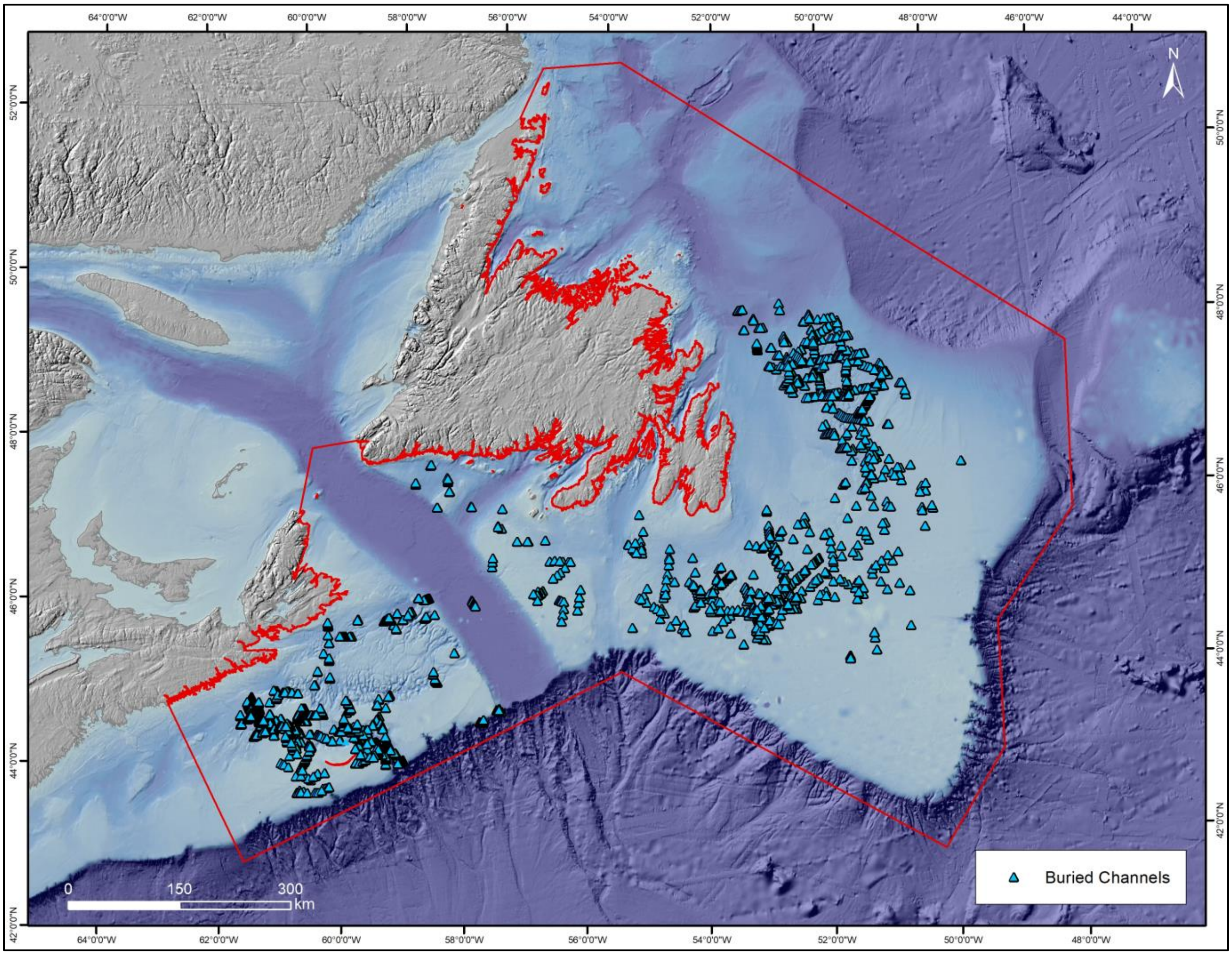


Figure 6: Spatial distribution of buried channels comprising mainly fluvial/glacially-excavated valleys with complex and diverse infill.

3.6 SEDIMENT MOBILITY INDEX

Sediment Mobility Index (SMI) is an index that quantifies sediment mobility by considering both the magnitude and frequency of the sediment mobilization process driven by waves and currents (Li et al., 2015; Li et al. 2024). The Sediment Mobility Index (SMI) is incorporated into the model as a general indicator of sediment mobility, which can pose risks to marine infrastructure by causing scour (erosion) or burial. These processes can alter environmental conditions beyond the structure's design parameters, potentially compromising its integrity and performance. Minimal to low mobility is ideal for all types of foundations, however scour may affect different OWE foundation types to different magnitudes. For instance, gravity base foundations have low tolerance for scour due to their lack of embedment in the surrounding soil. While scour and sediment mobility can be addressed during the design phase (e.g., through the installation of scour protection), doing so can increase costs and may present challenges in modeling. Proper evaluation of the SMI is therefore key to inform design and operational strategies and ensure the successful, sustainable deployment of OWE turbines.

The development of the SMI data used for this model is documented in (Li et al., 2024). The spatial distribution of sediment mobility index (SMI) inside the study area is shown on figure 7. Values of 0.1 or less are considered low mobility. Moderate mobility ranges between 0.1 – 0.5, moderately high sediment mobility between 0.5–1, high mobility between 1–2 and values above 2 are considered very high mobility. As discussed above, because sediment mobility is a geohazard that is not technically prohibitive to infrastructure development, and rather is a consideration for the design and construction phase of a project, it is incorporated in the model as a presence/absence input rather than a weighted or threshold value.

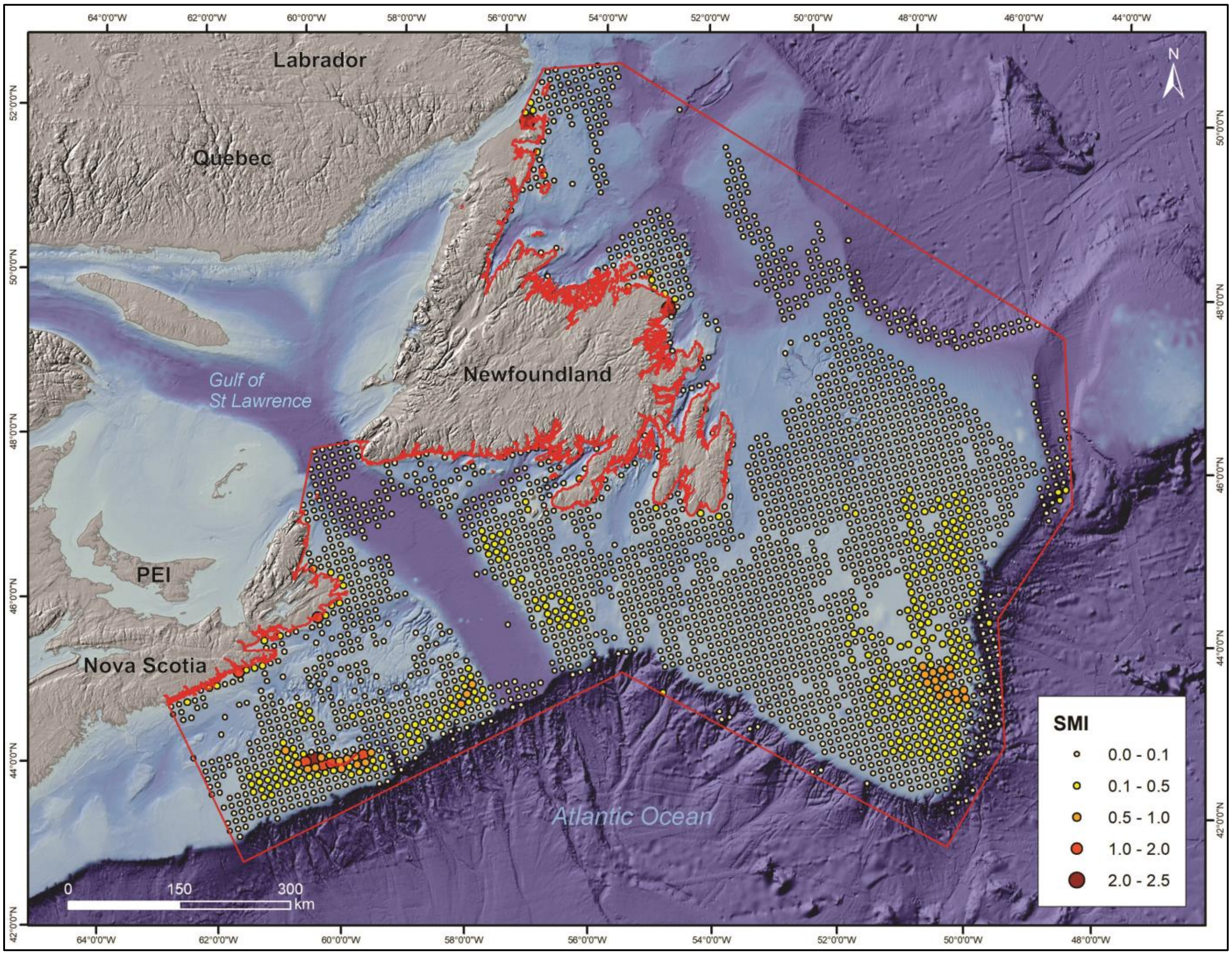


Figure 7: Sediment Mobility Index (SMI) classification from Li et al. (2024). Areas without legend symbols mean zero sediment mobilization.

3.7 AREAS EXPOSED BY LOWER POST-GLACIAL SEA-LEVELS

Following the Last Glacial Maximum, ~ 20 ka BP, the Laurentide Ice Sheet retreated from the study area and relative sea-levels varied by as much as 120 m when compared to the present day (Shaw et al., 2002). Immediately after retreat, areas closer to the edge of the continental shelf experienced lower relative sea-levels, such that the seabed was exposed as a terrestrial landscape across many of the shallow banks (e.g., Sable Island Bank, the Grand Banks). Areas closer to the modern coastline went through a more complex response, but many experienced subaerial conditions at some point between ice retreat and modern days. These environments are significant for offshore wind energy (OWE) developments due to three main factors: a) areas that once experienced coastal conditions would have been exposed to high-energy waves and currents, leading to extensive reworking and winnowing of finer sediments (Forbes et al., 1991; Stea et al., 1994) which commonly produces a coarse residual lag ranging from centimeters to metres thickness on the seabed, b) terrestrial environments may have facilitated the deposition and burial of organic-rich peaty or lacustrine sediments (Petrie et al., 2022) with diverse physical/behavioral engineering properties, c) buried coastal sediments might contain higher concentrations of biogenic gases, which could either be released at the seabed or accumulate within the sediments' pore spaces (Borges et al., 2016) (See section 3.9).

Reworking and winnowing of finer sediments in shallower areas of the glaciated continental shelf most commonly results in the development of a surficial lag of coarser sediments, with grain size largely determined by the source material. These lag deposits can be centimeters to metres thick and have very different engineering properties than the source sediments. Surficial maps emphasizing the immediate seabed character can mask this relationship. If thick and coarse enough, these lags deposits may pose an impediment to the installation of OWE infrastructure such as pile foundation driving refusal. Additionally, these processes can create poorly consolidated sedimentary layers due to rapid burial from sea-level changes, posing significant geotechnical challenges from an engineering perspective. Furthermore, in certain areas of the banks, such as the westernmost and eastern parts of Sable Island Bank, Banquereau, Middle Bank, and likely eastern Canso Bank and St. Pierre Bank, multiple stacked sand-rich deposits reveal significant erosion surfaces and abrupt changes in current direction. These layers are characterized by sharp, coarse-grained contacts, indicating episodes of rapid and substantial sediment transport, that may inhibit foundation emplacement (e.g., cause refusal in pile driving or provide a planar unconformity that reduces the strength of the sediments for supporting weight).

The presence of buried terrestrial sediment associated with past sea level low stands and subsequent transgression may result in problematic geotechnical properties of the soil. Peaty or gyttja (lacustrine) sediments are known for their high compressibility and/or low geotechnical strength (Nørgaard-Pedersen et al., 2022). High compressibility is especially problematic for gravity-based foundations, as the substantial weight of the foundation can lead to compression and uneven settling. Low geotechnical strength poses challenges for all foundation types.

To estimate the area of the seabed that potentially experienced sea-level lowstand conditions, a lowstand geography was derived from the paleotopography dataset by Godbout et al. (2023). The model comprises a series of 1 km spatial resolution rebound (isobase) surfaces, based on publicly available predictions from glacio-isostatic adjustment models ICE-5G, ICE-6G_C and ICE-7G_NA. These rebound surfaces were integrated with the GEBCO 2021 present-day elevation grid to reconstruct paleotopography for each temporal increment of the models and presented as raster files. All surfaces were combined to identify regions above zero meters elevation at any time from 20,000 years ago to present. The resulting surfaces (figure 8) are considered potentially susceptible to the hazardous conditions outlined above and are presented in the model as a presence/absence input.

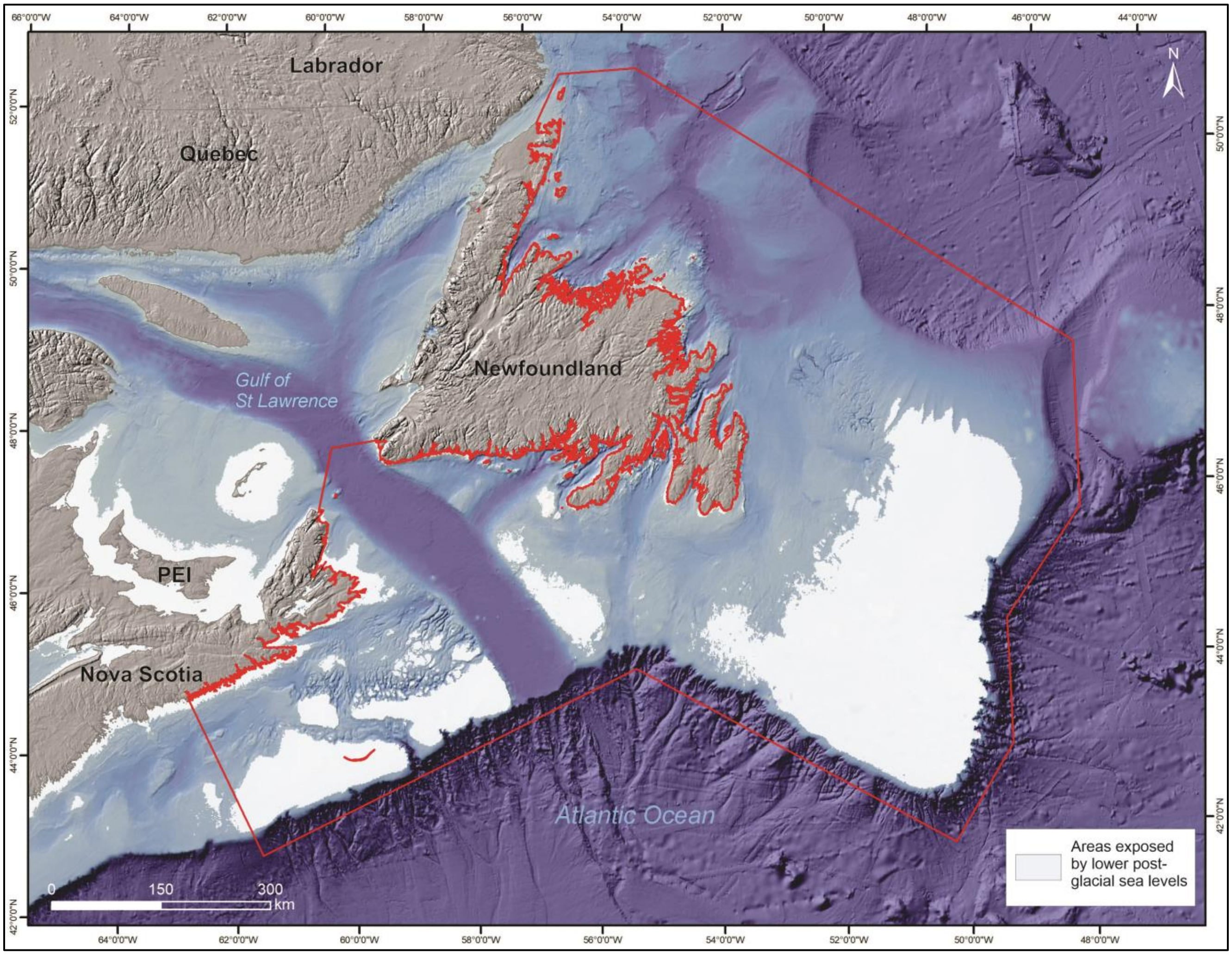


Figure 8: Areas exposed by post-glacial sea level lowstand. The white polygons show the surfaces that were above 0 m elevation from 20,000 years ago to present based on Godbout et al. (2023) model. These polygons represent the areas that are susceptible to contain buried terrestrial sediment within their stratigraphic sequence.

3.8 SALT

Salt diapirism poses a potential geohazard to offshore infrastructure through several mechanisms. These include the alteration, fracturing, or deformation of sediments or bedrock above or around the salt structure (Eamer et al., 2020), fluid flow or pore-pressure changes associated to traps or faulting caused by diapir movement (Petrie et al., 2022), and the induction of small-magnitude earthquakes or associated slope instability (Dahm et al., 2011; Schmuck and Paull, 1993). Seabed mapping data in the region indicate areas showing evidence of extensional and compressional stress, likely diminishing the structural strength of the host bedrock and sediments (Eamer et al., 2023, 2020).

The data used to map the distribution of salt diapirs are derived from (Shimeld, 2004) . The distribution of salt diapirs within marine sediment are shown on figure 9.

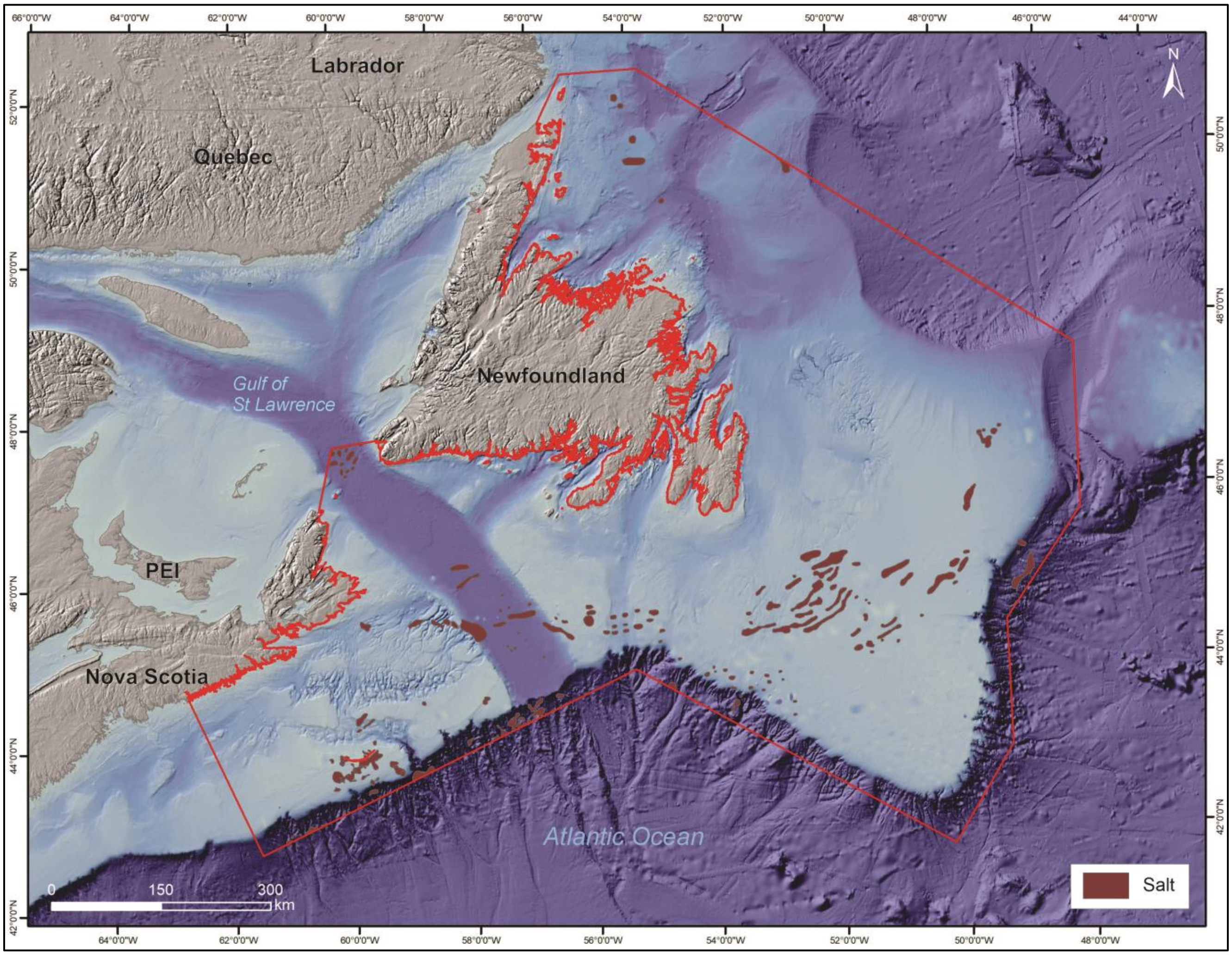


Figure 9: Distribution of salt within the marine sediment of the study area based on (Shimeld, 2004).

3.9 GAS CONTAINING SEDIMENTS

On the Scotian Shelf, while distribution of gas containing sediments can be localized to specific basins or buried strata, it is more generally widely spread across various areas (Fader, 1991). More recent data presented here includes details about the host medium and the depth of gas below the seabed, further highlighting its widespread occurrence (King et al., 2013; Josenhans et al., 1978). Since their discovery (King et al., 1970; King et al., 2013; Keiser et al., 1978), pockmarks have often been recognized as seabed indicators of fluid escape from below, with dense clusters frequently observed (Josenhans et al., 1978). Despite the widespread presence of pockmark fields, there is no definitive link between the fluid or gas source and current activity rates on the Scotian Shelf, with a few isolated exceptions. Pockmarks form primarily in mud-rich, basinal deposits, introducing a significant bias in the spatial distribution of fluid efflux. While both formational and in-situ biogenic gas sources are likely contributors (Keizer et al., 1978), other fluids may also play a significant role in their formation. Regions corresponding to drowned coastlines have been identified as areas most likely to both contain gas-rich sediments and exist at shallow depths suitable for fixed-bottom offshore wind energy infractructure (Borges et al., 2016).

Gas-rich sediments often exhibit high pore pressures, making them prone to instability due to natural gas expulsion or disturbances from surveying and construction activities (Nørgaard-Pedersen et al., 2022). Most of the documented occurrences in Figure 10 are found in mud-dominated, glacially carved basins at depths unsuitable for offshore wind energy (OWE) installations. However, very shallow gas pockets (ranging from a few meters to tens of meters) are common, and potential cable corridors could intersect them. Shallow gas detection, typically manifested as acoustic masking, is dependent on acoustic frequency, and even very low concentrations can be identified. This limitation, along with the restricted penetration of acoustic systems in most bank areas, introduces a bias in gas detection and is reflected in the distribution map. Although hydrocarbon exploration surveys conducted by industry are specifically designed to image shallow gas in bank areas, these surveys are not yet included in the Geological Survey of Canada (GSC) compilation. While most occurrences in bank areas are at depths beyond the range of pile-driving, their presence may still be relevant to planning and construction activities.

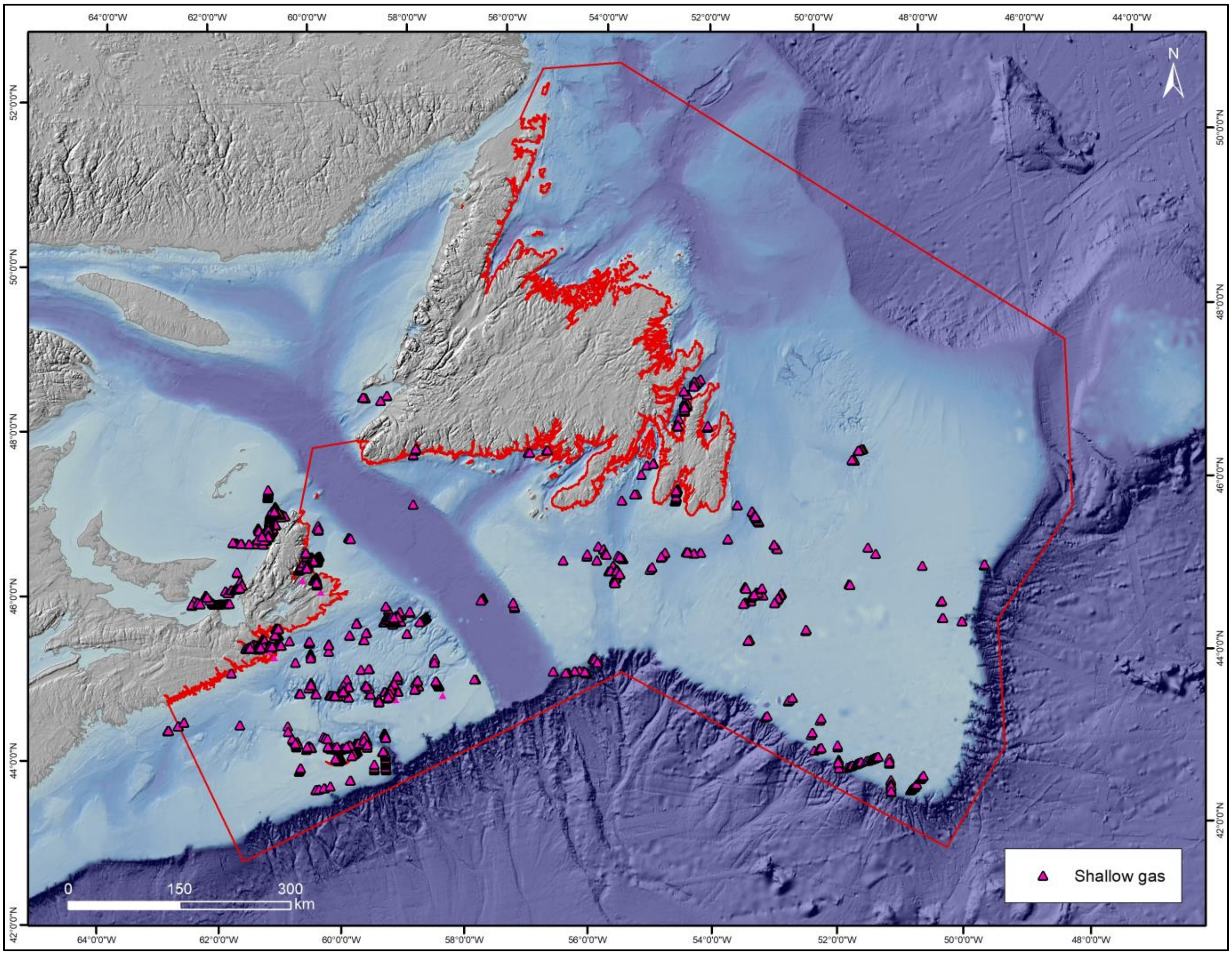


Figure 10: Spatial distribution of shallow gas in the study area. Note that no compilation exists north of 48◦ latitude.

4. MODEL BUILDING

The model was built in ESRI™ ArcGIS. First, a weight was assigned to each surficial geology category based on each type of turbine foundation. The indexes range from 1 to 3, 1 being the lowest suitability and 3 being the most suitable. The spatial distribution of each suitability index is shown on figure 11 for each type of foundation.

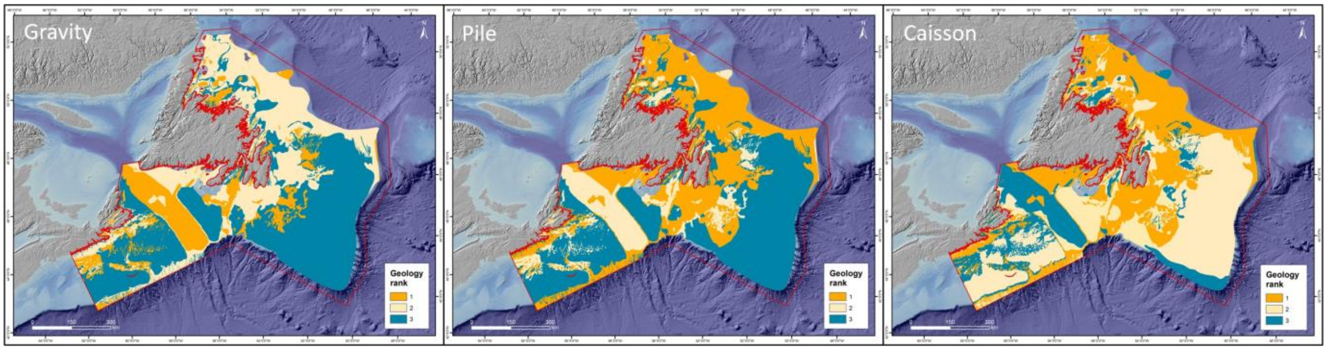


Figure 11: Geology rank for each type of foundation.

Depth values within the optimal ranges were extracted from the Gebco 2023 bathymetric data. The distribution of suitable depth for each type of foundation is shown on figure 12.

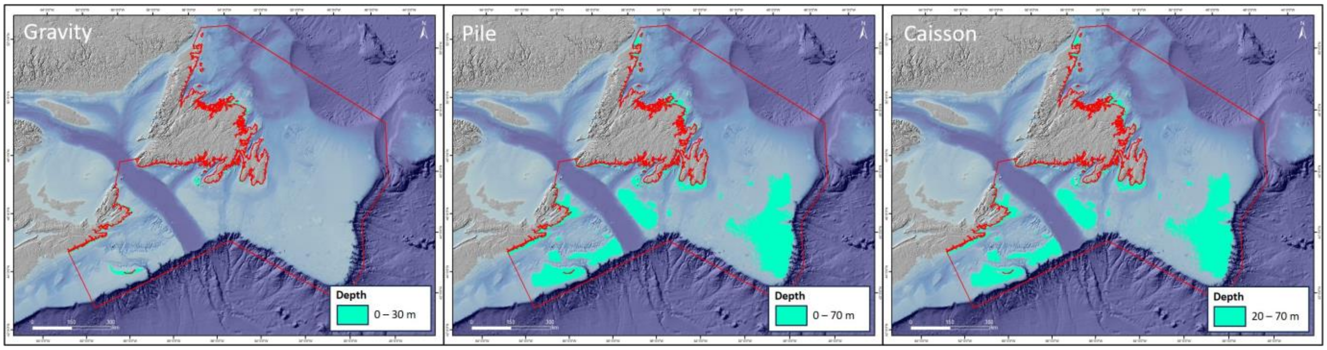


Figure 12: Suitable depth for each type of foundation. The optimal depth for gravity base foundation ranges between 0 and 30 m, between 0 and 70 m for pile and 20 to 70 m for suction caisson.

For each type of foundation, the surficial geology suitability was delineated within the areas of suitable depth. The resulting polygons were then compared to the minimum size requirement for a wind farm, which has been estimated to be approximately 70 km². This threshold was determined based on the recommendation of the Committee for the Regional Assessment of Offshore Wind Development in Nova Scotia, which suggests that the initial wind park will likely have a capacity of no less than 500 MW. Recent trends in the capacity density of newly installed wind farms indicate that future Canadian offshore wind farms could achieve a capacity density ranging from 3 to 7 MW/km². Consequently, the minimum area required for a 500 MW wind park would be between approximately 70 and 170 km² (Committee for the Regional Assessment of Offshore Wind Development in Nova Scotia, 2024). Any suitable polygons that were smaller than this minimum size were thus filtered out of the model. Figure 13 illustrates the distribution of geology indices within each polygon deemed suitable based on size and depth criteria.

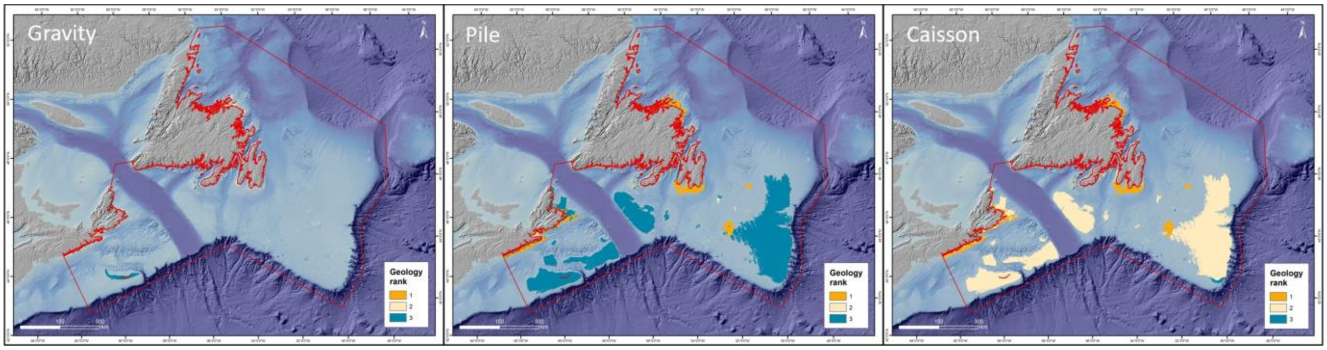


Figure 13: Surficial geology rank inside suitable depth polygons for each type of foundations.

Sediment thickness values from within these water depth- and surficial geology-limited polygons were extracted from the two sediment thickness datasets via an overlay. Statistics were computed from the points contained within each physiographic region to determine the variability of sediment thickness and potential for broad packages of sufficiently thick sediments for foundations such as piles or caissons (figure 14).

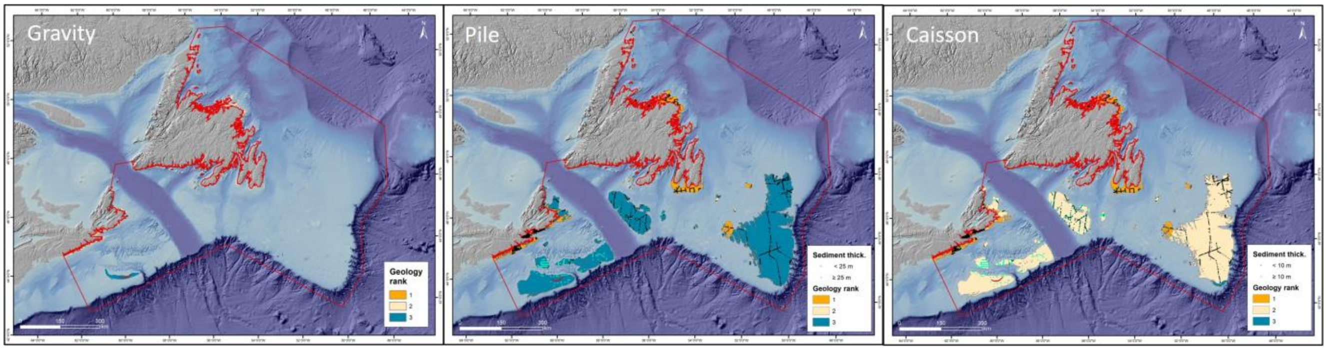


Figure 14: Sediment thickness and geology rank inside the suitable depth polygons for each type of foundations. The colored points show the points that are within the suitable sediment thickness range. The black points are less than the minimal suitable thickness.

Similarly, the buried channels, SMI, the areas exposed by post-glacial sea-level lowstand, salt diapir and shallow gas data were overlain on the areas defined by water depth and surficial geology and statistics were computed (figures 15 to 19).

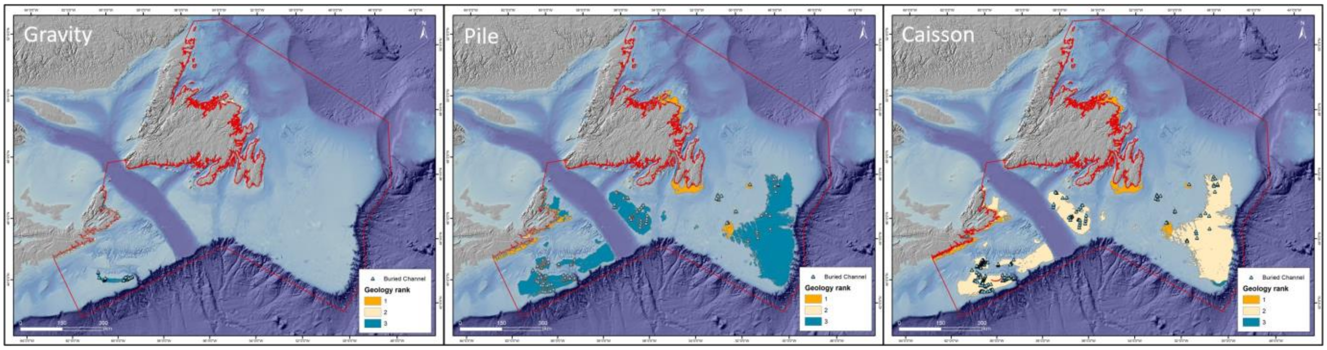


Figure 15: Buried channels and geology rank inside the suitable depth polygons for each type of foundations.

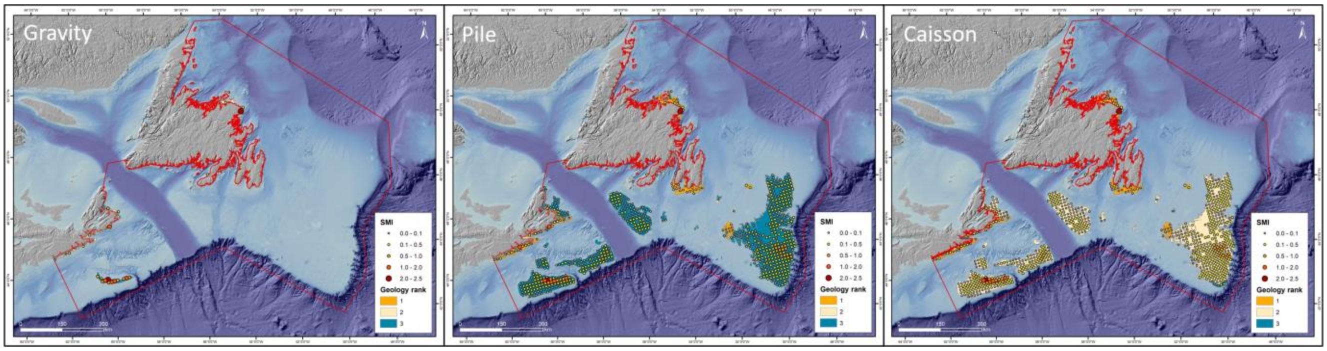


Figure 16: Sediment mobility index and geology rank inside the suitable depth polygons for each type of foundations.

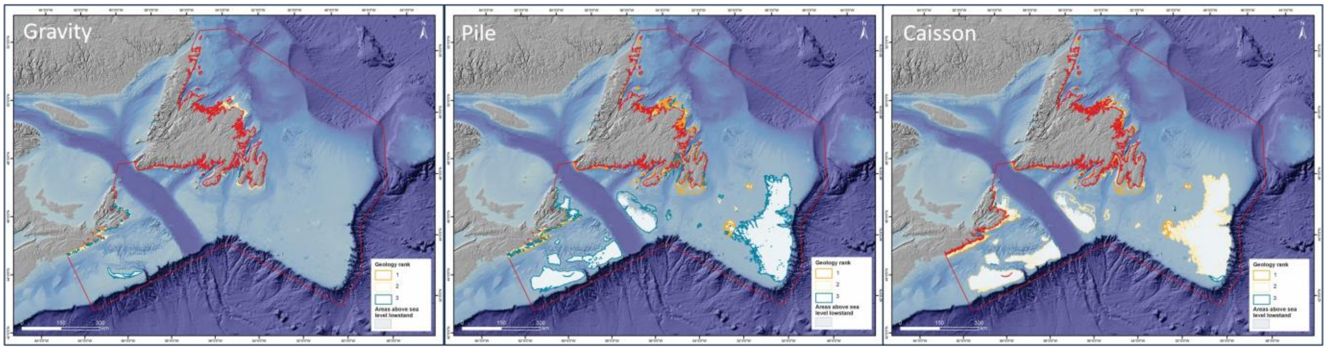


Figure 17: Areas exposed by post-glacial sea level lowstand and geology rank inside the suitable depth polygons for each type of foundations.

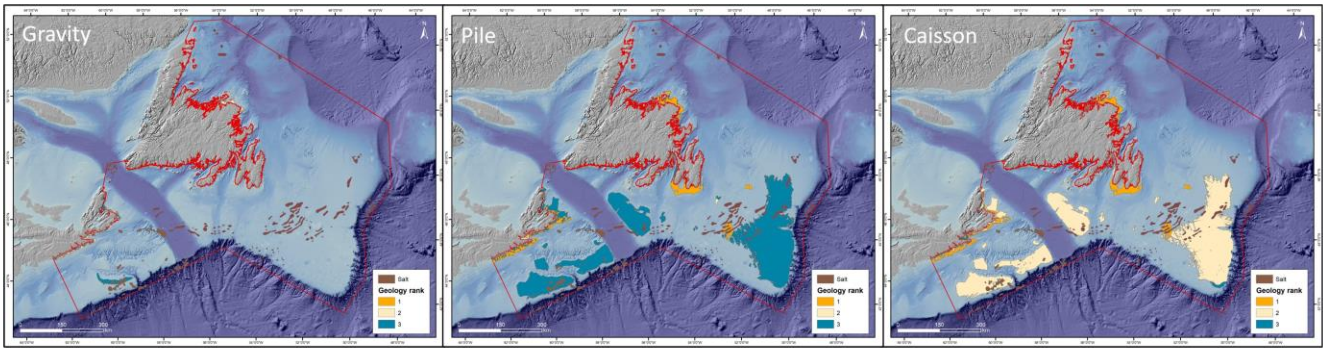


Figure 18: Salt and geology rank inside the suitable depth polygons for each type of foundations.

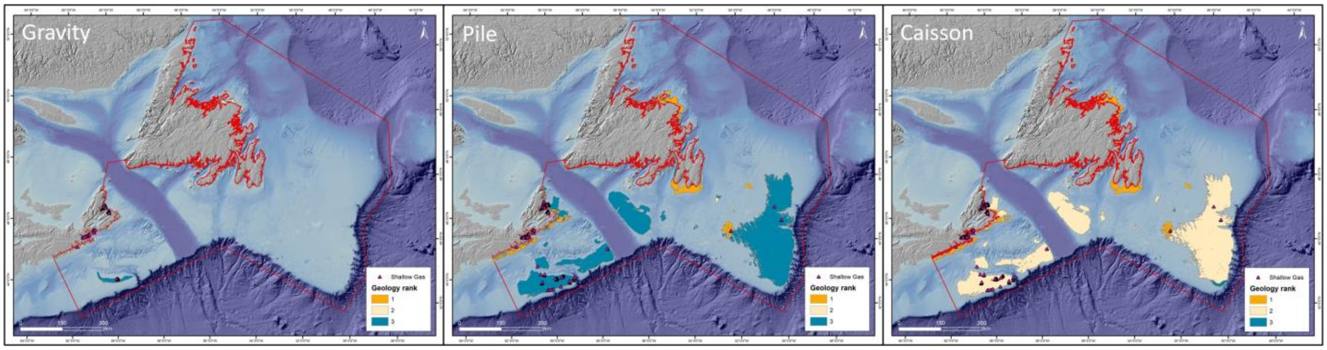


Figure 19: Shallow gas and geology rank inside the suitable depth polygons for each type of foundations.

5. RESULTS

5.1 GRAVITY BASE FOUNDATIONS

As gravity base foundations are ideally sited in water depths between 0 to 30 m, water depth is a significant limiting factor for this foundation type in the study area. Only 5424 km² of seabed exists between 0 and 30 m water depth which corresponds to less than 1% of the study area. Those areas are mainly located in the shallow coastal settings including around Sable Island. The areas that are located all along the shore span from the coastline to approximately 10 to 12 km offshore. Among those areas, 0.3% have an index of suitable surficial geology of 3, 0.4% have an index of 2 and 0.05% is characterized by an index of 1 (table 4).

The model results for gravity base foundations are shown on figure 18. For further analyses, where statistics were calculated from other metrics (e.g., SMI, sediment thickness), the resultant polygons were defined into physiographic regions which correspond to the black numbers on figure 18. Five main physiographic regions were defined for gravity base foundations i.e. 1) Eastern Shore of Nova Scotia, 2) Cape Breton Island, 3) Sable Island Bank, 4) East of Placentia Bay and 5) Northeastern Newfoundland. The detailed results for each of these physiographic regions are shown on figures 21 to 24 in Annex 1.

Table 4: Proportion of surficial geology ranks inside the areas of suitable depth (0 – 30 m) for gravity foundations

Surficial geology rank	Area km²	% of whole study area
1	325	0.05
2	2 678	0.41
3	2 421	0.37
Total	**5 424**	**0.82**

The areas that are characterized by a geology rank of 3 (most suitable) corresponds mainly to post-glacial sand and gravel and gravelly or cobbly glacial diamict. The areas with an index of 2 mostly correspond to bedrock that is outcropping or covered with a thin and commonly patchy layer of sediment. The area with a geology index of 1 (least suitable) correspond for the most to post-glacial mud mostly found in inlets along the coast. The areas with suitable surficial geology are in “patchy” areas near to the Nova Scotia coastline, likely reflecting the transgressive nature of the seabed, where mobile sediments have been reworked and deposited in bathymetric lows. Large areas of moderate suitability (> 50%) are mostly exposed bedrock, which is suitable as a supportive substrate but likely requires a great deal of surface preparation. The area on Sable Island Bank is most suitable, classified as sand and gravel. A notable inner shelf bench in Placentia Bay, Newfoundland, is classified as most suitable, while thin sediments over bedrock characterize the remainder of shallow areas around Newfoundland.

Slope does not present any notable constraints. Sectors where the slope is 5° or less extend over 630 000 sq km which corresponds to 96% of the study area. The sectors where the slope is more than 5° are mainly located along the continental slope and on the steeper slopes of the channels or tunnel valleys incised on the shelf.

Infilled channel systems are present in the shallow seabed around Sable Island (as discussed in the above section) but are likely deeply buried enough to not pose any challenges to gravity base foundations infrastructure. No other areas overlapping with the gravity base foundations water depth suitability indicate buried channel systems.

Most of SMI values along the shore of Nova Scotia are considered low to moderate mobility, except for Country Harbour and Isaac Harbour, close to Fourchu on Cape Breton Island as well as Alder Point. The area around Sable Island Bank, due to its exposed location, extreme metocean conditions, and surficial geology, is classified as high SMI. This would need to be considered at the planning and engineering stage as gravity base foundations are particularly susceptible to scour. The shallow bench in Placentia Bay is of a low SMI in addition to the most suitable surficial geology class. A high SMI on the "Strait Shore" in Northeast Newfoundland is notable.

Due to shallow water depths, nearly all of the area classified for gravity base foundation suitability analysis experienced subaerial conditions due to low sea-levels since the Last Glacial Maximum. Gravity base foundations are particularly susceptible to settling; the potential for organic-rich beds in the shallow stratigraphy would need to be investigated due to the high compressibility of these layers.

Areas overlapping with postglacial low sea-levels along the Nova Scotia coastline are the only areas where gas-containing sediments are found, consistent with the link between preserved coastal stratigraphy and biogenic gas. An example of this is in Chedabucto Bay and in Sydney Bight.

Salt diapirism within OWE suitable sub-areas is only evident under the Sable Island Bank area, and this is likely of a sufficient depth, so as to not be relevant to this discussion.

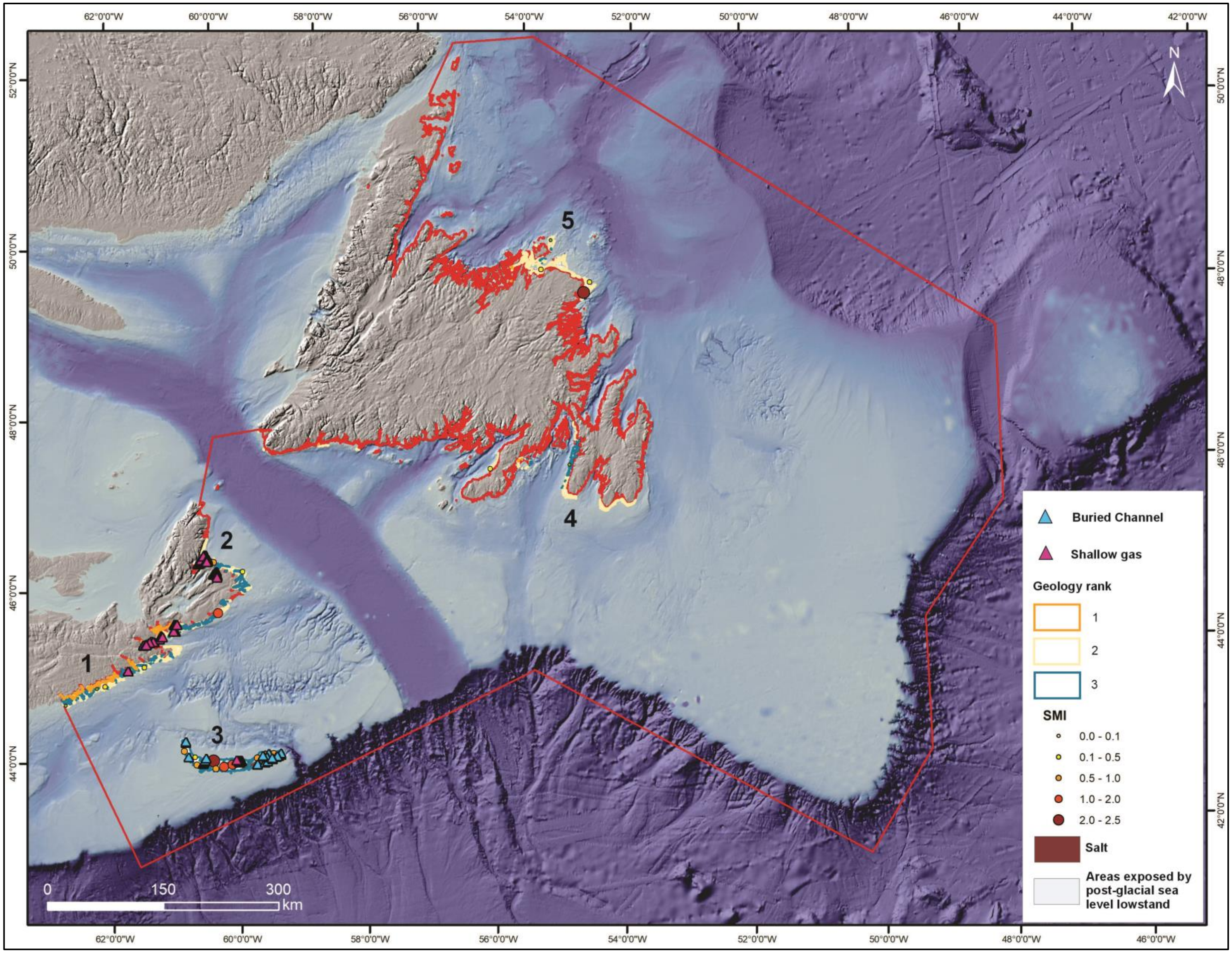


Figure 20: Seabed characteristics inside suitable polygons for gravity foundations. The resultant polygons were defined into physiographic regions which are identified by black numbers on the figure. The detailed results within each of these physiographic region are shown on figures 21 to 24 (annex 1).

5.2 PILE FOUNDATIONS

Pile foundations, whether monopile, tripod, or jacket, are considered suitable for water depths between 0 and 70 m, which covers nearly 100 000 km^2 or 15% of the seabed within the study area (table 5). The primary surficial geology nominal rank is 3, or more suitable, reflecting the fact that the primary locations where these water depths are found are on shallow offshore banks which typically have a sand and gravel seabed type.

The model results for piled foundations are shown on figure 19. The black number corresponds to the main physiographic regions that were defined based on the resultant polygons. Ten physiographic regions were defined for pile foundations i.e. 1) Eastern Shore of Nova Scotia, 2) Cape Breton Island, 3) Middle Bank, 4) Sable Island Bank, 5) Banquereau Bank, 6) St. Pierre Bank, 7) Green Bank, 8) East of Placentia Bay, 9) Grand Bank and 10) Northastern Newfoundland. The detailed results for each of these physiographic regions are shown on figures 25 to 29 in Annex 2.

Table 5: Proportion of surficial geology ranks inside the areas of suitable depth (0 – 30 m) for pile foundations.

Surficial geology rank	Area sq km	% of whole study area
1	12 260	1.86
2	847	0.13
3	86 007	13.04
Total	99 114	15.03

The areas characterized by the surficial geology rank of 3, or most suitable, are overwhelmingly postglacial sand and gravel, but the expression of that surficial geology at depth is notably different across the banks and in areas close to the coast. For instance, Sable and Middle Bank as well as Banquereau, on the Scotian Shelf, generally consist of thick (> 25 m) Quaternary sediments under sand and gravel, whereas the area east of Cape Breton and the Grand Bank all generally consist of shallow sediments, thus the sand and gravel are assumed to form a more surficial veneer rather than a thick package suitable for driven piles. Generally, available data is insufficient to conclude that sediments are not thick enough in coastal regions around both Nova Scotia and Newfoundland. However, the existing data predominantly indicates that sediment thickness is relatively thin, typically less than 25 m. Canso Bank and Misaine Bank (two areas in figure 26 not given designations due to insufficient subsurface data) are large enough to host offshore renewable infrastructure and consist of suitable surficial geology. St. Pierre and Green Bank, located south of Newfoundland, exhibit highly variable subsurface geology, with sediment depths ranging significantly from no sediment cover to up to 525 meters thick. Coastal areas with a surficial geology rank of 1 or 2, or low/moderate suitability, are predominantly shallow areas near the coast with insufficiently thick sediments for driven piled foundations, such as exposed bedrock or glacial diamict.

Slopes are not a factor in the areas considered for piled foundations. Salt diapirs exist under several of the model result areas, including Sable Bank, Banqureau, St. Pierre Bank, and the Grand Banks.

Buried channel systems occur frequently in the mid- to outer-shelf shallow bank systems outlined in Figure 19, such that the heterogenous subsurface geology typically found in these systems would likely be encountered by piled installations on Middle, St. Pierre, and Sable Island Banks, as well as Banquereau. Any installation seaward of these systems (e.g., were infrastructure to be emplaced on Grand Banks) would likely encounter buried channel systems if a landfalling cable or pipeline required burial.

Sediment mobility is generally moderate to high across most of the outer bank locations considered for piled foundations. However, notable exceptions to this pattern are found in the western parts of the Scotian Shelf banks, the area east of Cape Breton, and the banks south of Newfoundland. Closer to the coast, the SMI is more variable, likely due to the high spatial variability in sediment grain size, which affects susceptibility to entrainment. Sable Island Bank is the only regions with small areas (mostly around the Sable Island) classified with a "very high" SMI.

Similar to gravity base foundations, much of the area shown in figure 19 was once subaerially exposed during periods of lower relative sea levels, including all of the Scotian Shelf banks and the Grand Banks. Most coastal areas of Nova Scotia also experienced these conditions, with the exception of the outer portion of the inner shelf east of Cape Breton. Although St. Pierre Bank may have been partially submerged during the lowstand, even areas that were not fully exposed likely experienced nearshore, shallow water conditions. Consequently, the risks associated with paleo-coastal environments, such as geotechnically challenging sediments and gas charging still apply.

Gas-containing sediments overlap with the areas in Figure 19, most notably Sable Island Bank and the nearshore areas of Nova Scotia and southeastern Newfoundland. These areas are associated with the sea-level lowstand and may be the result of buried organic sediments that are producing biogenic gasses. Deeper basins with thicker sediments, like those found north of Sable Island Bank and elsewhere in the rugose areas of the shelf, frequently host gas-charged sediments – a consideration for any infrastructure that is to connect an offshore wind energy installation and the mainland (e.g., landfalling cable).

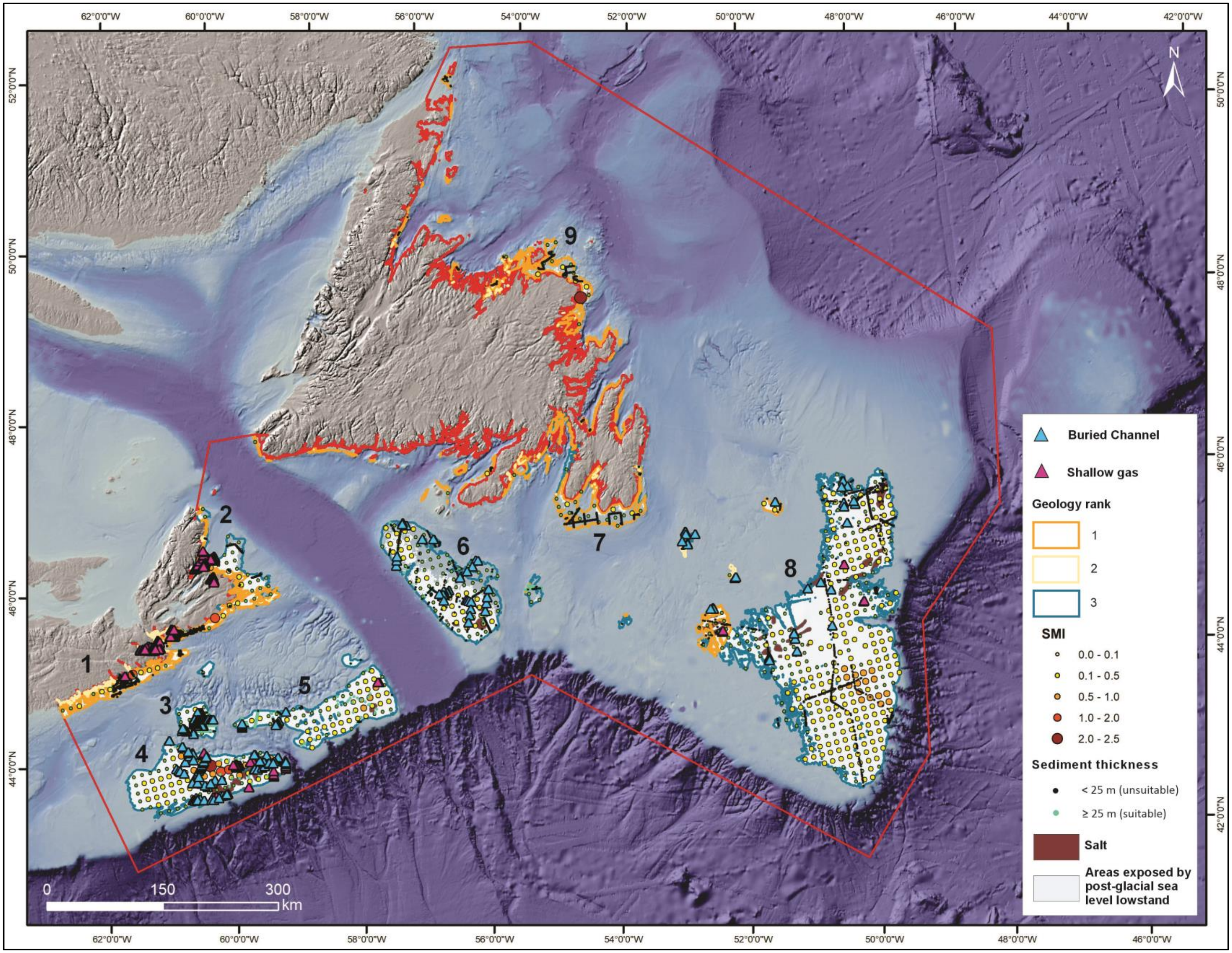


Figure 21: Seabed characteristics inside suitable polygons for pile foundation. The resultant polygons were defined into physiographic regions which area identified by black numbers on the figure. The detailed results within each of these physiographic regions are presented on figures 25 to 29 in annex 2.

5.3 CAISSON FOUNDATIONS

Suction caissons are ideally sited in water depths ranging from 20 to 70 m, due to a high susceptibility to scour at shallow water depths, and a lower limit of cost/engineering feasibility. Within the study area, 99 249 km² or 15% of the seabed falls within this area. As with areas considered for other foundation types, these areas are mainly focused along the coast and on shallow offshore banks. Among those areas, 0.19% have an index of suitable surficial geology of 3, 12.99% have an index of 2 and 1.87% is characterized by an index of 1 (table 6).

The model results for caisson foundations are presented in figure 20, where the black numbers indicate the physiographic regions delineated by the resultant polygons. Ten physiographic regions were identified for caisson foundations, consistent with those defined for piled foundations. Detailed results for each of these physiographic regions can be found in Figures 30 to 34 in Annex 3.

Table 6: Proportion of surficial geology ranks inside the areas of suitable depth (20 – 70 m) for caisson foundations.

Surficial geology rank	Area sq km	% of whole study area
1	12 311	1.87
2	85 678	12.99
3	1 260	0.19
Total	99 249	15.05

As the water depth thresholds are similar to those of the piled foundations, the seabed areas under consideration thus represent a similar surficial geology. However, due to the engineering parameters considered more suitable for caissons including finer sediments than those for piles, more of the offshore is designated as a moderate suitability for caissons. As discussed above, most of the seabed found on the outer banks of Newfoundland and Nova Scotia is classified as postglacial sand and gravel. However, this interpretation comes with a caveat (which will be further explored in the following section): it is based largely on regional data. The surficial geology may indeed reflect a more heterogenous, complex, and potentially contain finer sediments than what is represented by the postglacial sand and gravel classification. This is likely to be corroborated by recent data collection in many of these offshore areas (Broom et al., in prep; Desiage et al., in prep). Areas with ideal surficial geology include an area in the southern tail of Grand Banks and areas very near to shore and confined to inlets in Nova Scotia and Newfoundland. The latter almost certainly reflects modern sedimentary processes where fluvial outputs and coastal processes result in fine sediment depocenters ideal for caisson emplacement.

As with other foundation types, slopes over 5% do not occur within any of the model result areas based on the bathymetric data resolution. As with piled foundations, salt diapirism exists under Sable Island Bank, Banquereau, St. Pierre Bank, and the Grand Banks.

The threshold sediment depth required for caissons, for this model classified as > 10 m, is less constraining than the threshold considered for driven pile foundations (> 25 m). Therefore, a broader model result for suitable sediment depths is encountered, indicating that areas east of Cape Breton and the banks south of Newfoundland host sufficiently thick sediments for suction caissons (provided the sediment type would support them). Areas deemed suitably deep for piles such as the banks offshore Nova Scotia are also included here, yet the Grand Banks again is considered to be a thin veneer of unconsolidated sediment unsuitable for penetrating-type foundations such as caissons.

The discussion of sediment mobility index, gas-containing sediments, buried channel systems, and paleo-coastal sediments found at lowstand locations provided above for piled foundations is essentially unchanged for caissons. However, it's notable that despite similar spatial distributions for these data, SMI and gas have a greater effect on the sustainability of a caisson foundation than that of a pile due to the pore pressures required to emplace a caisson and the lower tolerance for scour, whereas buried channel systems likely affect a piled foundation to a greater degree due to the greater penetration requirement.

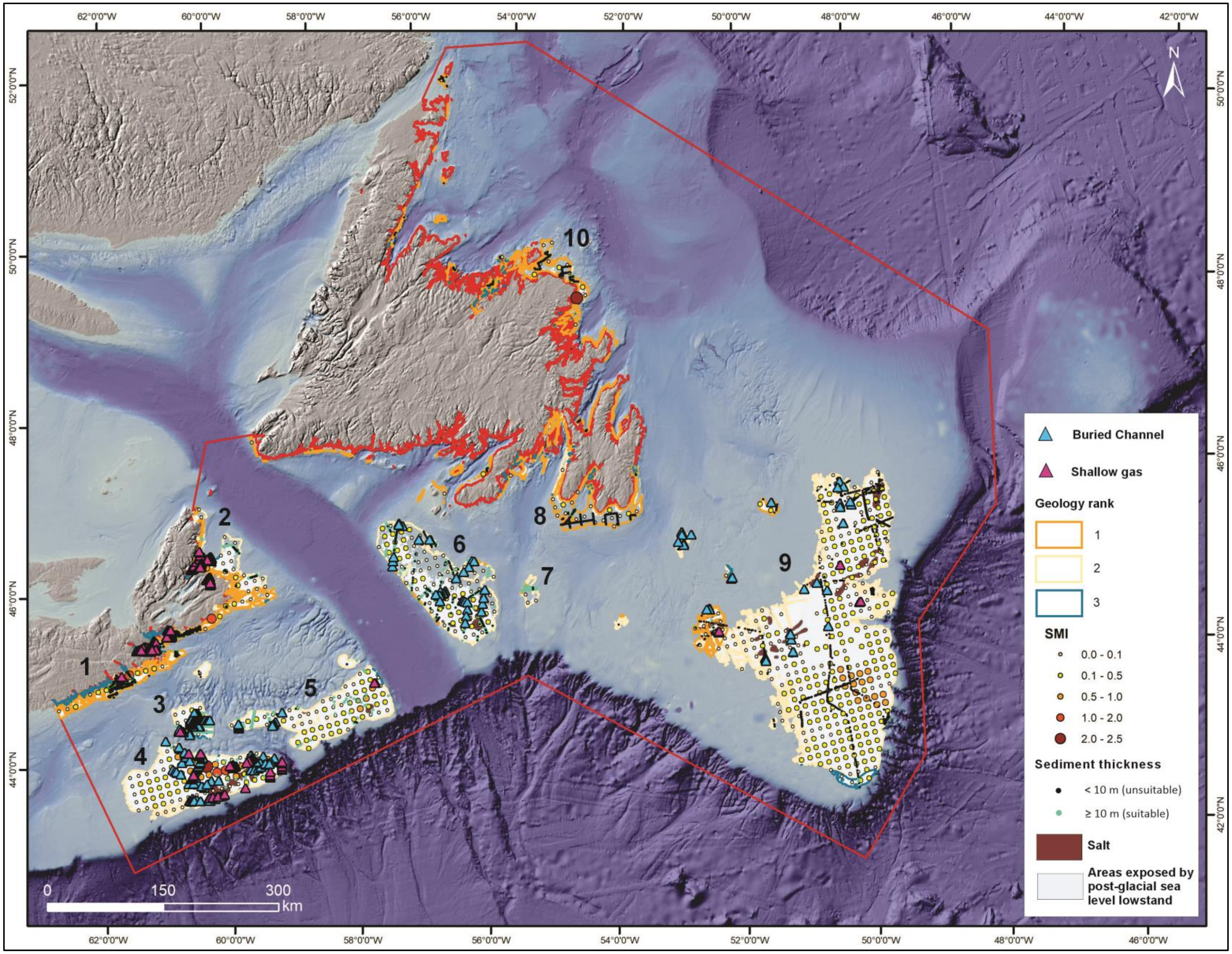


Figure 22: Seabed characteristics inside suitable polygons for caisson foundation. The resultant polygons were defined into physiographic regions which area identified by black numbers on the figure. The detailed results within each of these physiographic regions are shown on figures 30 to 34.

6. MODEL LIMITATIONS

It's important to recognize that this study does not account for other aspects of offshore installations that may also depend on specific geological data, such as pipelines, inter- and intra-farm cables, and cable landfall sites. While some of the input layers used in developing the suitability model are likely relevant to these components, they may require additional data beyond the scope and scale of what is provided here. These elements are critical for ensuring the sustainable and cost-effective development of future projects.

Offshore wind energy, compared to many other renewable energy technologies, has benefited from substantial recent investment and research, leading to rapid advancements. As a result, building a model based on current constraints (e.g., water depth, sediment thickness) risks becoming quickly outdated. For example, the increasing size and capacity of turbines require larger and, in the case of piles, deeper-driven foundations. This trend pushes fixed-bottom foundations into deeper waters, particularly for larger offshore wind installations (Musial et al., 2023). Therefore, the parameters used in this study's model should be seen as a baseline for 2024, with the understanding that they are likely to change.

The sediment depth dataset, derived from interpretations of often scanned archival 2D seismic records, lacks spatial continuity in most areas (King, 2001). For regions like eastern Cape Breton, where subsurface geology is likely highly heterogeneous, relying on a single 2D seismic line near the outer edge of the area of interest is insufficient to draw broader conclusions about sediment depth. Additionally, a simple "depth of Quaternary" measurement does not fully account for the potential complexity of the subsurface. For instance, a thick, well-sorted sand layer is not equivalent to a complex sequence of glaciogenic sediments, which may include a transgressive lowstand sedimentary sequence. Such detailed analyses can only be conducted at the site level and are not feasible or relevant on a regional scale.

There is a general lack of geotechnical context supporting many of the variables included in this study. For example, the engineering properties of ice-contact sediments can vary widely, ranging from overconsolidated diamict with frequent boulders (posing a high risk for pile-driving refusal) to non-cohesive ablation till, which may consist mostly of well-sorted sands. Other variables are similarly impacted by this lack of geotechnical context. For instance, the potential geohazard posed by buried coastal organic sediments remains uncertain because these sediments have not been sampled or subjected to laboratory testing—the assumption of geohazard is based solely on literature and tests conducted on sediments from other regions. Additionally, sediment mobility, which is inferred from grain size and hydrodynamics, would be influenced by factors such as cohesion (e.g., hardpan or bioherm development), which are not accounted for in this study. Finally, the classifications used (e.g., postglacial sands and gravels being deemed ideal for offshore wind installations) are based on assumptions and suitability assessments from other regions, which may not accurately reflect the geotechnical properties of Atlantic Canada's geological units.

Many of the factors identified as geohazards in this study—such as salt diapirs, lowstand paleogeography, gas-charged sediments, and sediment mobility—merely indicate the potential presence of a geohazard, which has yet to be thoroughly investigated. These areas must be the focus of any site-specific studies or data collection campaigns, and their inclusion in this model is intentionally broad. Additionally, other critical geohazards for offshore infrastructure, such as liquefaction potential or the presence or likelihood of subsea landslides, have not been systematically characterized across the study area and are therefore not included in the model.

Finally, in Atlantic Canada's offshore regions, past data collection efforts have primarily been driven by other research priorities, leading to extensive data on the outer shelves and continental slope. As a result, priority areas for offshore renewable energy remain understudied and require significant effort and investment to collect data to the necessary standard. It is possible that through new data collection, previously unknown variables and parameters crucial for offshore renewable energy will emerge. The purpose of this report and the associated model is to guide data collection efforts, ensuring the most efficient and effective campaigns for future decision-making in Atlantic Canada’s offshore regions.

7. REFERENCES

ABSG Consulting, 2021. Floating offshore wind turubine development assessment. OCS Study - BOEM 2021-030.

Borges, A.V., Champenois, W., Gypens, N., Delille, B., Harlay, J., 2016. Massive marine methane emissions from near-shore shallow coastal areas. Sci. Rep. 6, 27908. https://doi.org/10.1038/srep27908

Broom, L., Eamer, J., Fraser, P., Hayward, S., Manning, D., Meslin, P., Patton, E., Leger, M., Norris, M., Priddle, S., and Knaga, P. In prep. RV Coriolis II 2024001: Seabed mapping of Middle Bank, offshore Nova Scotia. Geological Survey of Canada, Open File.

Cameron, G., King, E., 2010. Quaternary geology of Laurentian Channel and Southwest Grand Banks of Newfounland. Geol. Surv. Can. Open File 6451.

Collie, J.S., (Vic) Adamowicz, W.L., Beck, M.W., Craig, B., Essington, T.E., Fluharty, D., Rice, J., Sanchirico, J.N., 2013. Marine spatial planning in practice. Estuar. Coast. Shelf Sci. 117, 1–11. https://doi.org/10.1016/j.ecss.2012.11.010

Committee for the Regional Assessment of Offshore Wind Development in Nova Scotia, 2024. Interim Report - Regional Assessment of Offshore Wind Development in Nova Scotia. March 2024. 73pp.

Coughlan, M., Long, M., Doherty, P., 2020. Geological and geotechnical constraints in the Irish Sea for offshore renewable energy. J. Maps 16, 420–431. https://doi.org/10.1080/17445647.2020.1758811

Courtney, R.C., 2013. Canada GEESE 2: Visualization of Integrated Marine Geoscience Data for Canadian and Proximal Waters. Geosci. Can. 40, 141. https://doi.org/10.12789/geocanj.2013.40.0010

Dahm, T., Heimann, S., Bialowons, W., 2011. A seismological study of shallow weak micro-earthquakes in the urban area of Hamburg city, Germany, and its possible relation to salt dissolution. Nat. Hazards 58, 1111–1134. https://doi.org/10.1007/s11069-011-9716-9

Desiage, P.-A., Philibert, G., Campbell, L., Robertson, A., Bompas, R., Frost, D., MacDonald, K., Patton, E., Smith, B., and Whorley, K. In prep. NR Coriolis II Expedition 2024-002: Surface and sub-surface seafloor investigations of the Eastern Scotian Shelf, Sydney Bight and Shortland Canyon; Geological Survey of Canada, Open File.

Eamer, J.B.R., Greaves, C., King, E.L., 2023. The science questions underpinning the potential for offshore wind turbines on Atlantic Canada's continental shelves (No. 158). https://doi.org/10.4095/331697

Eamer, J.B.R., Shaw, J., King, E.L., MacKillop, K., 2021. The inner shelf geology of Atlantic Canada compared with the North Sea and Atlantic United States: Insights for Atlantic Canadian offshore wind energy. Cont. Shelf Res. 213, 104297. https://doi.org/10.1016/j.csr.2020.104297

Eamer, J.B.R., Shaw, J., King, E.L., MacKillop, K., 2020. Seabed conditions on the inner shelves of Atlantic Canada (No. 8731). https://doi.org/10.4095/326514

Fischer, J., Jost, O., Richter, M., Wiemann, J., n.d. Presentation and Comparison of Site Investigation Methods for Offshore Wind Energy in the European North Seas Countries in the Context of the EU North Seas Energy Cooperation.

Forbes, D.L., Boyd, R., Shaw, J., 1991. Late Quaternary sedimentation and sea level changes on the inner Scotian Shelf. Cont. Shelf Res. 11, 1155–1179. https://doi.org/10.1016/0278-4343(91)90095-N

Godbout, P.-M., Brouard, E., Roy, M., 2023. 1-km resolution rebound surfaces and paleotopography of glaciated North America since the Last Glacial Maximum. Sci. Data 10, 735. https://doi.org/10.1038/s41597-023-02566-5

Josenhans, H.W., King, L.H. & Fader, G.B. (1978) A side-scan sonar mosaic of pockmarks on the Scotian Shelf. *Can. J. Earth Sci.* 15, 831–840

Keizer, P.D., Dale, J. and Gordon Jr, D.C., 1978. Hydrocarbons in surficial sediments from the Scotian Shelf. *Geochimica et Cosmochimica Acta*, *42*(2), pp.165-172.

Kilpatrick, R.J., Wakim, C., Caesar, G., 2023. Preliminary considerations analysis of offshore wind energy in Atlantic Canada. https://doi.org/10.4095/331855

E.L. King, S. Hynes, G.D.M. Cameron, 2013. A catalogue of seabed and shallow sub-surface geologic features of the Grand banks of Newfoundland; a GIS database. Geological Survey of Canada Unpublished Technical Report and Geographic Information System Database

King, E.L., 2014. Quaternary unconsolidated sediment thickness on the Grand Banks of Newfoundland and northeast Newfoundland Shelf; a GIS database (No. 7513). https://doi.org/10.4095/295113

King, E.L., 2001. A glacial origin for Sable Island: ice and sea-level fluctuations from seismic stratigraphy on Sable Island Bank, Scotian Shelf, offshore Nova Scotia.

Li, M.Z., Hannah, C.G., Perrie, W.A., Tang, C.C.L., Prescott, R.H., Greenberg, D.A., 2015. Modelling seabed shear stress, sediment mobility and sediment transport in the bay of Fundy. Can. J. Earth Sci. 52, 757–775. https://doi.org/10.1139/cjes-2014-0211.

Li, M.Z., Wu, Y., Hannah, C.G., Perrie, W.A., Shen, H., King, E.L., 2021. Modelling seabed disturbance and sediment mobility on the Canadian Atlantic Shelf (No. 8805). https://doi.org/10.4095/328363

Li, M.Z., Wu, Y., Perrie, W.A., Shen, H. and King, E.L., 2024. Intensity and frequency of seabed shear stress and sediment mobilization on the Canadian Atlantic Shelf — a modelling study. Continental Shelf Research, 275, 105181; https://doi.org/10.1016/j.csr.2024.105181 MacKillop, K., Eamer, J.B.R., Greaves, C., 2023. Geotechnical characteristics of near-surface or surficially exposed glaciomarine sediments on the inner shelf of Pacific Canada, British Columbia (No. 8953). https://doi.org/10.4095/331501

MacKillop, K., Eamer, J.B.R., Greaves, C., 2023. Geotechnical characteristics of near-surface or surficially exposed glaciomarine sediments on the inner shelf of Pacific Canada, British Columbia (No. 8953). https://doi.org/10.4095/331501

Musial, W., Beiter, P., Spitsen, P., Nunemaker, J., Gevorgian, V., n.d. 2018 Offshore Wind Technologies Market Report.

Musial, W., Spitsen, P., Duffy, P., Beiter, P., Shields, M., Hernando, D.M., Hammond, R., Marquis, M., King, J., Sriharan, S., 2023. Offshore Wind Market Report: 2023 Edition.

Nørgaard-Pedersen, N., Vangkilde-Pedersen, T., Lomholt, S., 2022. Screening of seabed geological conditions forthe offshore wind farm (OWF) area Nordsøen 1, Område E. Desk Study Dan. Energy Agency RAPPORT 2022/7.

Osezua Akeme, K., 2018. INSTALLATION CONSTRAINTS OF SUCTION ASSISTED FOUNDATIONS AND ANCHORS FOR OFFSHORE ENERGY DEVELOPMENT. Int. J. GEOMATE 15. https://doi.org/10.21660/2018.47.3695

Petrie, H.E., Eide, C.H., Haflidason, H., Watton, T., 2022. A conceptual geological model for offshore wind sites in former ice stream settings: the Utsira Nord site, North Sea. J. Geol. Soc. 179, jgs2021-163. https://doi.org/10.1144/jgs2021-163

Philibert, G., Todd, B.J., Campbell, D.C., King, E.L., Normandeau, A., Hayward, S.E., Patton, E.R., Campbell, L., 2024. Updated surficial geology compilation of the Scotian Shelf Bioregion, offshore Nova Scotia and New Brunswick, Canada (No. 8911). https://doi.org/10.4095/330474

Schmuck, E.A., Paull, C.K., 1993. Evidence for gas accumulation associated with diapirism and gas hydrates at the head of the Cape Fear Slide. Geo-Mar. Lett. 13, 145–152. https://doi.org/10.1007/BF01593187

Shaw, J., Gareau, P., Courtney, R., 2002. Palaeogeography of Atlantic Canada 13–0kyr. Quat. Sci. Rev. 21, 1861–1878. https://doi.org/10.1016/S0277-3791(02)00004-5

Shimeld, J., 2004. A comparison of salt tectonic subprovinces beneath the Scotian Slope and Laurentian Fan; in Salt-Sediment Interactions and Hydrocarbon Prospectivity: Concepts, Applications, and Case Studies for the 21st Century, in: Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists; Society for Sedimentary Geology, Gulf Coast Section (GCSSEPM), 24th Annual Bob F. Perkins Research Conference, Houston. pp. 291–306.

Staal, P., Fader, G., 1997. Sediment thickness study of the eastern Canadian continental shelf. Geol. Surv. Can. Open File 1427.

Stea, R.R., Boyd, R., Fader, G.B.J., Courtney, R.C., Scott, D.B., Pecore, S.S., 1994. Morphology and seismic stratigraphy of the inner continental shelf off Nova Scotia, Canada: Evidence for a −65 m lowstand between 11,650 and 11,250 C14 yr B.P. Mar. Geol. 117, 135–154. https://doi.org/10.1016/0025-3227(94)90011-6

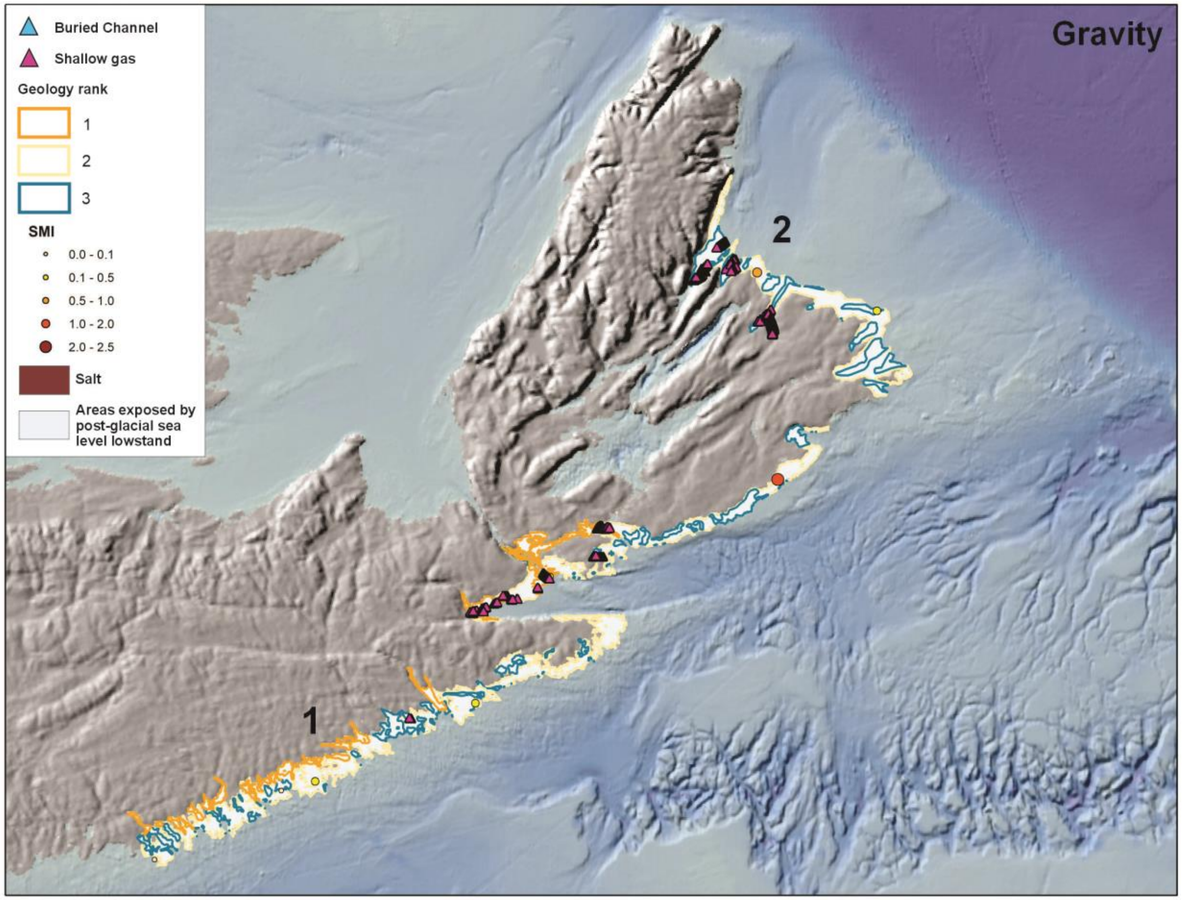
Syvitski, J., Waters, C.N., Day, J., Milliman, J.D., Summerhayes, C., Steffen, W., Zalasiewicz, J., Cearreta, A., Gałuszka, A., Hajdas, I., Head, M.J., Leinfelder, R., McNeill, J.R., Poirier, C., Rose, N.L., Shotyk, W., Wagreich, M., Williams, M., 2020. Extraordinary human energy consumption and resultant geological impacts beginning around 1950 CE initiated the proposed Anthropocene Epoch. Commun. Earth Environ. 1, 1–13. https://doi.org/10.1038/s43247-020-00029-y

Velenturf, A.P.M., Emery, A.R., Hodgson, D.M., Barlow, N.L.M., Mohtaj Khorasani, A.M., Van Alstine, J., Peterson, E.L., Piazolo, S., Thorp, M., 2021. Geoscience Solutions for Sustainable Offshore Wind Development. Earth Sci. Syst. Soc. 1, 10042. https://doi.org/10.3389/esss.2021.10042

Westwood Global Energy Group, 2023. Global offshore wind report 2023.

Williams, R., Feng, Z., 2023. GWEC Global offshore wind report 2023.

ANNEX 1 – GRAVITY FOUNDATIONS DETAILED RESULT FIGURES



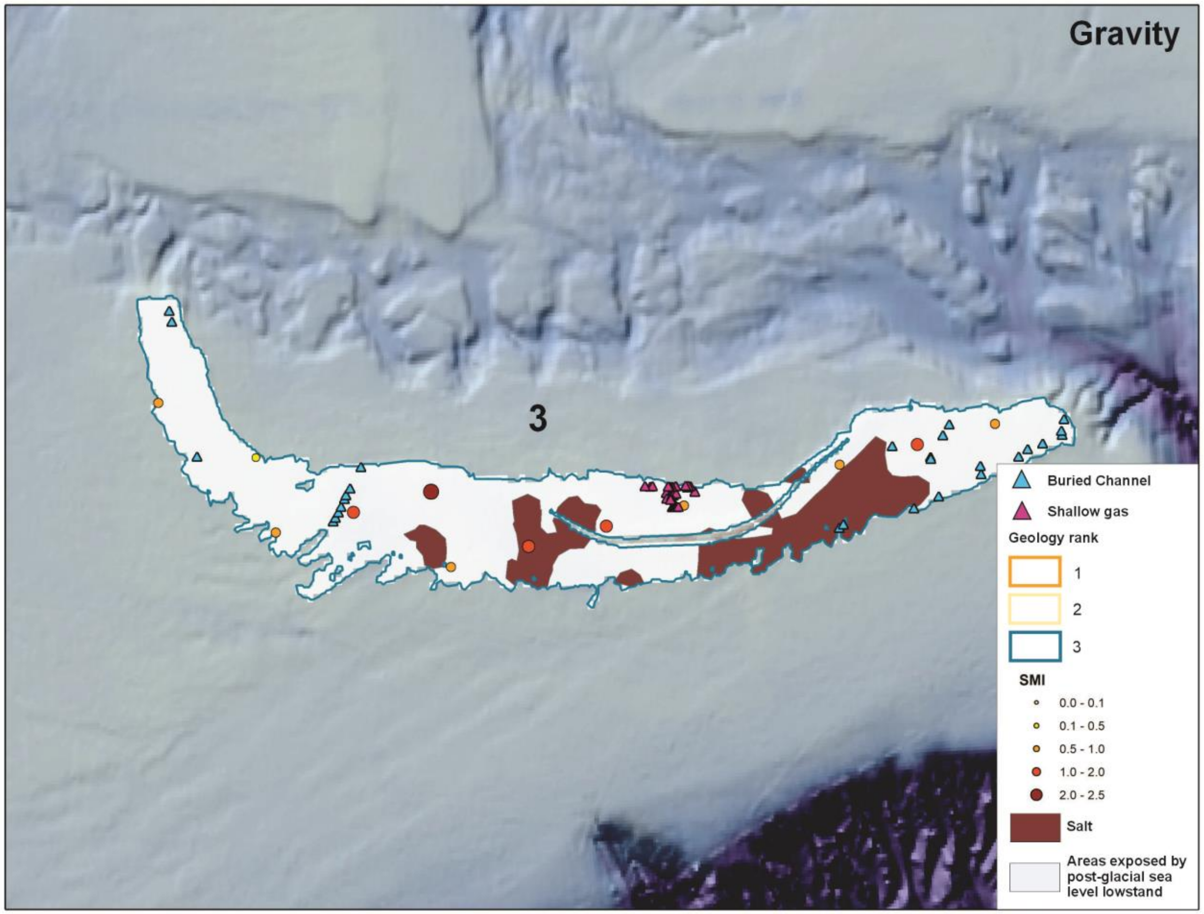
1. Eastern Shore of Nova Scotia

Area within suitable depth range (0 - 30 m) : 1180 km²
Surface Geology : Bedrock, post-glacial sand and gravel and post-glacial marine mud
Surface Geology Rank : 1 (13%), 2 (71%), 3 (16%).
Sediment thickness : Does not impact gravity base foundation
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Present

2. Cape Breton Island

Area within suitable depth range (0 - 30 m) : 1300 km²
Surface Geology : Bedrock and post-glacial sand and gravel
Surface Geology Rank : 1 (12%), 2 (57%), 3 (31%).
Sediment thickness : Does not impact gravity base foundation
SMI : Moderate to high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Present

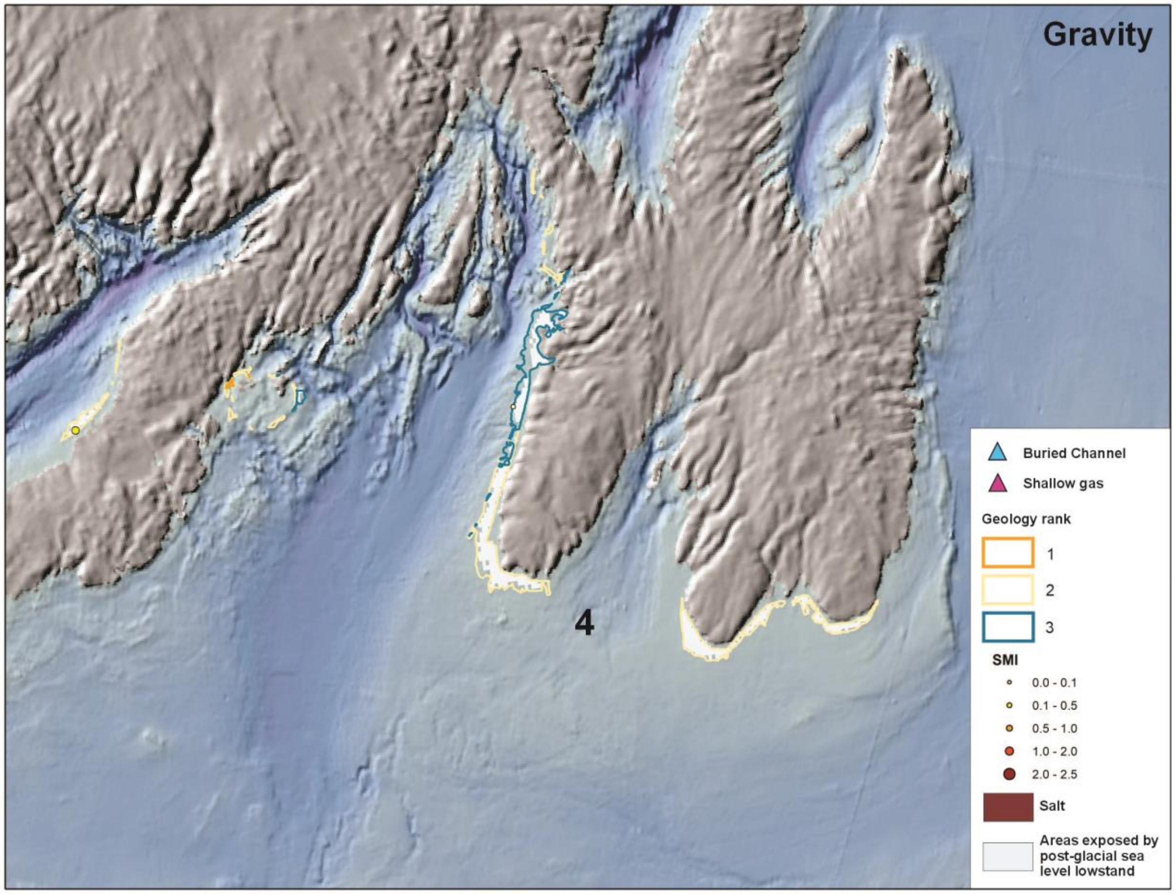
Figure 23:Seabed characteristic inside the physiographic regions 1. Eastern shore of Nova Scotia and 2. Cape Breton Island.



3. Sable Island Bank

Area within suitable depth range (0 - 30 m) : 1700 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 3 (100%)
Sediment thickness: Does not impact gravity base foundation
SMI : Moderate to very high
Slopes : Suitable
Areas exposed by post-glacial sea level : 100 %
Salt : 20 %
Buried channels : Present
Shallow gas : Present

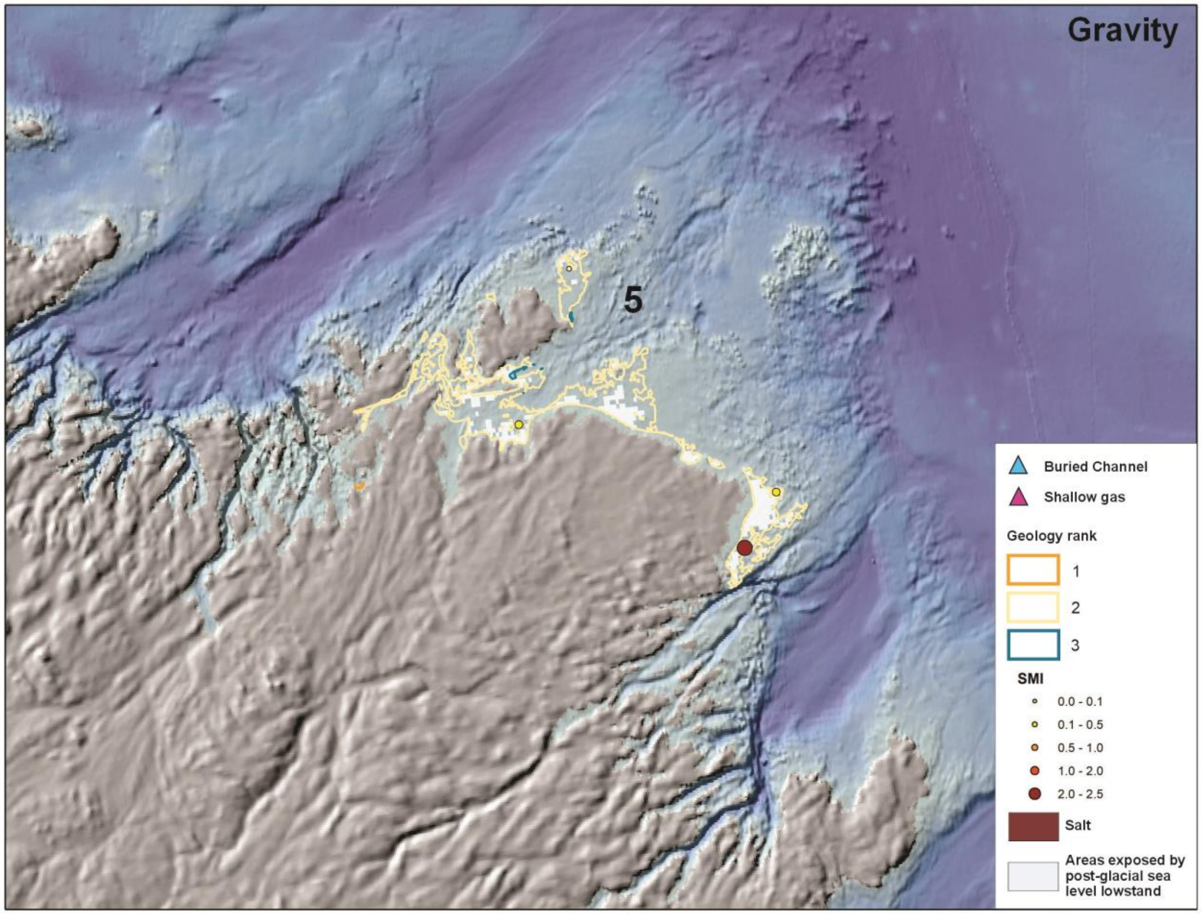
Figure 24: Seabed characteristic inside the physiographic region of 3. Sable Island Bank.



4. East of Placentia Bay

Area within suitable depth range (0 - 30 m) : 360 km²
Surface Geology : Post-glacial sand and gravel and glacial diamict
Surface Geology Rank : 2 (70%), 3 (30%)
Sediment thickness: Does not impact gravity base foundation
SMI : Low
Slopes : Suitable
Areas exposed by post-glacial sea level : 95%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

Figure 25: Seabed characteristic inside the physiographic region of 4. East of Placentia Bay.

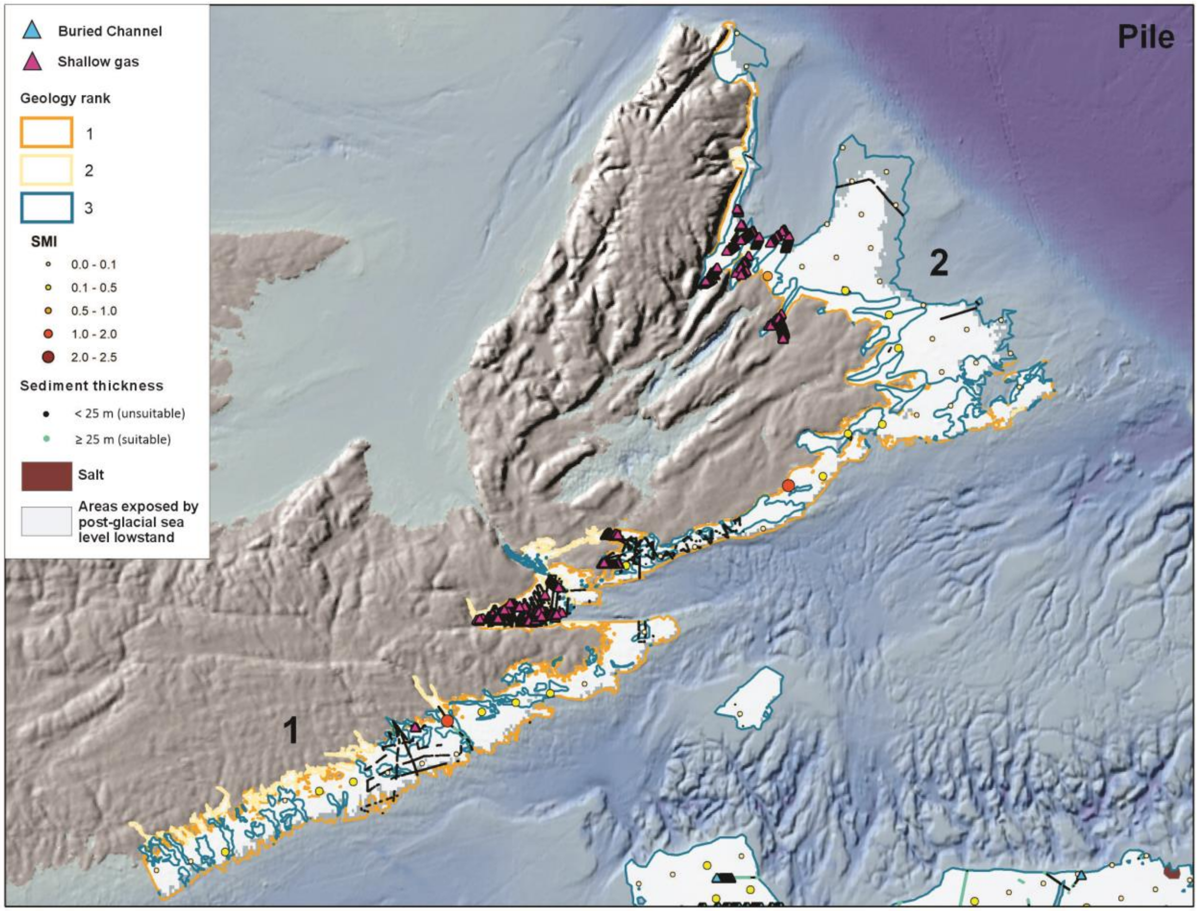


5. Northeastern Newfoundland

Area within suitable depth range (0 - 30 m) : 800 km²
Surface Geology : Glacial diamict
Surface Geology Rank : 1 (0.5%), 2 (99%), 3 (0,5%)
Sediment thickness: Does not impact gravity base foundation
SMI : Low to very high
Slopes : Suitable
Areas exposed by post-glacial sea level : 38 %
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

Figure 26: Seabed characteristic inside the physiographic region of 5. Northeastern Newfoundland.

ANNEX 2 – PILE FOUNDATIONS DETAILED RESULT FIGURES



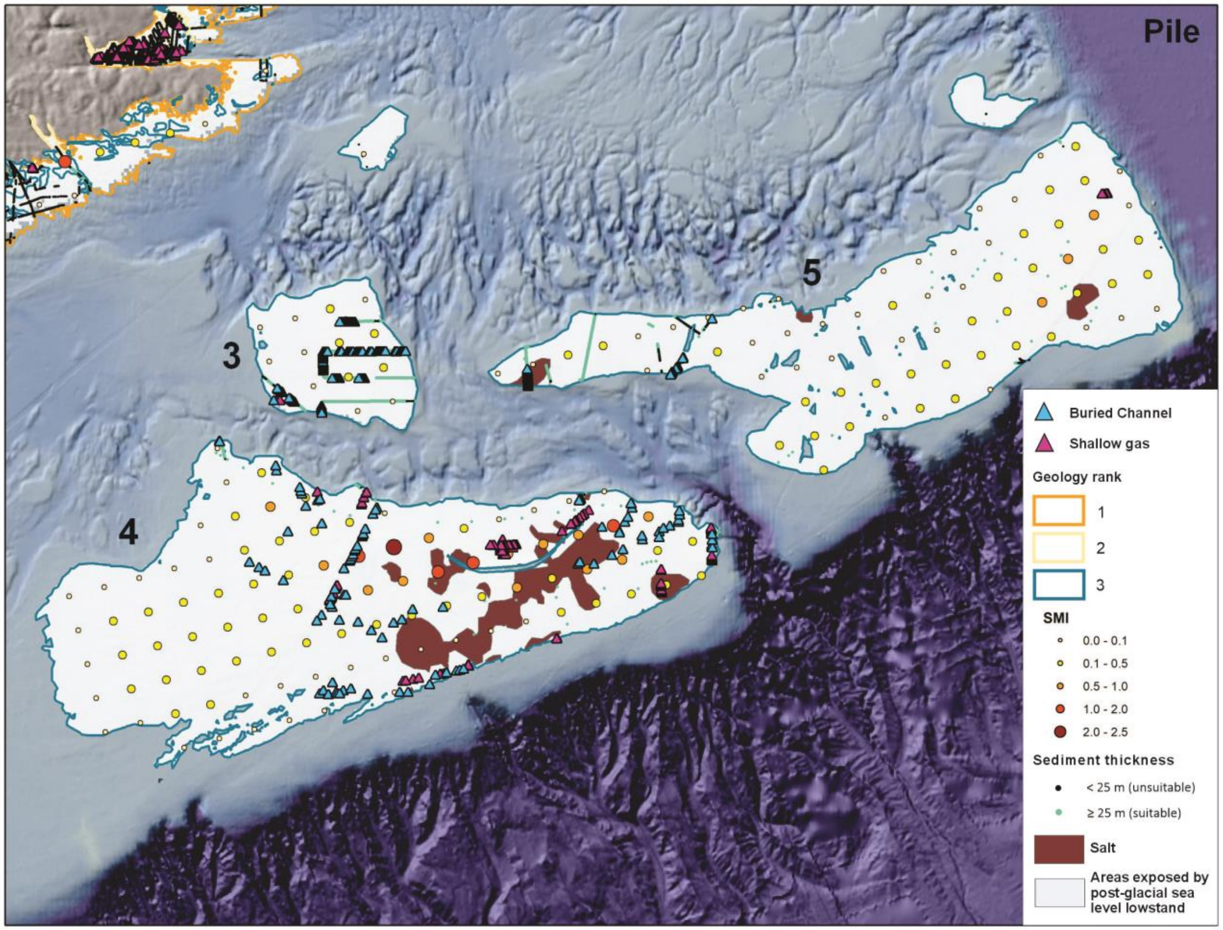
1. Eastern Shore of Nova Scotia

Area within suitable depth range (0 - 70 m) : 3000 km²
Surface Geology : Bedrock, post-glacial sand and gravel and post-glacial marine mud
Surface Geology Rank : 1 (70%), 2 (15%), 3 (15%).
Sediment thickness data range : 0 to 85 m
Sediment thickness data coverage : Insufficient
SMI : Low to high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 95%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Present

2. Cape Breton Island

Area within suitable depth range (0 - 70 m) : 5000 km²
Surface Geology : Bedrock and post-glacial sand and gravel
Surface Geology Rank : 1 (38%), 2 (2%), 3 (60%).
Sediment thickness data range : 0 to 50 m
Sediment thickness data coverage : Insufficient
SMI : Low to high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 90%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Present

Figure 27: Seabed characteristic inside the physiographic regions 1. Eastern shore of Nova Scotia and 2. Cape Breton Island.



3. Middle Bank

Area within suitable depth range (0 - 70 m) : 1700 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 3 (100%)
Sediment thickness data range : 18 to 225 m
Sediment thickness data coverage : Good
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : Absent on available dataset.
Buried channels : Present
Shallow gas : Present

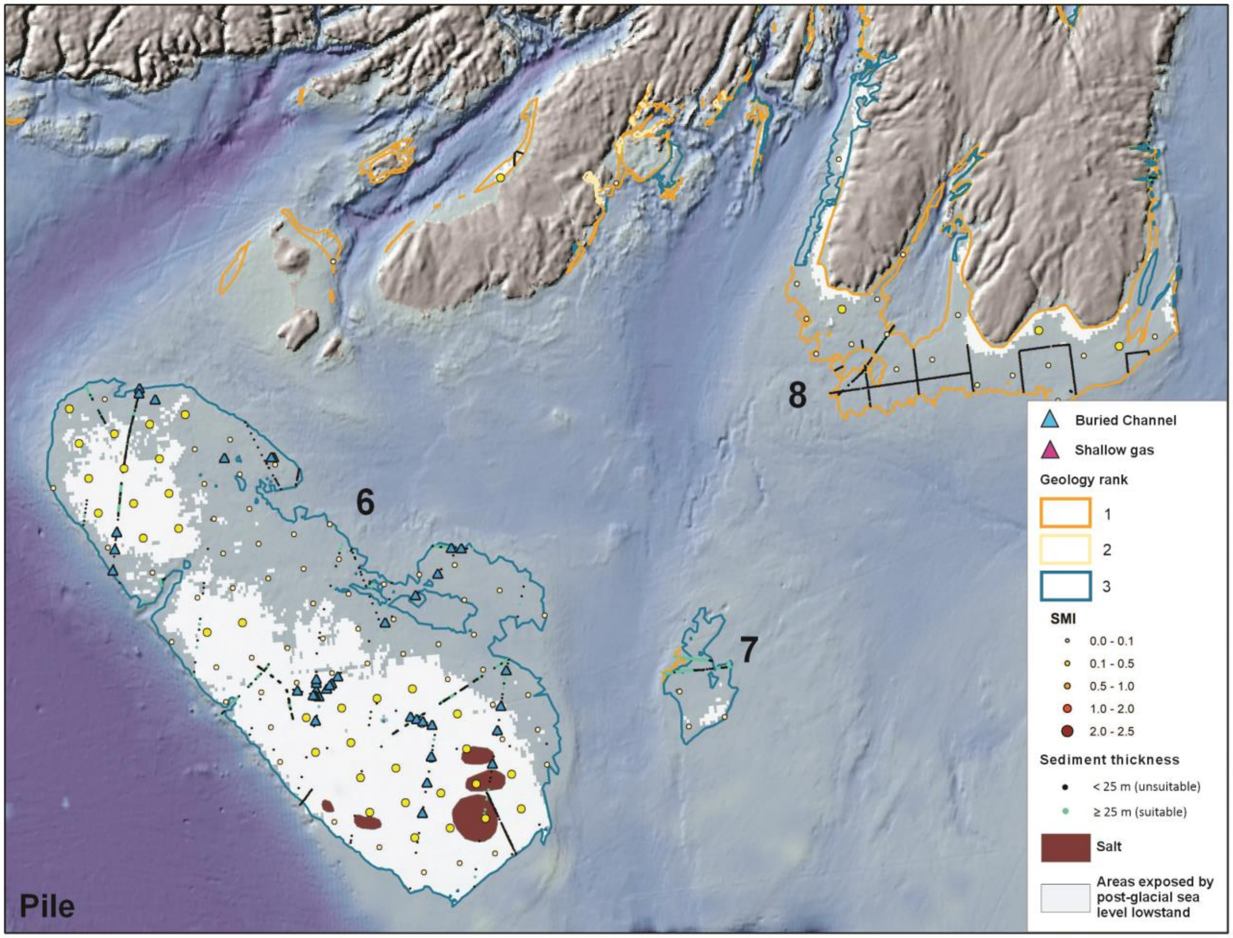
4. Sable Island Bank

Area within suitable depth range (0 - 70 m) : 11 300 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 3 (100%)
Sediment thickness data range : 14 to 180 m
Sediment thickness data coverage : Insufficient
SMI : Low to very high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : 9 %
Buried channels : Present
Shallow gas : Present

5. Banquereau Bank

Area within suitable depth range (0 - 70 m) : 8200 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 3 (100%)
Sediment thickness data range : 2 to 242 m
Sediment thickness data coverage : Insufficient
SMI : Low to moderately high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : 1.7 %
Buried channels : Present
Shallow gas : Present

Figure 28: Seabed characteristic inside the physiographic regions 3. Middle Bank, 4. Sable Island Bank and 5. Banquereau Bank.



6. St Pierre Bank

Area within suitable depth range (0 - 70 m) : 12 100 km²
Surface Geology : Sand and gravel over till and post-glacial sand
Surface Geology Rank : 3 (100%)
Sediment thickness data range : 0 to 525 m
Sediment thickness data coverage : Insufficent and variable
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 60%
Salt : 2.5 %
Buried channels : Present
Shallow gas : Absent on available dataset.

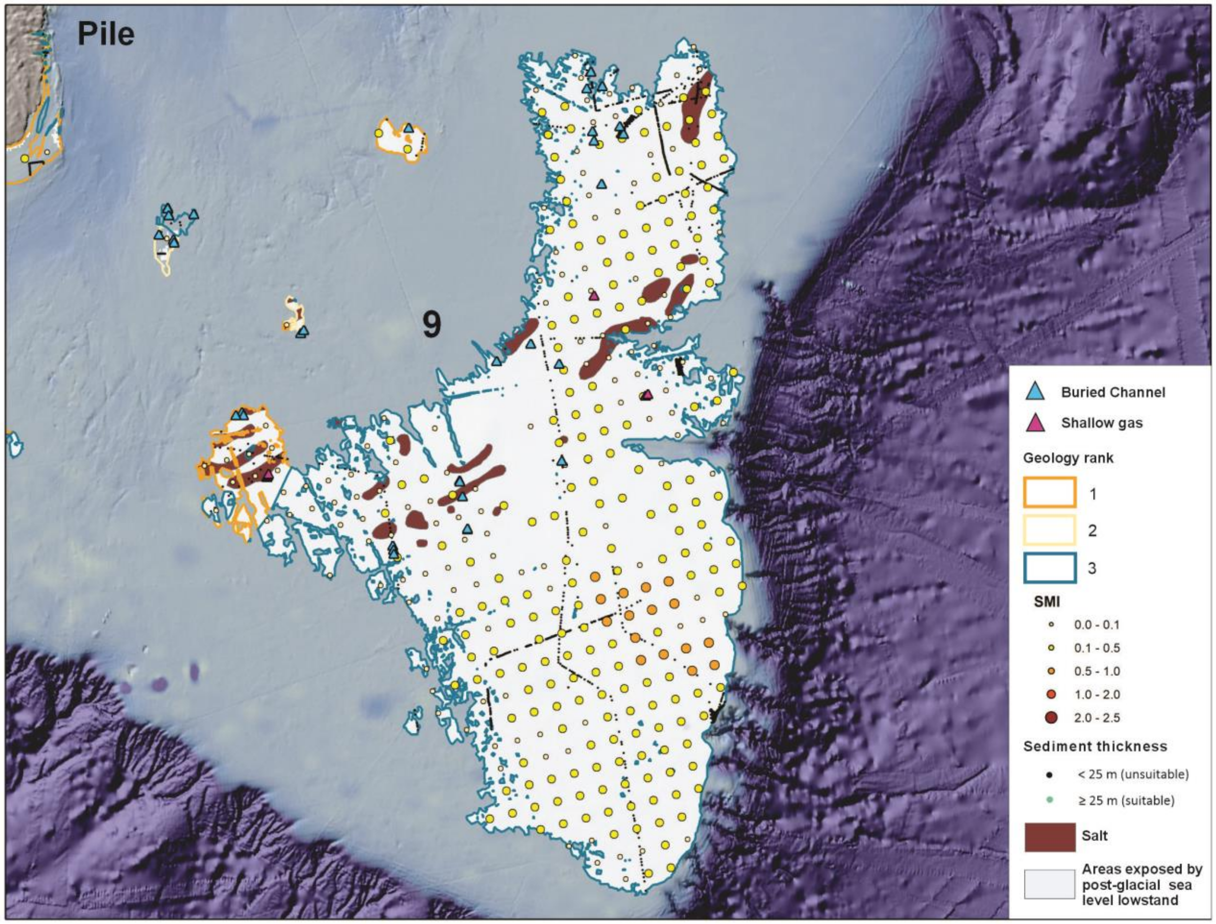
7. Green Bank

Area within suitable depth range (0 - 70 m) : 460 km²
Surface Geology : Postglacial sand and gravel and glacial till
Surface Geology Rank : 1 (5%), 3 (95%)
Sediment thickness data range : 3 to 155 m
Sediment thickness data coverage : Insufficient
SMI : Low
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 10%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

8. East of Placentia Bay

Area within suitable depth range (0 - 70 m) : 3100 km²
Surface Geology : Postglacial sand and gravel and glacial till
Surface Geology Rank : 1 (90 %), 3 (10 %)
Sediment thickness data range : 0 to 70 m
Sediment thickness data coverage : Good
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 20%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

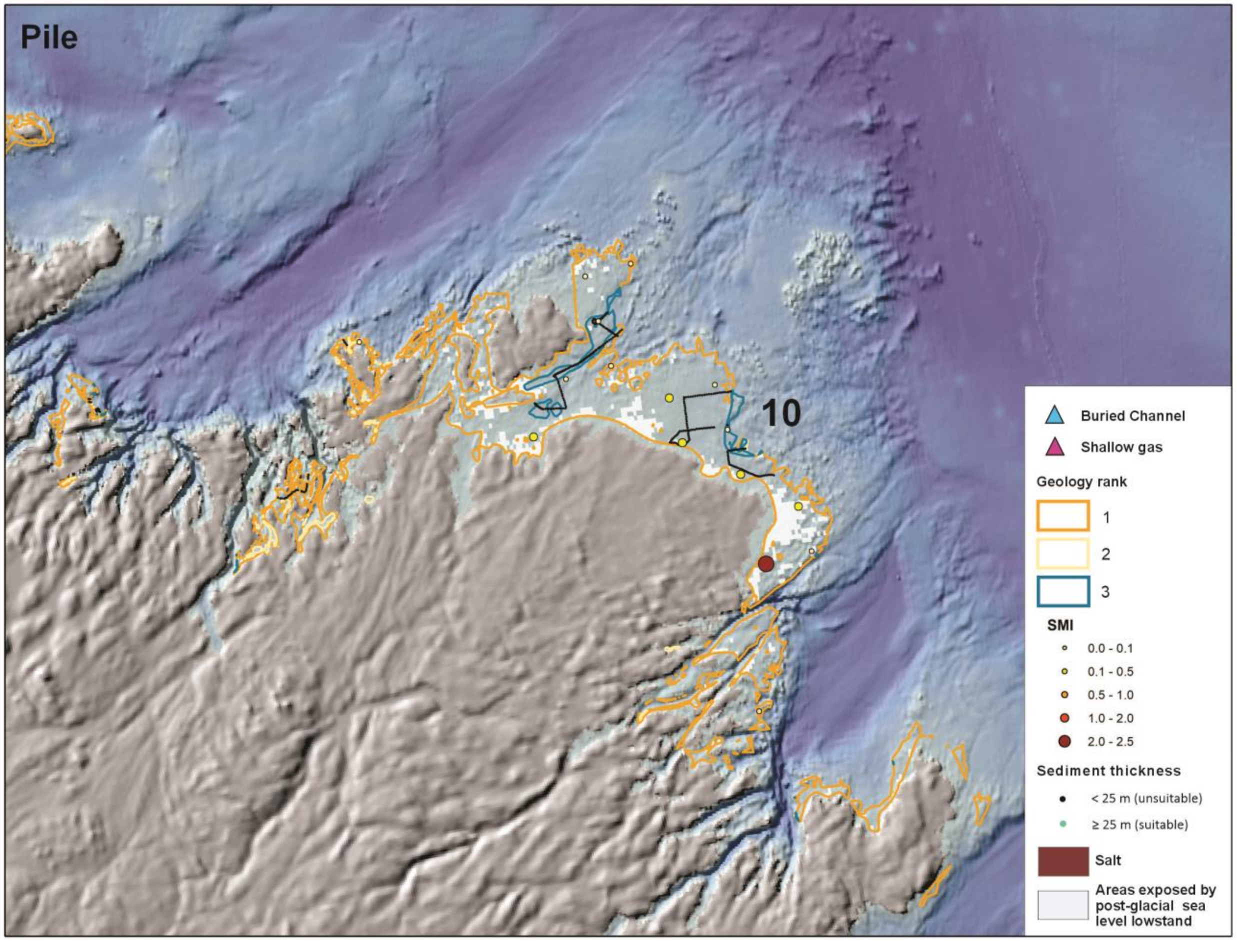
Figure 29: Seabed characteristic inside the physiographic regions 6. St. Pierre Bank, 7. Green Bank and 8. East of Placentia Bay.



9. Grand Bank

Area within suitable depth range (0 - 70 m) : 48 700 km²
Surface Geology : Postglacial sand and gravel and glacial till
Surface Geology Rank : 1 (3%), 3 (97%)
Sediment thickness data range : 0 to 20 m
Sediment thickness data coverage : Insufficient
SMI : Low to moderately high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : 4%
Buried channels : Present
Shallow gas : Present

Figure 30: Seabed characteristic inside the physiographic region of 9. Grand Bank.

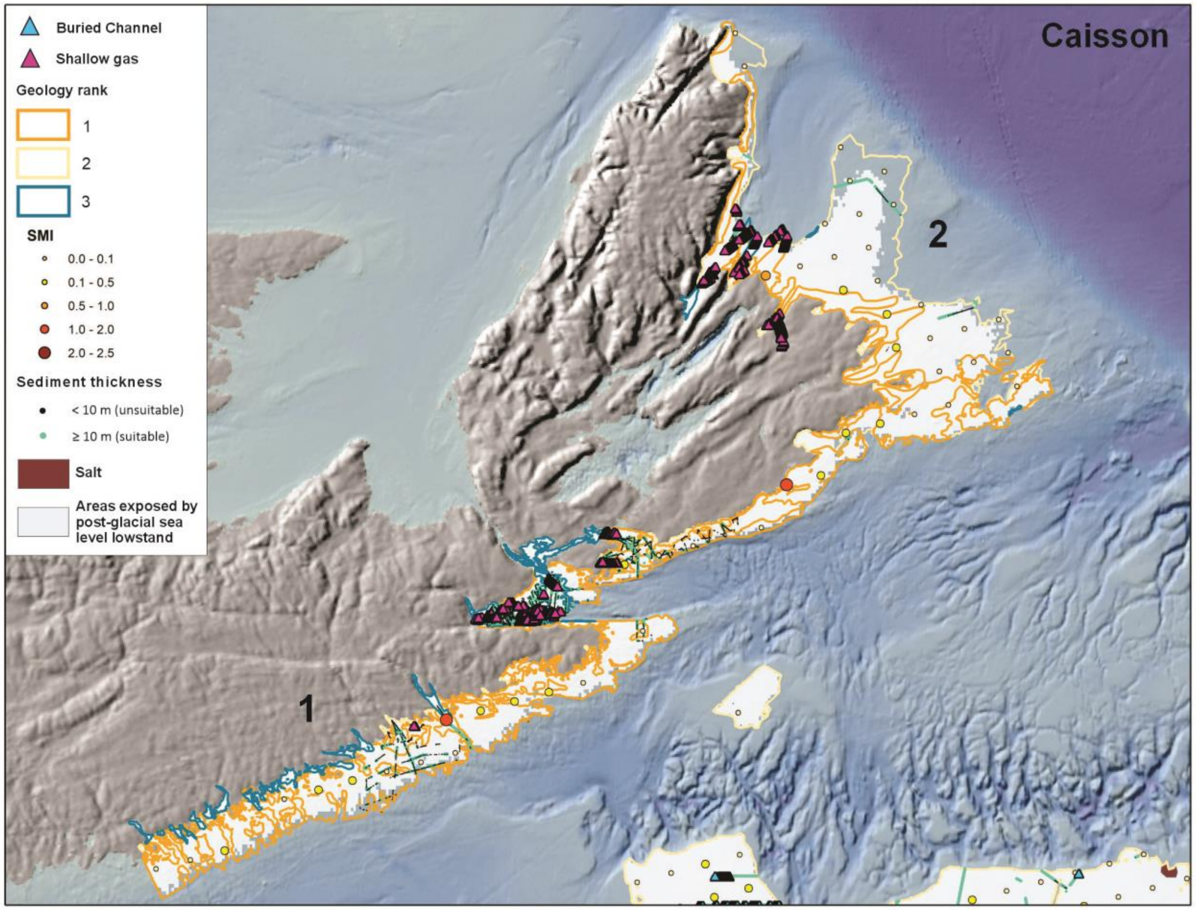


10. Northeastern Newfoundland

Area within suitable depth range (0 - 70 m) : 2300 km²
Surface Geology : Glacial diamict
Surface Geology Rank : 1 (94,5%), 2 (0,5%) 3 (5%)
Sediment thickness data range : 0 to 20 m
Sediment thickness data coverage : Good
SMI : Low to very high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 13%
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

Figure 31: Seabed characteristic inside the physiographic region of 10. Northeastern Newfoundland.

ANNEX 3 – CAISSON FOUNDATIONS DETAILED RESULT FIGURES



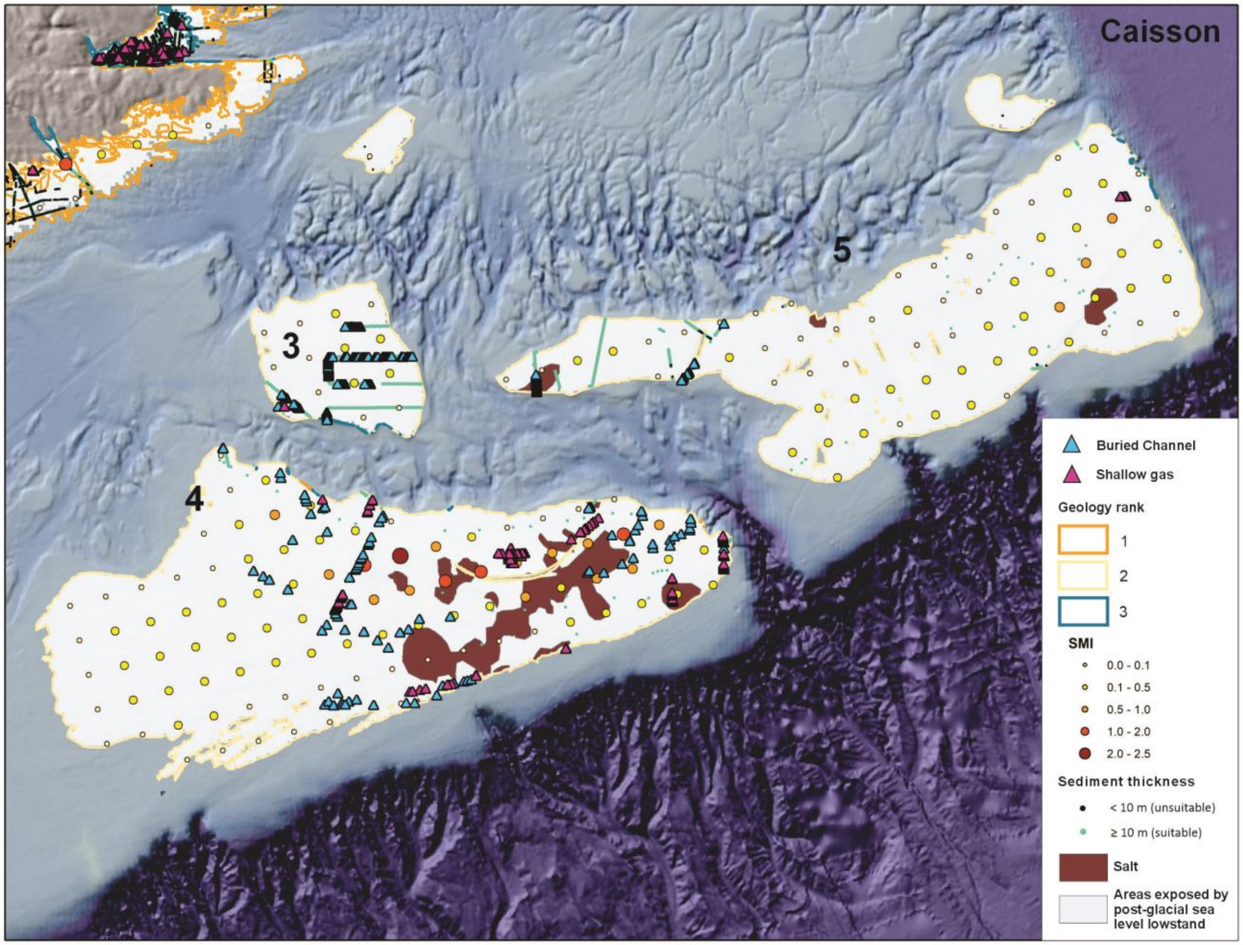
1. Eastern Shore of Nova Scotia

Area within suitable depth range (20 - 70 m) : 3000 km²
Surface Geology : Bedrock, post-glacial sand and gravel and post-glacial marine mud
Surface Geology Rank : 1 (70%), 2 (15%), 3 (15%).
Sediment thickness data range : 0 to 85 m
Sediment thickness data coverage : Insufficient
SMI : Low to high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 95 %
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Present

2. Cape Breton Island

Area within suitable depth range (20 - 70 m) : 5000 km²
Surface Geology : Bedrock and post-glacial sand and gravel
Surface Geology Rank : 1 (38%), 2 (60%), 3 (2%).
Sediment thickness data range : 0 to 50 m
Sediment thickness data coverage : Insufficient
SMI : Low to high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 90 %
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Present

Figure 32: Seabed characteristic inside the physiographic regions 1. Eastern shore of Nova Scotia and 2. Cape Breton Island.



3. Middle Bank

Area within suitable depth range (20 - 70 m) : 1700 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 2 (100%)
Sediment thickness data range : 18 to 225 m
Sediment thickness data coverage : Good
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : Absent on available dataset.
Buried channels : Present
Shallow gas : Present

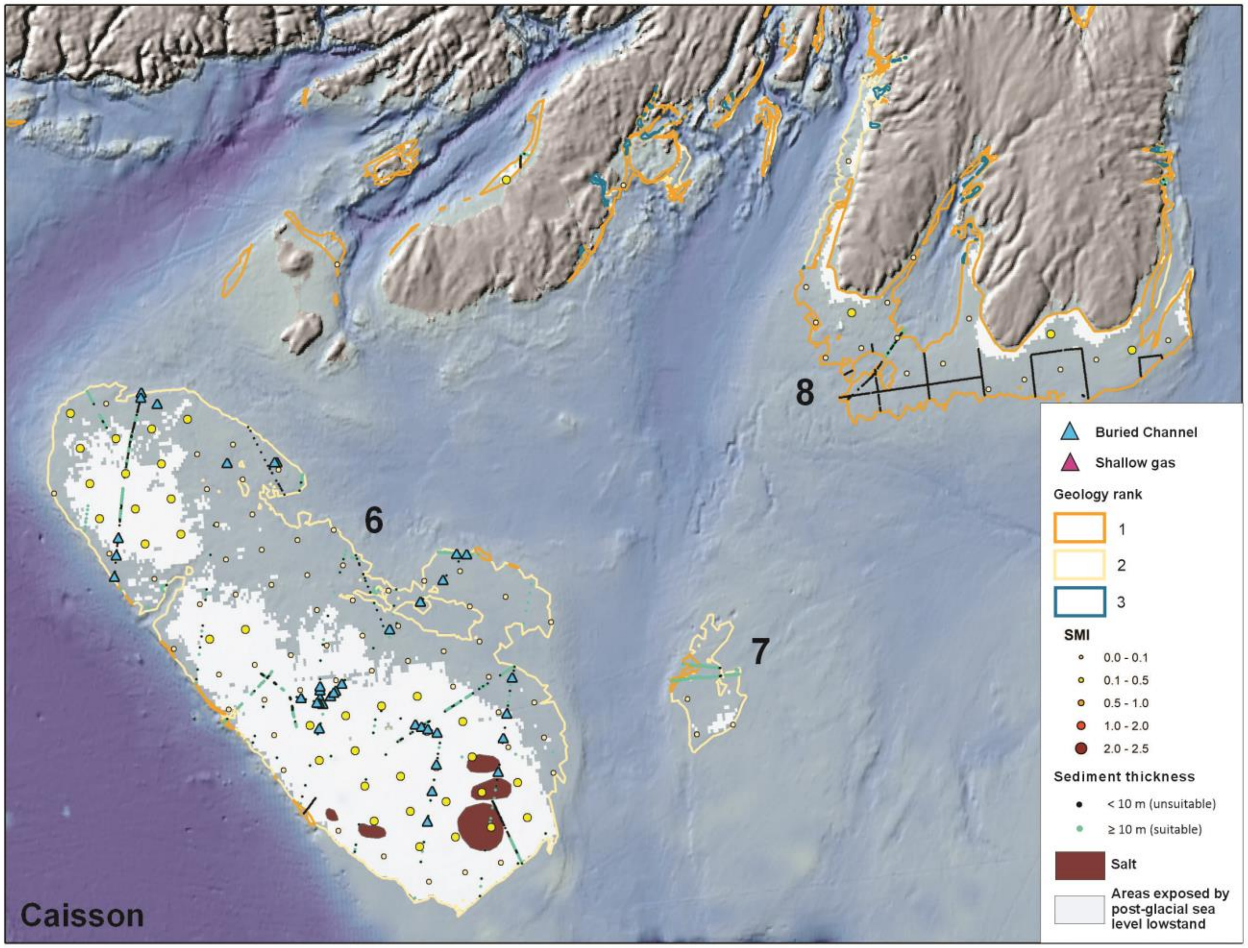
4. Sable Island Bank

Area within suitable depth range (20 - 70 m) : 11 300 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 2 (100%)
Sediment thickness data range : 14 to 180 m
Sediment thickness data coverage : Insufficient
SMI : Low to very high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : 9 %
Buried channels : Present
Shallow gas : Present

5. Banquereau Bank

Area within suitable depth range (20 - 70 m) : 8200 km²
Surface Geology : Post-glacial sand and gravel
Surface Geology Rank : 2 (100%)
Sediment thickness data range : 2 to 242 m
Sediment thickness data coverage : Insufficient
SMI : Low to moderately high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : 1.7 %
Buried channels : Present
Shallow gas : Present

Figure 33: Seabed characteristic inside the physiographic regions 3. Middle Bank, 4. Sable Island Bank and 5. Banquereau Bank.



6. St Pierre Bank

Area within suitable depth range (20 - 70 m) : 12 100 km²
Surface Geology : Sand and gravel over till and post-glacial sand
Surface Geology Rank : 2 (100%)
Sediment thickness data range : 0 to 525 m
Sediment thickness data coverage : Insufficent and variable
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 60 %
Salt : 2.5 %
Buried channels : Present
Shallow gas : Absent on available dataset.

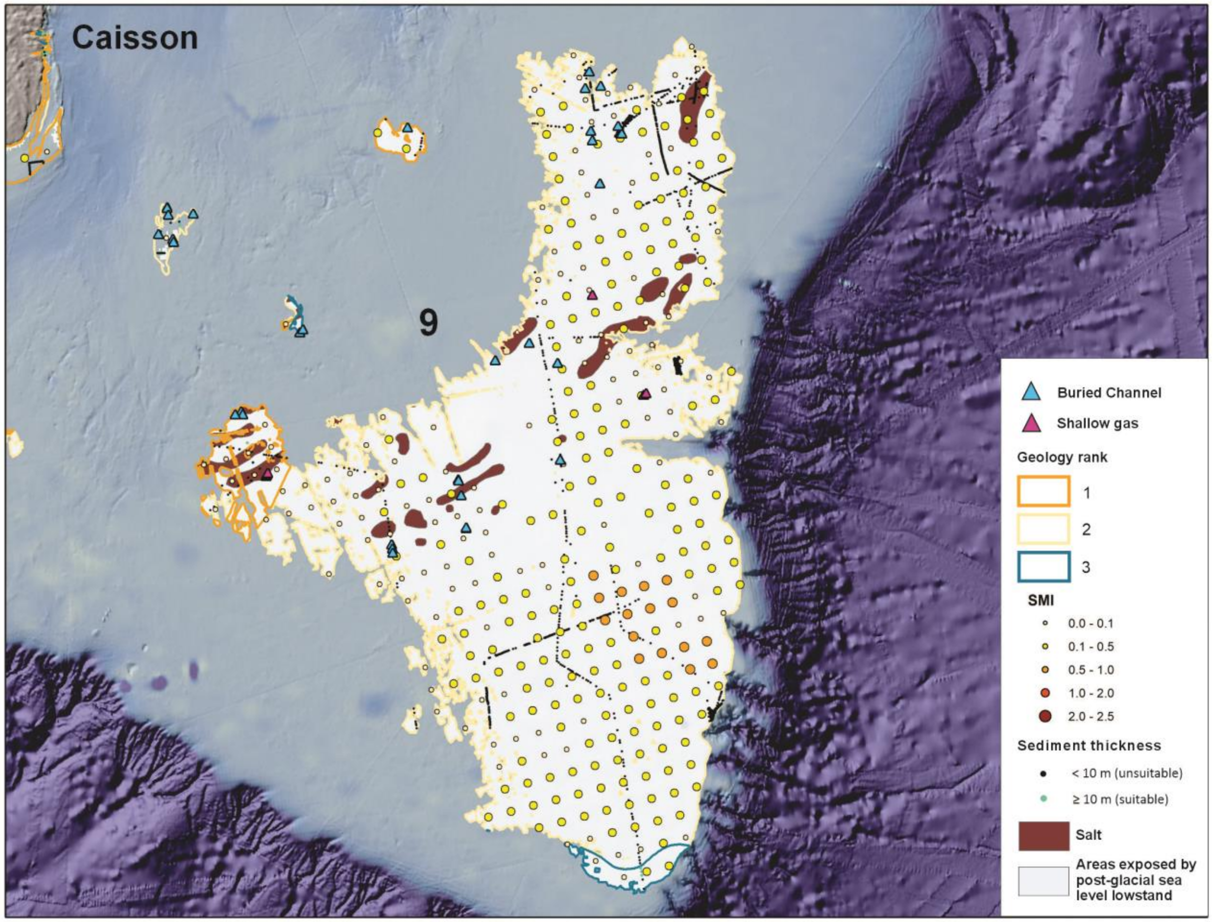
7. Green Bank

Area within suitable depth range (20 - 70 m) : 460 km²
Surface Geology : Postglacial sand and gravel and glacial till
Surface Geology Rank : 1 (5%), 2 (95%)
Sediment thickness data range : 3 to 155 m
Sediment thickness data coverage : Insufficient
SMI : Low
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 10 %
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

8. East of Placentia Bay

Area within suitable depth range (20 - 70 m) : 3100 km²
Surface Geology : Postglacial sand and gravel and glacial till
Surface Geology Rank : 1 (90 %), 2 (9 %), 3 ((1%)
Sediment thickness data range : 0 to 70 m
Sediment thickness data coverage : Good
SMI : Low to moderate
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 20 %
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

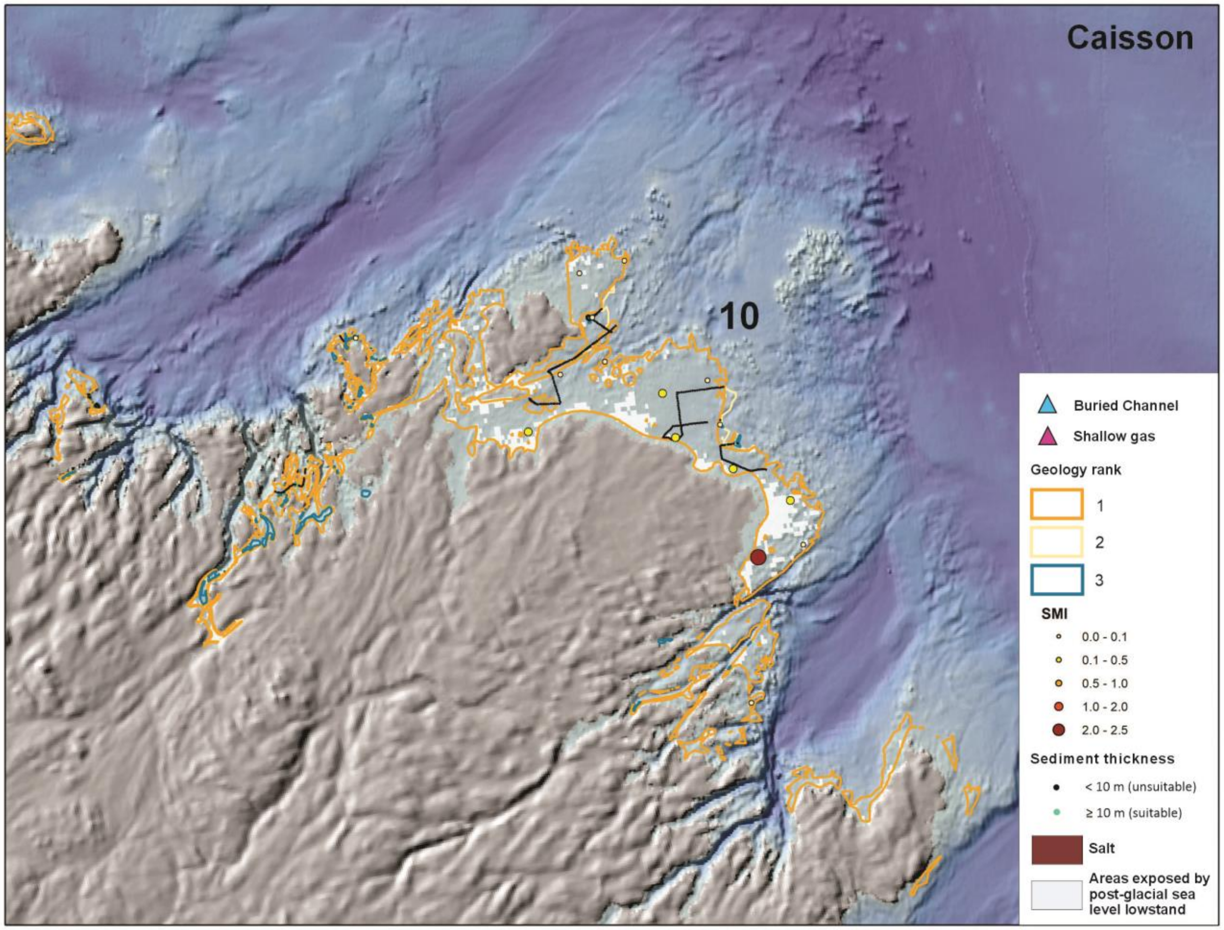
Figure 34: Seabed characteristic inside the physiographic regions 6. St. Pierre Bank, 7. Green Bank and 8. East of Placentia Bay.



9. Grand Bank

Area within suitable depth range (20 - 70 m) : 48 700 km²
Surface Geology : Postglacial sand and gravel and glacial till
Surface Geology Rank : 1 (3%), 2 (93%), 3 (1%)
Sediment thickness data range : 0 to 20 m
Sediment thickness data coverage : Insufficient
SMI : Low to moderately high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 100 %
Salt : 4%
Buried channels : Present
Shallow gas : Present

Figure 35: Seabed characteristic inside the physiographic region of 9. Grand Bank.



10. Northeastern Newfoundland

Area within suitable depth range (20 - 70 m) : 2300 km²
Surface Geology : Glacial diamict
Surface Geology Rank : 1 (94 %), 2 (5 %) 3 (1 %)
Sediment thickness data range : 0 to 20 m
Sediment thickness data coverage : Good
SMI : Low to very high
Slopes : Suitable
Areas exposed by post-glacial sea level lowstand : 13 %
Salt : Absent on available dataset.
Buried channels : Absent on available dataset.
Shallow gas : Absent on available dataset.

Figure 36: Seabed characteristic inside the physiographic region of 10. Northeastern Newfoundland.