

Seabed Characterization



George Marling

A desktop assessment

Who should read this paper?

Parties and people interested in offshore wind development of the Canadian East Coast and those who wish to gain a high-level understanding of the geological conditions and development constraints of the Nova Scotia designated Wind Energy Areas (WEAs) will be interested in this paper.

Why is it important?

This work compiles existing data, often consisting of recent geophysical and geotechnical survey works, to develop a high-level understanding of the seabed and sub-seabed conditions of each of the Nova Scotia WEAs. It offers an understanding of the development and geological constraints of the WEAs and of the amount of data that is (and will be) publicly available. Finally, it enables early planning to address the most significant construction/development constraints and highlights the potential development works, key considerations, and site characterization data.

About the author

George Marling is a chartered senior geotechnical engineer at OWC, a specialist renewables engineering consultancy, where he takes a leading role supporting offshore windfarm developers in the Americas. He brings a wealth of experience as geoscience lead, having fulfilled various geoscience package management and cables owners engineer roles in Taiwan, South Korea, and the US. Based in New York, he acts as OWC's regional coordinator for geo projects in the Americas region, which includes Canada, the US, Brazil, and Colombia, working closely with offshore wind developers to de-risk their projects through site investigations, site characterization, ground modelling, geo-hazard identification, and front-end engineering design.

GEOLOGICAL CHARACTERIZATION OF OFFSHORE WIND ENERGY AREAS ON THE SCOTIAN SHELF

George Marling

OWC, An ABL Group Company, New York, NY, USA

Corresponding author: george.marling@owcltd.com

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ABSTRACT

The Scotian Shelf offshore Nova Scotia has emerged as a region of significant interest for large-scale offshore wind development, with four designated Wind Energy Areas (WEAs): French Bank, Middle Bank, Sable Island Bank, and Sydney Bight. These WEAs are notable for their exceptional spatial extent, variable water depths, and complex geological history shaped through glacial processes, sea level fluctuations, and post-glacial marine reworking. This paper synthesizes publicly available geological data to provide an integrated desktop assessment of seabed and sub-seabed conditions across the Nova Scotia WEAs. Particular attention is given to surficial sediment distribution, shallow stratigraphy, bedrock exposure, glacial landforms, and geological hazards such as shallow gas and challenging minerology. The implications of these conditions for offshore wind foundation concepts, cable installation, and development strategy are discussed. The analysis highlights that while large portions of the WEAs are broadly suitable for offshore wind development, spatial heterogeneity in seabed conditions will strongly influence site selection, turbine layout optimization, and engineering design. Early-stage geological understanding is, therefore, critical to de-risk development and to identify viable sub-areas within these exceptionally large lease zones.

1. INTRODUCTION

Global offshore wind is gaining momentum as nations seek to decarbonize electricity systems while maintaining energy security. Canada, particularly Atlantic Canada, has recently emerged as a frontier region for offshore wind development. Nova Scotia's offshore environment is characterized by high wind resource potential, proximity to North American markets, and an established offshore energy and marine engineering legacy. In recognition of this potential, several sizeable Wind Energy Areas (WEAs) have been identified on the Scotian Shelf, offshore Nova Scotia.

While the wind resource and electrical export potential of these areas are increasingly well recognized, the geological and geotechnical conditions of the Scotian Shelf introduce both opportunities and challenges for offshore wind development. Unlike many established offshore wind regions, such as the southern North Sea, the Scotian Shelf retains a strong imprint of glaciation, limited fluvial sediment input, and locally extensive shallow bedrock. These characteristics can significantly affect foundation feasibility, installation methodology, and project cost.

This paper presents a geological desktop study of the Nova Scotia WEAs, synthesizing existing datasets from federal and provincial sources, academic literature, and offshore surveys. The objective is to characterize seabed and shallow subsurface conditions at a scale relevant to early-stage offshore wind development and to assess the implications for engineering design and development strategy.

2. STUDY AREA AND WIND ENERGY AREAS

2.1 Regional Setting

The Scotian Shelf is a broad continental shelf extending from the coastline of Nova Scotia into the northwest Atlantic Ocean. It is bounded to the south by the continental slope and to the northeast by the Laurentian Channel. The shelf has been shaped by repeated Pleistocene glaciations, with ice sheets advancing across the shelf and retreating during interglacial periods. These processes have produced a complex seabed morphology consisting of banks, basins, ridges, and palaeochannels.

Unlike many sediment-rich continental shelves, the Scotian Shelf has experienced relatively limited riverine sediment input. As a result, glacial and post-glacial sediments are often thin, and bedrock is locally exposed or shallowly buried, particularly in nearshore and mid-shelf settings.

2.2 Wind Energy Areas

Four WEAs have been identified offshore Nova Scotia for further development (Figure 1):

- French Bank (approximately 20 km offshore)
- Sydney Bight (approximately 25 km offshore)
- Middle Bank (approximately 60 km offshore)
- Sable Island Bank (up to approximately 110 km offshore) [1]

These WEAs are exceptionally large, ranging from approximately 1,285 km² (Sydney Bight)

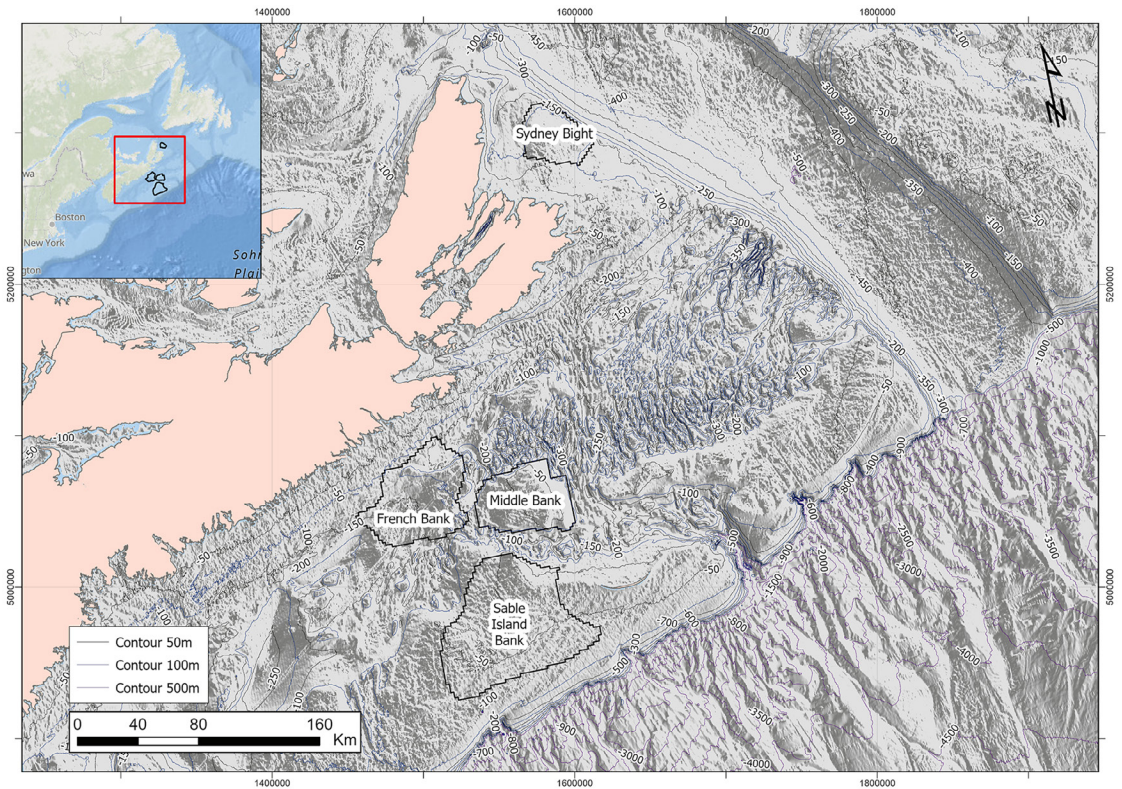


Figure 1: Location of Nova Scotia Wind Energy Areas (WEAs). Map developed by OWC.

to approximately 5,850 km² (Sable Island Bank) [2]. For context, Hornsea 2, currently the world’s largest operational offshore wind farm, occupies approximately 460 km² [3]. The scale of the Nova Scotia WEAs implies that only a subset of each area is likely to be developed, with geological and bathymetric constraints playing a key role in determining viable development zones.

2.3 Water Depths and Bathymetry

Water depths across the WEAs vary substantially (Figure 2):

- French Bank: ~70-210 m (deepest of the four)
- Middle Bank: ~40-160 m
- Sydney Bight: ~50-150 m
- Sable Island Bank: ~20-80 m (shallowest)

Publicly available bathymetric data indicate that large areas of the WEAs are relatively flat, which is favourable for offshore wind development. However, localized ridges, scarps, and depressions are present, reflecting underlying geological structures and glacial landforms (Figure 3).

3. DATA SOURCES AND METHODOLOGY

This study is based on a desktop review of publicly available geological and geophysical datasets, including:

- Surficial geology compilations of the Scotian Shelf from Natural Resources Canada
- Bathymetric datasets and seabed morphology interpretations from

General Bathymetric Chart of the Oceans

- Geological Survey of Canada seismic stratigraphy studies
- Grab sample and seabed imagery from recent survey expeditions
- Peer-reviewed academic literature on Scotian Shelf geology

The analysis focuses on seabed and shallow subsurface conditions (upper tens to one hundred metres), which are most relevant to offshore wind foundations and cable installation. No new field data were collected as part of this study; rather, existing data were synthesized to provide a development oriented geological interpretation.

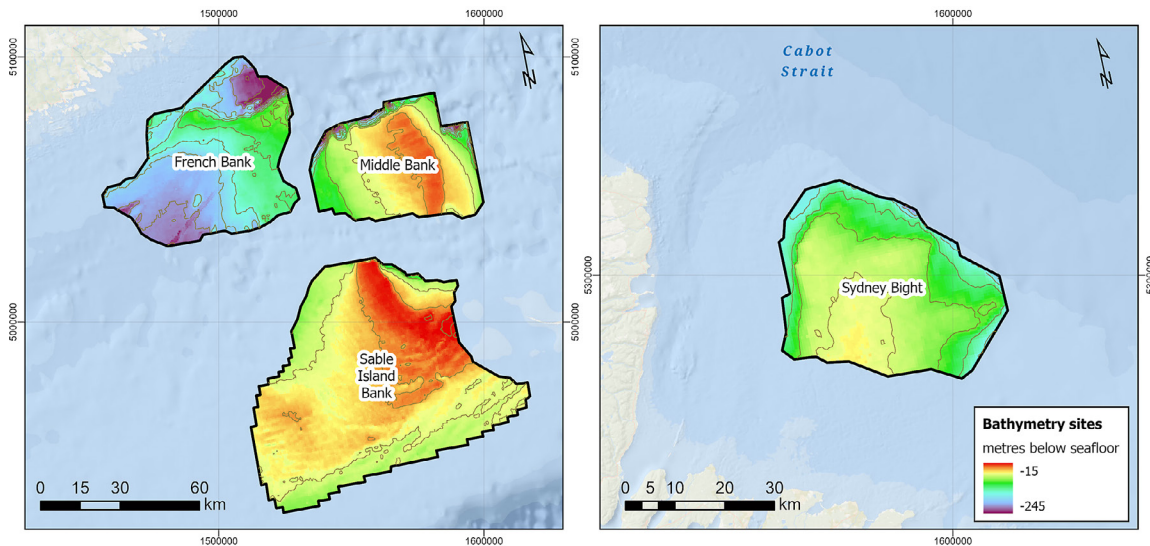


Figure 2: Bathymetry of the Wind Energy Areas (WEAs). Map developed by OWC with data sourced from [4].

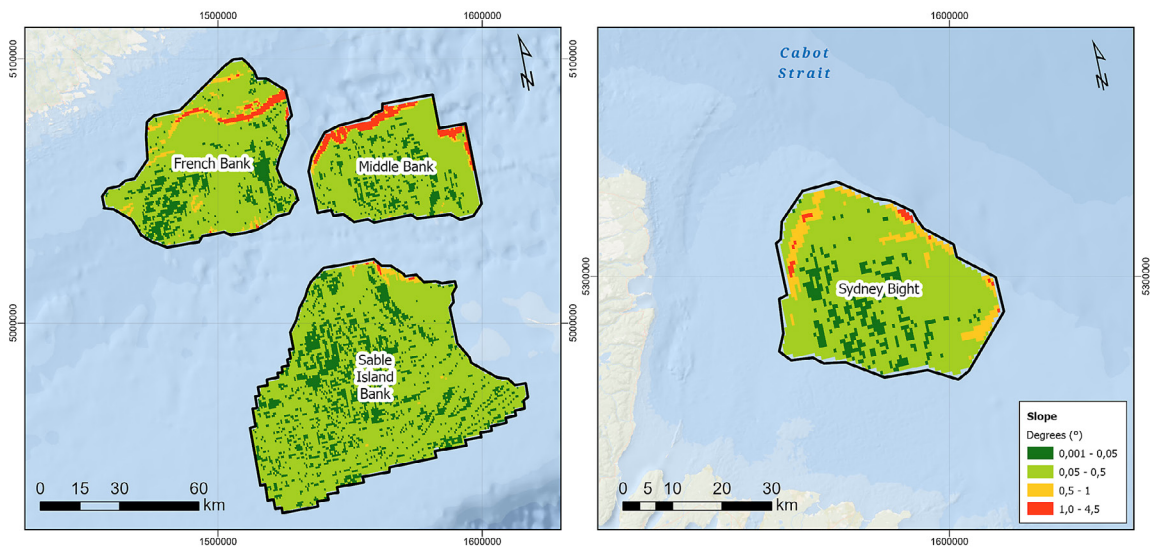


Figure 3: Seabed slopes of the Wind Energy Areas (WEAs). Map developed by OWC with data sourced from [4].

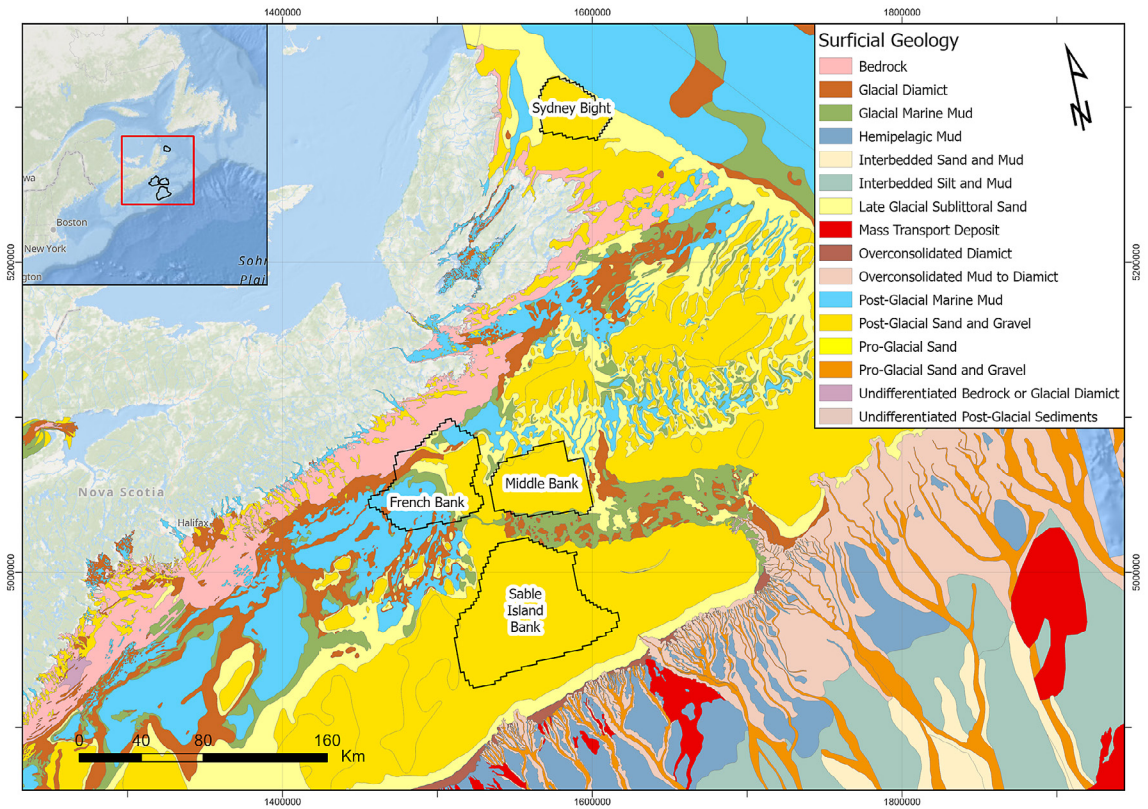


Figure 4: Seabed sediments across the Scotian Shelf. Map developed by OWC with data sourced from [5].

4. SURFICIAL SEABED SEDIMENTS

4.1 Overview of Sediment Types

The surficial geology of the Nova Scotia WEAs is dominated by post-glacial sands and gravels, with local occurrences of glacial diamict, marine muds, and exposed bedrock (Figure 4). Sediment distribution varies between WEAs, reflecting differences in glacial history, water depth, and post-glacial marine processes (sea level transgression).

4.2 Sydney Bight

Sydney Bight is characterized predominantly by post-glacial sand and gravel deposits. At water depths less than approximately 100 m, sediments are often thin, with bedrock locally exposed through a veneer of sand and gravel. The seabed is generally flat, but minor

roughness occurs, where bedrock ridges may be present. Coal-bearing formations extend offshore in this region, reflecting the geological continuity between Cape Breton and Newfoundland.

4.3 French Bank

French Bank exhibits a more diverse assemblage of surficial sediments, including:

- Post-glacial sand and gravel
- Late glacial sublittoral sands
- Glacial and post-glacial marine muds
- Glacial diamict
- Local bedrock exposure

This diversity reflects the strong influence of glacial deposition and ice-marginal processes in the near- to mid-shelf environment.

4.4 Middle Bank

Middle Bank is dominated by post-glacial sand and gravel deposits. Recent surveys indicate generally flat seabed conditions with local scour depressions. In some locations, geophysical data suggest the presence of a “competent” layer sitting 10-20 m beneath the seabed, interpreted as either dense glacial material or shallow bedrock [6].

4.5 Sable Island Bank

Sable Island Bank is characterized by thick, sand-dominated deposits formed through repeated cycles of deposition and erosion associated with sea level transgression and storm-dominated marine processes. While clay-rich tills are not expected to be widespread, local interbedded clays and scattered cobbles and boulders are likely to be present beneath the thick sand sequences, particularly in palaeochannel fills [7]. Surficial cobbles and boulders are also likely to be present in the north-northwest areas of Sable Island Bank.

5. SUBSURFACE GEOLOGICAL FRAMEWORK

5.1 Glacial Landforms and Deposits

The inner shelf regions, particularly around French Bank, display classic glacial landforms such as moraines and drumlins. These features reflect ice movement and glacial deposition across the shelf and are associated with glacial till deposits. Such deposits can vary significantly in grain size, density, and strength over short distances, posing challenges for foundation design.

5.2 Bedrock Characteristics

Bedrock lithologies identified in the region

include slate, greywacke, and quartzite, all of which are known to be hard, competent materials (Figure 5). Shallow bedrock such as this presents challenges for driven foundations and cable burial. In areas where bedrock is exposed or covered by only a thin sediment layer, alternative installation techniques may be required.

5.3 Palaeochannels and Stratigraphic Complexity

Across the Scotian Shelf, numerous palaeochannels have been identified. These channels are incised into bedrock or competent sediments, and partially infilled with sand, gravel, and locally clay-rich sediments. The infill materials are often highly variable in composition and compaction, introducing uncertainty in geotechnical behaviour.

5.4 Sable Island Bank Stratigraphy

Seismic stratigraphy studies of Sable Island Bank reveal a classic sequence stratigraphic framework, with cyclic transgressions and regressions of sea level producing layered sedimentary sequences (Figure 6). Sediments generally thicken as we look further offshore, with older and potentially more indurated units present at depth.

6. GEOLOGICAL HAZARDS AND ENGINEERING CONSIDERATIONS

6.1 Shallow Bedrock

Shallow bedrock (i.e., bedrock located at the seabed surface to approximately 30-40 m below seabed) has been identified across the Scotian Shelf and is likely present at French Bank and Sydney Bight WEAs. It has not been

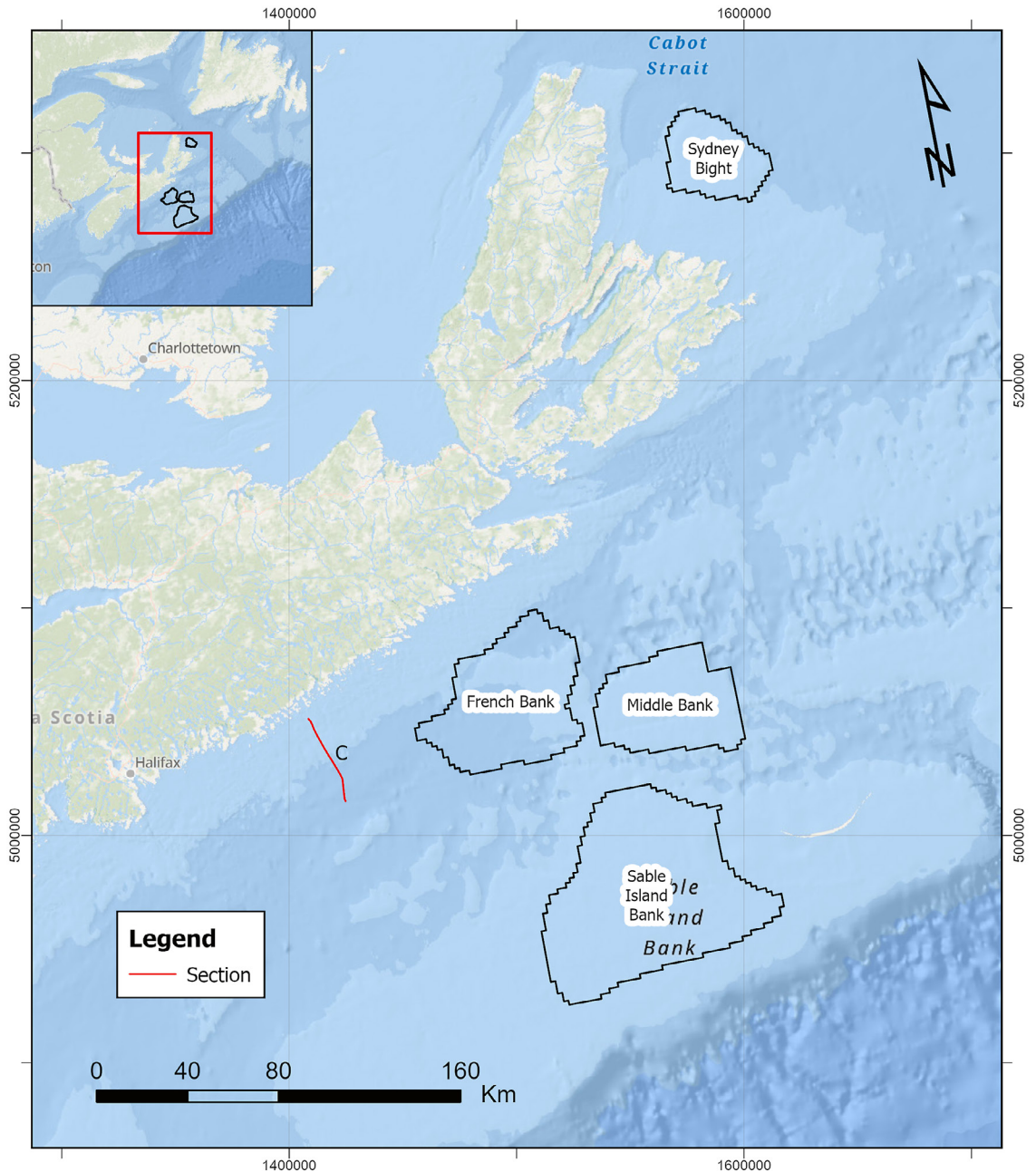
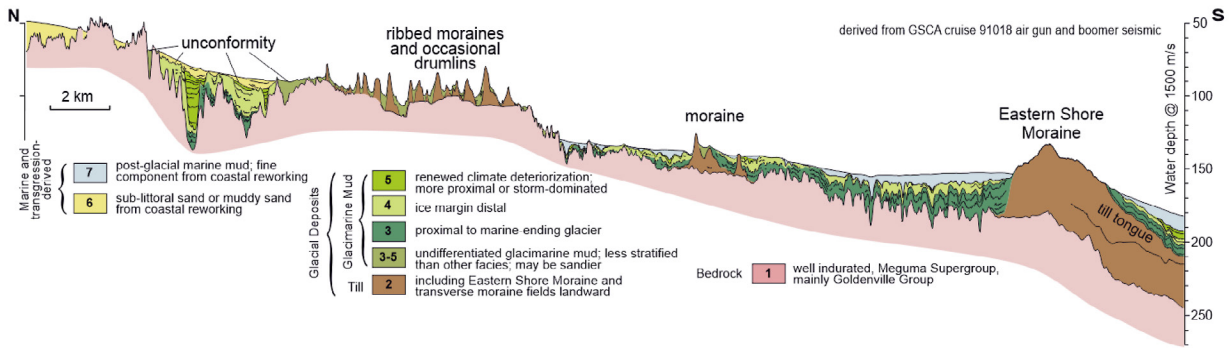


Figure 5: Subsurface profile (top) [8]. Map (bottom) developed by OWC providing approximate location of the profile in relation to the Wind Energy Areas (WEAs).

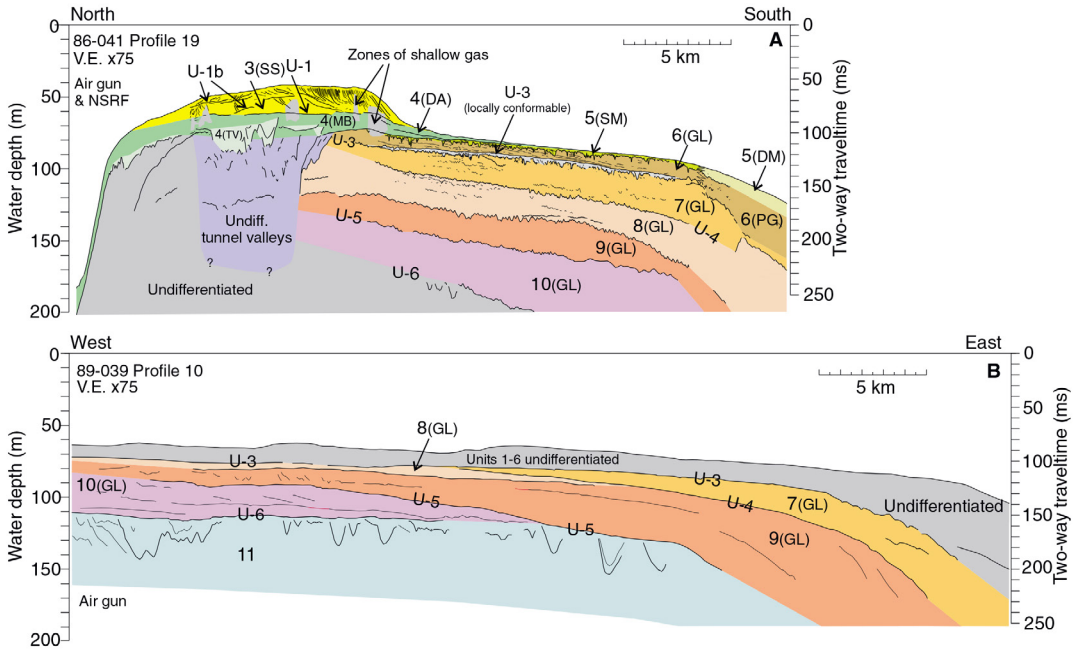


Figure 6: Soil profiles extracted from [7]. Both profiles are in close proximity to Sable Island Bank Wind Energy Area (WEA) site. Top image shows profile from nearshore to offshore (left-right), displaying clear layering of sediments, getting thicker as the profile progresses toward the Outer Continental Shelf. Bottom image shows profile running parallel to shore, where palaeochannels can be identified as anomalies within the normal layering of sediments.

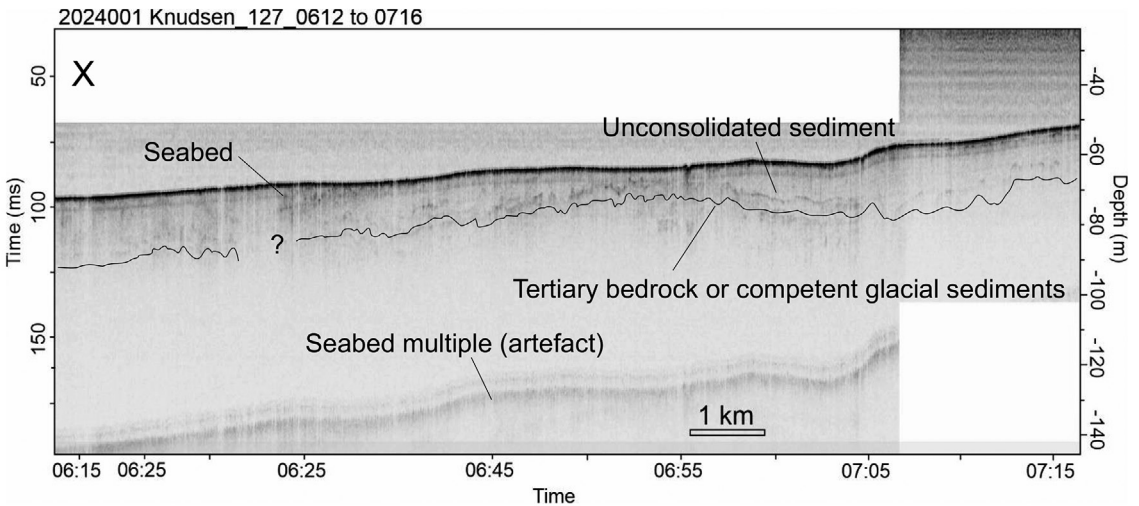


Figure 7: Subsurface soil profile acquired at a central location within Middle Bank Wind Energy Area (WEA). Profile extracted from [6].

verified whether Middle Bank also has areas of shallow bedrock; however, a sub-surface seismic profile acquired in 2023 indicates the presence of a competent soil layer within the first 10-20 m below seabed (Figure 7).

6.2 Shallow Gas

Shallow gas has been identified in parts of Sable Island Bank, generally at a local scale. While not necessarily widespread, the presence of shallow gas requires careful consideration during site investigation and foundation design. This is due to potential health risks to crew during drilling operations and stability of soils during asset installation/operation [7].

6.3 Glauconite or “Green Sand”

Recent research has identified glauconite content in parts of the Scotian Shelf, most notably at Sable Island Bank WEA [6]. Glauconite, that appears as a green sand, has gained infamous recognition in the US, where it has caused pile installation challenges for offshore wind projects offshore Massachusetts and Rhode Island. Although glauconite has so far been identified primarily in grab samples of seabed sediments, its potential presence warrants further investigation.

6.4 Seabed Mobility

Sand-dominated environments, particularly on Sable Island Bank, are subject to seabed mobility under storm-dominated wave and current regimes. Sandwaves and megaripples, bedforms that indicate the risk of seabed mobility, are likely to be present at Sable Island Bank WEA, and recent bathymetric survey data at Middle Bank show signs of scour depressions [9]. Bedform migration and scour around foundations may be significant

and must be accounted for in foundation design and cable protection measures for offshore wind projects.

7. IMPLICATIONS FOR OFFSHORE WIND DEVELOPMENT

7.1 Foundation Concepts

The geological diversity of the Nova Scotia WEAs suggests that no single foundation concept will be universally applicable. Potential foundation solutions include:

- Large-diameter monopiles (with or without pre-drilling)
- Drilled monopiles or socketed foundations in hard ground
- Suction caissons in suitable sedimentary conditions
- Floating foundations in deeper water areas (French Bank)

Experience from projects such as the Saint-Nazaire offshore wind farm demonstrates that drilled extra-large monopiles can be successfully deployed in rocky seabed conditions – although significant installation times, equipment damage, and expensive drilling apparatus will likely increase costs significantly.

7.2 Cable Installation

Cable routing may be challenging in areas with shallow bedrock, ridges, and variable sediment cover. However, in deeper water areas, cable burial may not be required, potentially simplifying installation. As many of the WEA names suggest, each of the sites sit on a bank, an area of relatively flat, elevated seabed. Between each of the banks is a basin or rougher terrain, which will need to be

navigated to successfully route export cables back to shore. It is, therefore, not sufficient to simply investigate the WEAs themselves but also potential cable routes back to Nova Scotia or further afield.

7.3 Development Strategy

Given the immense size of the WEAs, early-stage geological screening is essential to identify favourable sub-areas for development. Targeting zones with relatively uniform sediments, moderate water depths, and limited geological hazards can significantly reduce development risk and cost.

8. DISCUSSION

The Nova Scotia WEAs represent a geologically complex but highly promising offshore wind region. Compared to more established offshore wind provinces, the Scotian Shelf presents greater geological variability and uncertainty, particularly related to glacial landforms, shallow bedrock, and sediment heterogeneity. However, these challenges are not insurmountable and can be addressed through appropriate site investigation, engineering innovation, and adaptive development strategies.

9. CONCLUSION

1. The Scotian Shelf offshore Nova Scotia exhibits complex seabed and sub-seabed geology shaped by glaciation and post-glacial marine processes.
2. Surficial sediments are dominated by post-glacial sands and gravels, with localized glacial diamict, marine muds, and bedrock

exposure (most notably at French Bank).

3. Geological hazards such as shallow gas and glauconite require further investigation but are manageable with appropriate design approaches.
4. The exceptional size of the WEAs necessitates selective development, guided by early-stage geological understanding.
5. With informed planning and engineering, the Nova Scotia WEAs offer strong potential for large-scale offshore wind development.

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Author Declaration

- Funding: The author did not receive financial support from any organization for the submitted work.
- Ethical approval: This paper does not contain any studies with human participants or animals.
- Competing interests: The author declares that he has no competing interests.
- Availability of data and materials: Datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.
- Artificial intelligence was not used in this work.

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