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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8911

Updated surficial geology compilation of the Scotian Shelf bioregion, offshore Nova Scotia and New Brunswick, Canada

G. Philibert, B.J. Todd, D.C. Campbell, E.L. King, A. Normandeau, S.E. Hayward, E.R. Patton, and L. Campbell

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1. INTRODUCTION

1.1 CONTEXT AND OBJECTIVES

Understanding the composition, seabed morphology, stability and sensitivity of the seafloor is critical information needed for ocean management and evaluating cumulative anthropogenic and natural impacts. The Geological Survey of Canada's (GSC) seabed characterization activities provide a regional framework in advance of development activities in order to inform regulatory decisions and conditions related to the design, siting and operation of seabed infrastructure. Some seafloor areas are too sensitive or unstable to support industrial development and with less than 10% of Canada's offshore territory adequately mapped, there is insufficient baseline information to define these areas.

The Marine Geoscience for Marine Spatial Planning (MGMSP) Program is a GSC program funded through the Government of Canada horizontal initiative focused on improving impact assessments and regulatory processes (IARP). Natural Resources Canada (NRCan) is one of five departments supporting Environment and Climate Change Canada (ECCC) and Fisheries and Oceans Canada (DFO) in this initiative. Within NRCan, the GSC provides the federal expertise and capacity for detailed seafloor mapping and marine geoscience. Seafloor mapping and analysis aims to support marine regional planning. It is fundamental to acquire baseline information of the seafloor for evidence-based decision making on the impacts of marine activities and seabed use.

This report presents the surficial geology of the Scotian Shelf Bioregion (SSB) (DFO, 2009; Figure 1). The Scotian Shelf surficial geology had been interpreted in the past over the shallower portions of the bioregion (King, 1970; Maclean and King, 1971; Drapeau and King, 1972; Fader *et al*., 1977; Fader *et al*., 1978; Fader *et al*., 1982) as well as on the slope (Piper, 1991). Since these early maps were produced, more recent and higher resolution hydroacoustic data have been acquired. Therefore, the main objective of the present study is to update the existing surficial geology over the entire SSB, both shelf and slope, using new available maps and data sets. This report constitutes a review of all existing publically-available data sets and associated studies that provide information on surficial geology within the bioregion and describes how previous maps and recent data were amalgamated to produce a new updated version of the surficial geology within the SSB.

Specifically, the objectives of this study are to:

- Compile all available studies that have interpreted and mapped the surficial geology of the seafloor within the SSB;
- Compile available geoscience data that provide more recent and higher resolution information on the surficial geology and geomorphology of the seafloor within the SSB. These data include bathymetry, backscatter strength, sidescan sonar and sub-bottom;
- Update the early maps using the more recent and higher resolution maps and hydroacoustic data and standardize the information at a regional scale;
- Create a descriptive surficial geology legend that is uniform and consistent among all the different maps assembled as well as from one bioregion to another using a geoscientific language that meets the needs of all stakeholders.

A large format poster presenting the updated surficial geology map of the SBB accompanies this report to provide readers with greater detail than page-size presentations.

1.2 STUDY AREA

The Scotian Shelf Bioregion (SSB) covers approximately 470,000 km^2 and extends from the Gulf of Maine in the southwest to the Laurentian Channel in the northeast and includes the continental shelf and slope (Figure 1). To the south, the SSB extends to the lower continental slope where the seafloor reaches depths of 5000 m. The SSB includes the Bay of Fundy situated between the Provinces of Nova Scotia and New Brunswick.

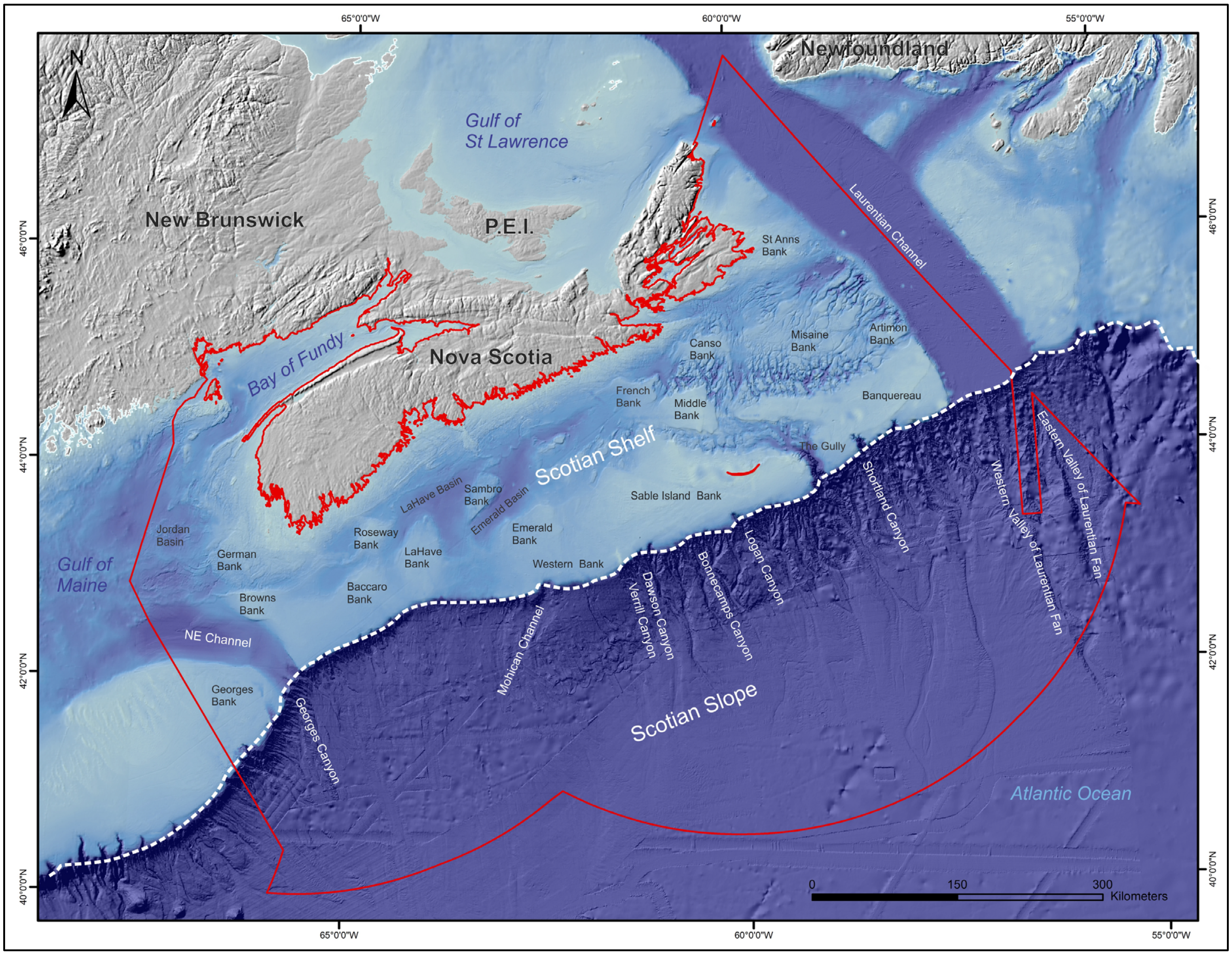

Figure 1: Location map of the Scotian Shelf Bioregion with main water bodies and bathymetric features identified.

The physiography and geomorphological structure of the seafloor of southeastern Canada is broadly controlled by its tectonic history. The continental margin is formed by the transition between continental and oceanic crust (Normandeau *et al.,* 2020). As a result, the seafloor area can be divided into two distinct physiographic units: (1) the continental shelf and (2) the continental slope (Figure 1).

1.2.1 The Continental Shelf

The continental shelf is located between the coast and the shelf break. The shelf width ranges from 125 to 230 km and the average gradient is about < 0.1° (Shaw *et al.*, 2014; Normandeau *et al.*, 2020). The continental shelf was affected by past glaciations and modified under the influence of sea level changes. Sediment transport processes on the seabed remain active today under the influence tidal and wave-induced currents as well as broader ocean circulation (e.g., Li *et al.*, 2007; Todd *et al.*, 2014). The overall low gradient morphology of the shelf is characterised by a series of shallow banks, separated by both shelf-crossing and shore-parallel troughs which have been deepened by ice streams during past glaciations (Shaw *et al*., 2012). The Laurentian Channel and the Northeast Channel are the two most prominent glacial troughs crossing the continental shelf within the region (Todd, 2016). The average depth on the shelf is about 60–70 m but reaches about 350 m in Northeast Channel and over 500 m in Laurentian Channel. Banks are separated by basins which are usually filled with a thick sequence of glacigenic and Holocene post-glacial sediment. Water depths on the banks range from 30 to 100 m and basins reach 200 to 250 m in depth. Sable Island Bank, which extends 255 km in length and 115 km in width, is the largest bank on the Scotian Shelf and partly extends above sea level forming Sable Island (King, 2001; Shaw *et al*., 2006) (Figure 1). Emerald Basin and LaHave Basin are the largest basins on the shelf (Shaw *et al*., 2006).

1.2.2 The Continental Slope

The upper bathymetric limit of the continental slope is defined by the continental shelf break located approximately 200 km southeast of the coast of Nova Scotia. Seaward of the shelf break, the low gradient of the continental shelf gives way to the steeper gradient of the slope. Within the Scotian Shelf Bioregion, the slope reaches a water depth of about 5000 m along the southern boundary. The slope gradient is about 2° (Mosher *et al*., 2017). The general morphology is influenced by the underlying bedrock, but the modern surface is a result of glacial processes that occurred during the Pleistocene Epoch (e.g. Mosher *et al*., 2004; Campbell *et al*., 2008a, b, c). Large quantities of glacigenic sediments were transported down the continental slope during the Last Glacial Maximum (LGM) through turbidity currents; which eroded submarine canyons. As a result, the slope is mostly characterized by landforms associated with gravitational processes such as canyon erosion, fan deposition and landslides (Normandeau *et al*., 2020). The slope morphology is due to high sediment supply combined with lower sea levels during deglacial episodes (Mosher *et al*., 2004; Campbell *et al*., 2008a, b, c; Piper *et al*., 2007; Normandeau and Campbell, 2020). The central portion of the Scotian Slope seafloor appears relatively featureless whereas the southwest and northeast sections of the slope exhibit a highly eroded seafloor and are characterised by the presence of gullies, channels and canyons. Mass-transport deposits are present on upper to lower slope throughout the bioregion (Mosher *et al.,* 2004; Piper *et al.,* 2005; Jenner *et al.,* 2007; Normandeau *et al.,* 2019b, c).

1.2.3 The transition from Continental Shelf to Slope

The factors governing surficial geology on the continental shelf in comparison to the continental slope are disparate enough to warrant two different surficial geology map approaches, one extending across the continental shelf, and the other covering the continental slope. These two approaches were the basis for the present study. There is little attempt at geologic integration of the two approaches, largely because the geologic features, history and processes differ fundamentally across the outer continental shelf edge and the existing mapping focus reflects this. The shelf edge generally marks the limit of glacial ice cover, the lower limit of sea-level low-stands, the limit of paleo-iceberg scour, the edge of down-slope mass-wasting processes, and the transition to different water column properties and currents.

2. DATA AND METHODS

2.1 SURFICIAL GEOLOGY BASE MAPS

Previous studies of the surficial geology of the bioregion provide nearly full coverage, however at different scales and with differing geologic focuses. This new map compilation presents a unification or normalization of the existing maps and presents them at a common scale that is comparable to the bioregional working scale of the present Scotian Shelf Bioregion study. For reasons expressed in the previous section, two different surficial geology maps were the basis for the present study. One map extends across the continental shelf (Fader *et al*., 2004) and the other covers the continental slope (Piper, 1991). The extents of the two maps are shown in Figure 2 and a brief description is provided in the following sections (2.1.1 and 2.1.2).

2.1.1 Scotian Shelf – base map data source

A compilation of the surficial geology of the Scotian Shelf from Georges Bank to the Laurentian Channel was undertaken by various authors in the 1970s and 1980s as part of a systematic regional mapping program that was conducted by the GSC over a period of approximately 20 years. This compilation comprises a set of 6 maps which includes, from west to east, eastern Gulf of Maine and Bay of Fundy (Fader *et al*., 1977), Yarmouth–Browns Bank map area (Drapeau and King, 1972), Halifax–Sable Island (King, 1970), Canso Bank and adjacent areas (Fader *et al*., 1978), Banquereau and Misaine Bank area (Maclean and King, 1971), and Laurentian Channel and the western Grand Banks of Newfoundland (Fader *et al*., 1982). In 2004, this compilation of surficial geology maps was digitized into a single, contiguous, digital (GIS) product (Fader *et al*., 2004). This digitized data set was used as one of the two base maps and main sources of the surficial geology of the bioregion. The data set defines the boundaries of surficial geology map units of Quaternary age. The legend is composed of five different types of sedimentary categories and does not include bedrock.

2.1.2 Scotian Slope – base map data source

The Scotian Slope surficial geology base map is from Piper (1991), who mapped the predominant sediment type in the upper few meters of the seabed. His interpretation is based on sidescan sonographs and 3.5 kHz and 12 kHz echosounder profiles calibrated with piston cores in areas where such data were available. In other areas, geological boundaries are more speculative and were extrapolated between widely spaced seismic profiles and core analyses. The upslope limit of the Piper (1991) map is the 200 m isobath or at the shelf break. Piper (1991) identified 13 categories of sediment types using a language that refers to texture and geomorphology features. Thin (less than 1–2 m) Holocene hemipelagic mud overlying Pleistocene sediment of different character is not shown in his interpretation.

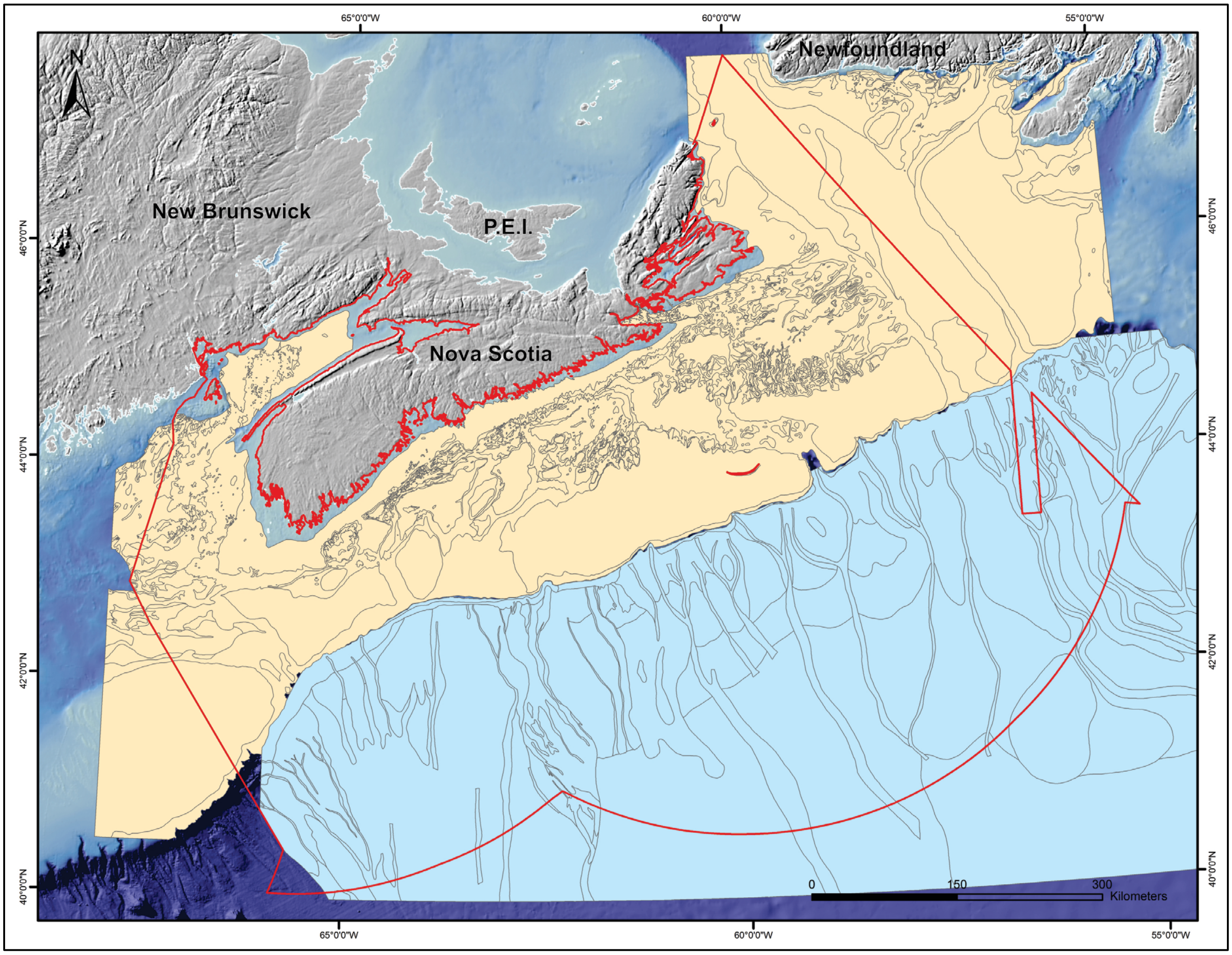

Figure 2: The surficial geology data sets used as base maps. The light yellow polygons covering the shelf correspond to the surficial geology compilation of Fader et al. (2004) and the light blue polygons covering the slope are from Piper (1991).

2.2 UPDATING THE SURFICIAL GEOLOGY BASE MAPS

Given that the two base maps (Piper, 1991; Fader *et al*., 2004) were produced more than two decades ago, a review of more recent maps and hydroacoustic data was carried out in order to update the regional surficial geology. Since the early publication of the maps contained in the Fader *et al*. (2004) compilation, new data have been collected in strategic parts of the Scotian Shelf, notably on the western portion and in the Bay of Fundy. On the slope, significant mapping efforts have been made since Piper (1991). Therefore, when applicable, the two base maps (Piper, 1991; Fader *et al*., 2004) were compared, updated and upgraded with the results of more recent studies where surficial geology has been interpreted within targeted areas using higher resolution data sets and a finer level of detail. The surficial geology maps that were used to upgrade the two base maps are displayed on Figure 3. Moreover, certain areas have been updated using more recent and higher resolution hydroacoustic data such as multibeam sonar, bathymetric LiDAR, 3D seismic, Olex single beam (license held by GSCA) and sidescan sonar data sets. These newer data sets benefit from a more precise georeferencing than the older base maps. The different hydroacoustic data sets that were used to upgrade the two surficial geology base maps are shown on Figure 4 (excluding the Non Navigational Bathymetric Data (NONNA; CHS, 2018) and Olex single beam). It is important to note that only the areas where new higher resolution maps or hydroacoustic data are available have been updated. In other areas, the base maps remain as the only existing representation of the surficial geology.

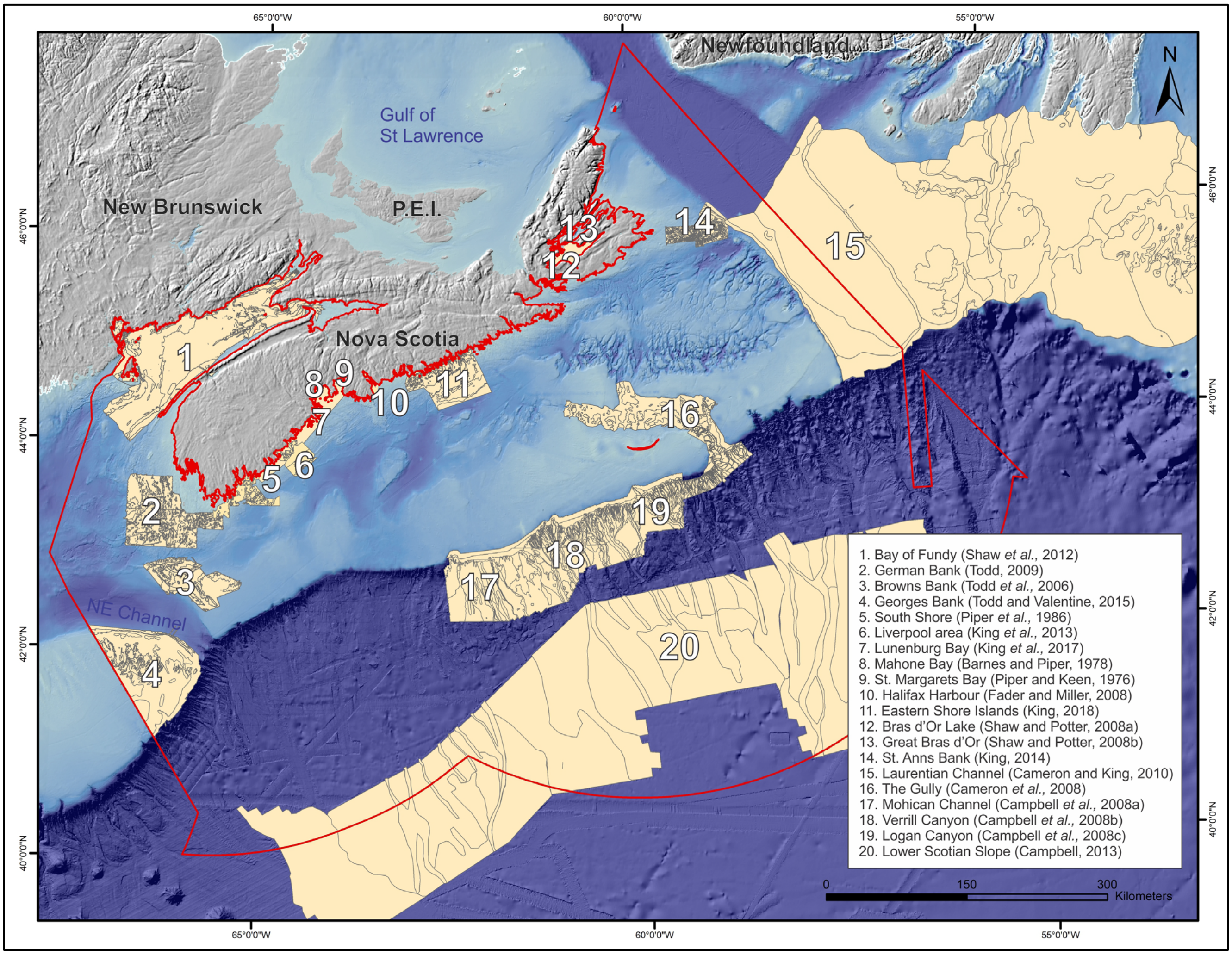

Figure 3: Location of the 20 surficial geology maps used to update the base maps.

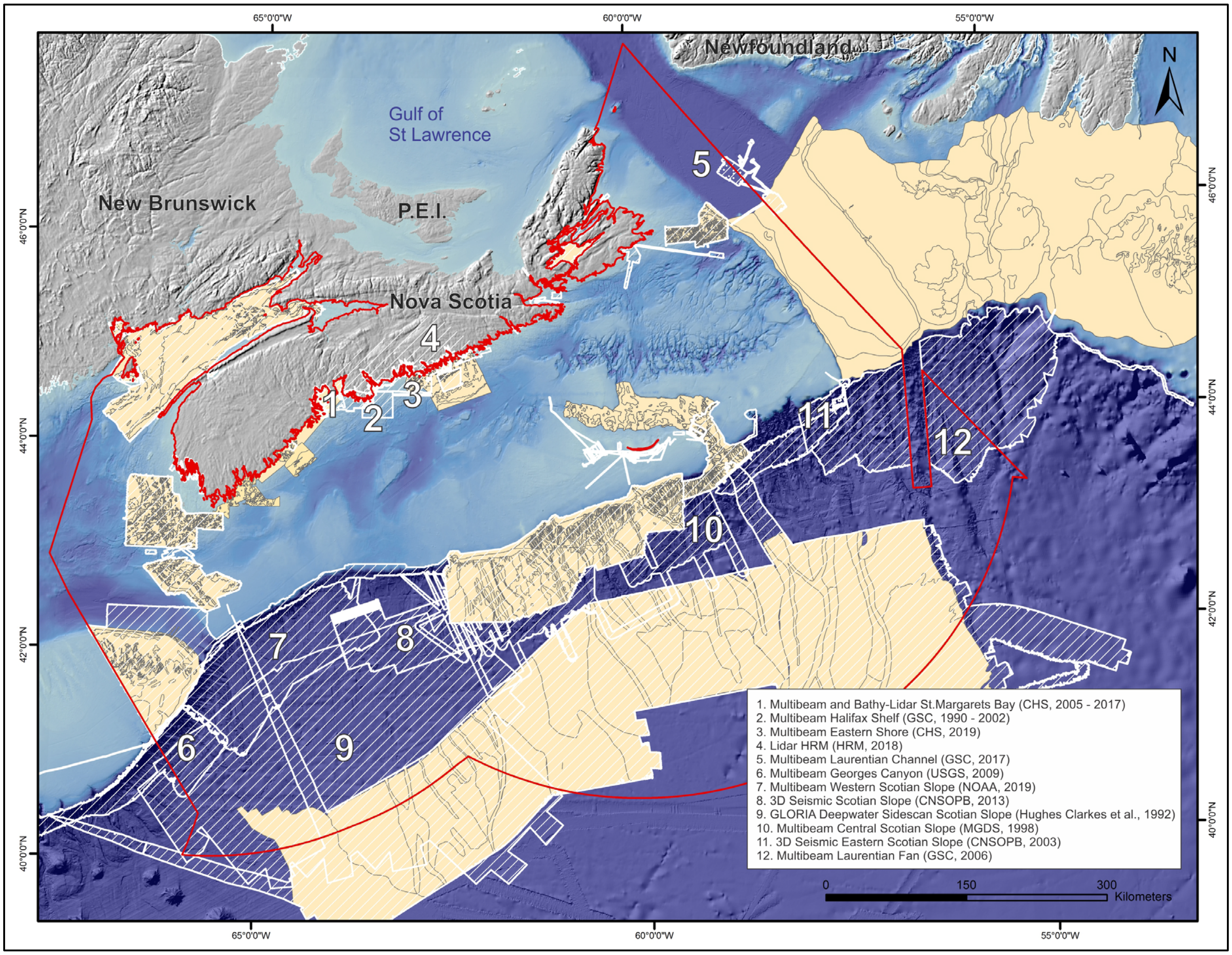

Figure 4: The new hydroacoustic data sets used to update the surficial geology base maps. The data sets are displayed along with the surficial geology maps also used for updates in order to highlight the areas where no recent data were available to perform any updates of the base maps. Not displayed on this figure are NONNA (CHS, 2018) data sets which covers the south-western and eastern inner shores as well as Olex single beam. These two data sets extend over most of the shelf at various resolutions.

It is important to acknowledge that a surficial geology interpretation from multibeam echosounders and sub-bottom profiles is utilizing acoustic proxies for seabed texture; these proxies depend on many factors such as water depth and the frequency of the instrument used. For example, a 12 kHz multibeam sonar echosounder used in 4000 m water depth will image approximately a 50–60 m horizontal pixel on the seafloor. In contrast, a 300 kHz MBES in 200 m of water depth will map a 2 m pixel size. Therefore, the resolution of the maps cannot be compared in deep and shallow water. In addition, the backscatter response will be different between frequencies and water depth; therefore, comparison between shallow and deep water is not possible. These variations in types of instruments used to map the seabed in different water depths inherently lead to bias in the surficial geology interpretations. In shallow water, higher frequency instruments usually enables the interpretation of the top metre of surficial sediments. In the deeper water of the slope, the top metre likely consists of mud. However, the backscatter strength and sub-bottom penetration is variable due to the sediments below the surficial mud. Thus in this report, the slope sediments comprising the bulk of the top few meters are considered.

2.2.1 Working scale of interpretation and updates

The more recent maps and data available for updating this map compilation generally targeted smaller study areas and were presented at a finer horizontal resolution than the compilation. This required adaptation and modification to fit the working scale of the current study (i.e., the bioregional scale). In the sectors where existing surficial geology maps derived from multibeam data were used, for example, the updates were simplified and increased in scale to match the working scale and to provide a more uniform result. The minimum size of the simplified polygons on the shelf is approximately 5000 m^2 (Fader *et al*., 2004) and 300 000 m^2 on the slope (Piper, 1991) in order to be consistent with the minimum size of the polygons from the base maps. Finally, in the sectors that have been completed and updated using new hydroacoustic data, the resolution of the available data is variable. Therefore the interpretation was undertaken in the scale range of 1: 100 000 to 1: 250 000.

2.3 SURFICIAL GEOLOGY LEGEND

The new maps present a compilation of surficial geology data from a variety of sources and each source used its own geoscientific language. Therefore a new and unifying legend was necessary. The objective is to apply consistent and comparable geoscience language from one bioregion to another within the Marine Geoscience for Marine Spatial Planning Program and also to meet the needs of DFO by employing a geoscience language that provides meaningful information to a non-specialist in geoscience. Thus, names referring to local nomenclature are not used in this standardized geoscience language. The new legend refers only to texture (e.g., sand, gravel, mud, etc.) and depositional environment or process (e.g., glacial, postglacial, marine, etc.). The unified science language adheres to the standard recently established by the Marine Science Language Committee, a group of experts from the GSC working under a data management initiative that aims to consolidate the marine science language into a unified geologic data model in order to produce standardized Canadian Geoscience Maps (CGMs). The legend used for this map has been developed such that it serves both the geo-scientific community but is also relevant to other researchers from fields such as benthic habitat mapping or seabed infrastructure engineering. A total of 16 surficial units were compiled in the present study. The various classes of materials identified on the shelf are described in Table 1 and those identified on the slope are described in Table 2.

Table 1. Unified Legend of Surficial Geology on the Shelf

Surficial Geology Unit	Description
Postglacial Transgressive Sand and Gravel PgTsg	Predominately composed of sand, gravelly sand or patchy gravel. Generally present on banks and the inner shelf in water depths less than 120 m. Generally less than 1–2 m thick, but much thicker on eastern outer shelf banks. Comprises the coarser remnants of reworked glacial deposits and other bank sediments following glacial retreat when low sea-level exposed them to subaerial weathering and erosion. Reworked and transported by wave and current action in littoral and sublittoral environments during the subsequent transgression (late Pleistocene and early Holocene). The finer grained sublittoral facies equivalents of this unit are LgSLs. Much of the sand was swept off bank areas, contributing to shelf-edge canyon development (erosion) and thalweg deposits. Some was preserved in thick (many metres), prograded sheets in an evolving transport pattern with sea level rise. Some entire banks were swept free of sand, leaving dominant gravel distribution. These sediments (up to small gravel size) can be reworked and redistributed in the upper centimetres or decimetres by bottom currents and storm waves. Patchiness is generally governed by diverse bedforms (dunes) generating sandy crests and gravelly troughs with metres to hundreds of metres spacing, especially in shallow (<30 m) water. Relict bedforms can be locally preserved in deeper areas. Time-transgressive genesis, from time of glacial retreat in deeper water depths to present day in shallow water depths. Locally reworked into periodically active bedforms (sand with gravel troughs), locally deeper in current-influenced channels.
Undifferentiated Postglacial Sediments PgUn	Characterized by a smooth surface in bathymetric data. Identified in areas where no further data beside bathymetry provide insight into the nature of the deposit. Located on the shelf, close to the coastline. Could either correspond to postglacial mud, postglacial sand or postglacial sand and gravel with possible bedrock and/or till outcrops. This interpretation is based on the context of the region and knowledge of the geological history of the area.
Postglacial Marine Mud PgMm	Mud consisting mostly of silty clay and clayey silt. Corresponds to the winnowing of silt and clay from glacial debris on banks during late Pleistocene and early Holocene sea-level rise, where finer material was deposited in lower lying depressions. This postglacial sediment has a predominantly ponded sedimentary style. Overlies glacial drift and glacial marine mud. It is a lateral equivalent to the postglacial sand and gravel. Mainly confined to basins and local depressions on the shelf.
Late Glacial Sublittoral Sand LgSLs	Muddy sand or silt with little gravel. Generally a thin (<1 metre) wedge, thinning significantly in deeper water depth. Generally restricted to a band along bank edges and along submarine terraces in water depths > 120 m, but may also be found in small embayments. Deposited in a mostly proglacial environment, along the littoral of the Late Pleistocene shoreline during sea level low stand. Locally reworked into periodically active bedforms. May overlie glacial diamict and may underlie postglacial sand and gravel. Some time equivalency with latest deposits of GMm and earliest PgMm and PgTsg.
Glacial Marine Mud GMm	Clayey to silty mud with variable content of scattered clasts. Distributed principally partially infilling large basins on the shelf in over 110 m water depth, overlying or locally interfingering with the glacial diamict map unit (Gd), near paleo-glacial margins. Up to tens of metres thick, generally >15 m, while thinning to zero at basin margins. Generally covered with postglacial mud (PgMm) in basins, but in shallower water depths commonly occurs as pockets in smaller topographic lows. Locally the uppermost surface has been partly eroded (up to several metres removed), developing a thin (centimetres to decimetres) surficial sandy and/or gravelly lag (PgTsg). Deposited during the last glaciation (~20 to 14 ka) beyond the ice sheet by proglacial meltwater plumes in a proximal to distal marine environment. Proximity of the ice front can be tens of kilometres distant, influencing the texture of the unit. Where present, clasts are generally ice-rafted debris while sand or mud layers were deposited from turbidity currents.

Glacial Diamict Gd	Poorly sorted homogeneous mixtures of mud with matrix-supported sand, gravel and cobble clasts. Generally competent. Dense to very stiff. Diamict can be referred to as glacial diamict or till where recognized as being deposited in direct contact with ice. Diamict has strong glacigenic origin in the study area, but is not necessarily all till. Commonly occurs on the inner shelf as multiple moraines at various scales. Less commonly occurs as drumlins, grounding zone wedges or variably thick (up to tens of metres) blankets with glacially sculpted surface (fluting or similar glacial lineations), indicating a subglacial and glacial margin origin. Its upper surface is commonly iceberg-turbated along the flanks of banks and shelf edge. Commonly overlain by sand and gravel and boulder lag deposits or by glacial marine mud and postglacial mud. Generally differentiated from map unit Br by geomorphic elements, samples, or homogeneous body character where seismic profiles depict acoustic penetration which is not common in bedrock. Chronology assessments invariably indicate deposition during the last glaciation, but with a complex and time-transgressive glacier flow and margin retreat pattern governed by basin and trough elements yet with a general retreat from west to east and from the shelf edge to the shoreline.
Undifferentiated Bedrock or Glacial Diamict BrGdUn	Chaotic and rugose surface on bathymetric/topographic renderings. Located on the inner shelf close to the coastline. Characterized by an undifferentiated, possibly patchy combination of map units Br and Gd. Bedrock and till are generally differentiated from detailed geomorphic elements; bedrock exhibits differential bedding relief, strike, sharp and irregular relief and acoustic basement while the diamict permits acoustic penetration, returns a homogeneous internal seismic character and smoother, but equal relief. Further, they can occur juxtaposed or with Gd cover on bedrock. Thus, their differentiation can be challenging, especially where lacking appropriate survey data, adequate resolution or further supporting data. This map unit encompasses areas where their differentiation is not sufficient to trace contacts beyond limited survey control.
Bedrock Br	Dominated by bedrock of various types and ages. Inner shelf areas dominated by granite or very competent schist, shale, or quartzite of Paleozoic age. Generally more diverse, older and competent rock types off Cape Breton. Mid and outer shelf outcrops are rare, mainly in the canyon walls along the continental slope, and comprise less competent Cenozoic age shales and sandstones. Inner shelf bedrock exposures are generally higher relief than in sediment-covered areas, exhibiting exposed mound or ridge and intervening hole or trough relief, reflecting alternating rock types or differential glacial sculpting. Relief can also be governed by bedrock structure, jointed or faulted; regional patterns can follow broad fold structure. Depressions are commonly partly sediment-filled, washed from the adjacent highs under past coastal conditions. This fill is generally patchy and can be composed of thin mud, sand, gravel and cobble or boulder lags and less commonly pockets of till or moraines.

Table 2. Unified Legend of Surficial Geology on the Slope

Surficial Geology Unit	Description
Hemipelagic Mud Hm	Silty and clayey mud, may contain sparse clasts. Mostly present on inter-canyon ridges. Generally 1 to 3 m thick. Deposited by suspension settling sourced from adjacent shelf. Clasts are likely ice-rafted. Sand and mud layers deposited from turbidity currents in adjacent canyon thalwegs. This map unit may be under-represented across large parts of the slope because it is thin, faithfully drapes underlying topography and thus may be largely unrecognized from most hydroacoustic images.
Proglacial Sand and Gravel Gsg	Predominantly comprised of mixed sand and gravel confined to large down-slope channels and canyon floors. Deposited during the Late Pleistocene by high velocity density currents at the front of the ice sheet. May be covered in places with a thin drape of pelagic or hemipelagic sediment (Hm).
Proglacial Sand Gs	Thin sand-rich sheets on the mid to lower slope, generally associated with down-slope channels. Recognized largely from high acoustic backscatter values. Deposited during the Late Pleistocene by sediment density currents at the front of the ice sheet. Mostly located on gently sloping deep-sea fans beyond the mouth of canyons. Generally associated with turbidite sand sheets.
Interbedded Sand and Mud Gsm	Sandy mud, often stratified, and may contain occasional ice-rafted debris. Up to tens of metres thick, generally preserved on the mid or upper slope and commonly associated with large down-slope channels. Deposited during the Late Pleistocene, beyond the front of the ice sheet by sediment density currents. Generally associated with sediment waves and/or flow lineations on levees, differentiating them from map unit Gstm. May have a very thin (decimeters) cover of Hm.
Interbedded Silt and Mud Gstm	Silty mud, often stratified, and may contain occasional ice-rafted debris. Up to tens of metres thick, generally preserved on the mid to lower slope, deposited during the Late Pleistocene beyond the ice sheet margin near the shelf edge by proglacial sediment density currents. Generally associated with levee deposits without sediment waves. May encompass more than one glaciation phase. On the western slope it comprises >15 m and overlies glacigenic debris flows.
Glacial Overconsolidated Diamict GOd	Diamict of glacial origin (till) with interbedded mud and sand, deposited at the seaward limit of glaciers. Distributed at the shelf edge and at canyon heads where it crops out on the upper slope between 300 m and 500 m water depth. Contact with its stratified proglacial equivalents in deeper water is commonly disturbed by iceberg scouring or removed by canyon erosion but less commonly interfingering with a broad but thin diamict wedge approximately marking the former glacial margin. A higher competence of the till compared to underlying deposits appears to moderate canyon retrogression.

Overconsolidated Mud to Diamict Omd	Exhumed mud and diamict situated on canyon and mass-transport scarps. Middle Pleistocene and older overconsolidated sediment mostly exposed on canyon walls with progressive headwall and tributary erosion. Can locally have thin surficial cover of other map units. Comprises a wide range of deposits formed through the burial and compaction diagenesis of ice-margin, proglacial and hemipelagic sediment.
Mass-transport deposits MTD	Poorly sorted and structurally disturbed mud and sandy mud and clasts. Several to tens of metres thick. Headwall and sidewall scarps, chutes, and depositional lobes and wedges. Derived from mass failure of surficial sediments, locally repeated. Present on inter-canyon ridges and gullies over a range of water depths. Parent sediments mainly glacigenic, but failure masses locally incorporate older, more deeply buried (upper 10–50 m) and more consolidated material (can involve most map units). Rugose and lineation-rich morphology, commonly with ridge and trough oriented normal to downhill flow (rotational faulting) and transport chutes with downhill-oriented linear flow fabric. Less rugose where parent sediment disintegrated almost completely. Includes creep, slides, slumps, mass flows, slope failure complexes, but excludes turbidites. Includes only MTDs located at the sediment water interface, usually associated to most recent events. Buried MTDs with variable thickness cover (2–20 m) of units Gsm, Gstm and Hm are common in places but not identified on this map.

2.4 LIMITATIONS TO THE INTERPRETATION AND UPDATES

The objective of the bioregion-scale study is to provide an overall evaluation of geological conditions on a regional scale. The only data used to update the base maps (Piper, 1991; Fader *et al*., 2004) are surficial geology maps from more recent and more spatially detailed studies, new multibeam sonar bathymetric and associated backscatter strength data or sidescan sonar data (see section 3.2). It should be noted that no groundtruth information, such as cores, sediments samples and photographs or video camera footage of the seabed, was used in this study. Similarly, for most areas, no sub-bottom profiles or seismic reflection records were analyzed or integrated to this phase of the project. Only where existing maps were known to have clear shortcomings in comparison to unpublished compilations or those in progress were acoustic survey data consulted. This is the case in a few very specific sites on the slope and the shelf between Cape Breton and Laurentian Channel. Inclusion of groundtruth information will be the purview of future revisions of the map created here.

3. UPDATES

3.1 UPDATES BASED ON EXISTING SURFICIAL GEOLOGY MAPS

A total of 20 surficial geology maps were used to update the two base maps (Figure 3). These were interpreted in the context of various studies that targeted smaller areas and, for the most part, used greater horizontal and vertical resolution data than were previously available.

On the continental shelf, it was possible to update 16 areas using new surficial geology maps:

- The largest of the revised areas is the Bay of Fundy. The surficial geology interpreted by Shaw *et al*. (2012) allowed us to make several changes to the interpretation of Fader *et al*. (2004) which distinguished only three units in the bay (i.e., glacial till, postglacial sublittoral sand and postglacial marine mud). The interpretations of Shaw *et al*. (2012) benefitted from high resolution multibeam sonar bathymetry and backscatter strength data. Shaw *et al*. (2012) identified glacial marine mud, bedrock and sandy features such as a variety of dunes (Figure 3, data set 1). Shaw *et al*. (2012) also mapped glacial drift deposits over a larger area than the Fader *et al*. (2004) interpretation. The Shaw *et al*. (2012) interpretation was used with very few modifications. The legend was simplified and some of the polygons that identified habitats (i.e. Horse Mussel reefs) were merged into surficial geology polygons (i.e., postglacial sand and gravel) to be consistent with the theme and language of the present study (Figure 5).

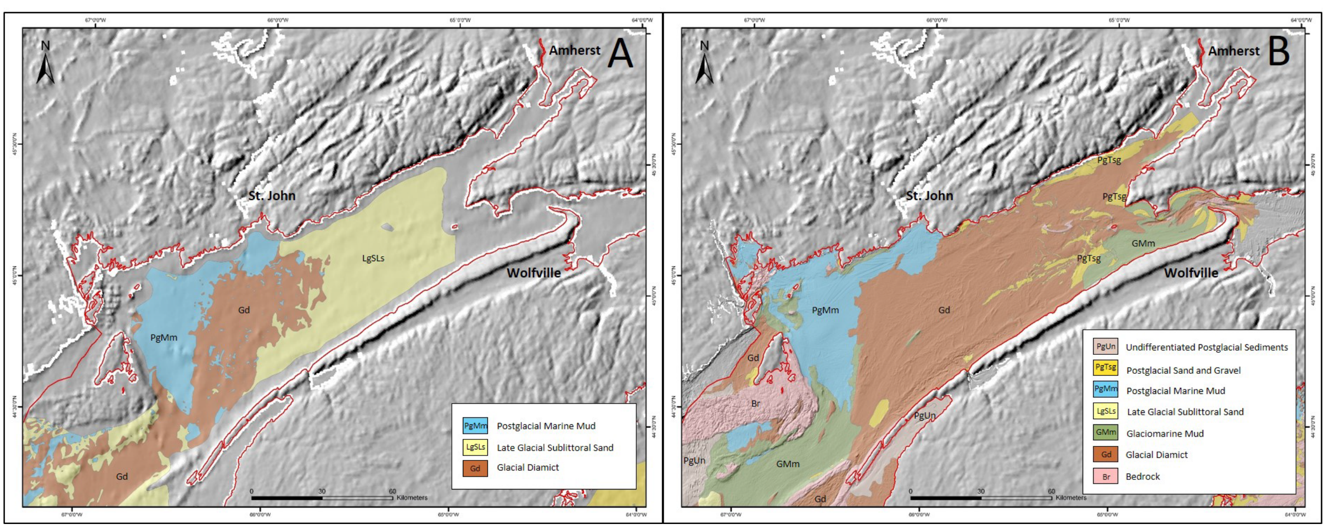

Figure 5: A) Base map (Fader et al., 2004) the Bay of Fundy. B) Updates made to the base map using Shaw et al. (2012).

- German Bank (Figure 3, data set 2), Browns Bank (Figure 3, data set 3) and Georges Bank (Figure 3, data set 4) have undergone several modifications based on more recent studies (Todd and Valentine, 2015; Todd *et al*., 2006, Todd, 2009). The compilation of Fader *et al*. (2004) interpreted the banks as being composed of postglacial sand and gravel. However, the more recent studies have distinguished glacial deposits (till) often present in the form of moraines on Browns Bank and German Bank (Todd *et al*., 2006 ; Todd, 2009) (Figure 6). German Bank is dominated by outcropping bedrock alternating with depressions filled with postglacial sediment (Todd, 2009) in an area that was previously identified as being sand and sand and gravel. All these newer maps were simplified to be consistent with the mapping scale of the present study.

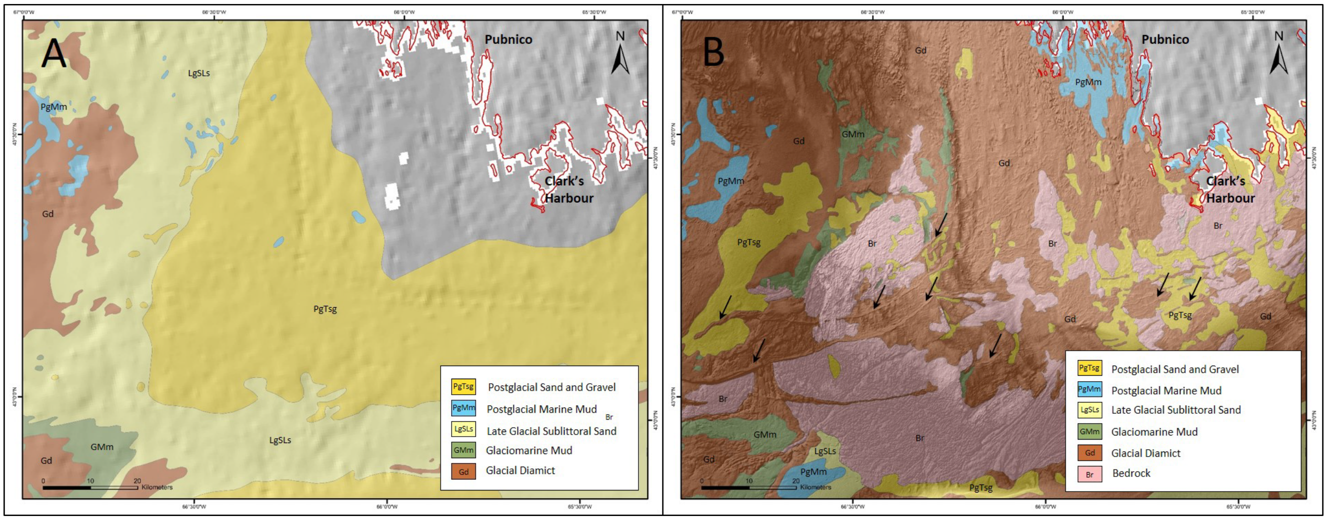

Figure 6: A) Base map (Fader et al., 2004) in German Bank area. B) Updates to the base map using Todd (2009), Olex single beam sonar, and multibeam sonar data which enabled the interpretation of bedrock outcrop and moraines as well the extension of the interpretation landward to the coast. The black arrows are pointing to moraines.

- The coastal section and inner shelf along the south western shore of Nova Scotia, between Sable River and Halifax Harbour, was updated using the maps of Piper *et al*. (1986) along the coast (Figure 3, data set 5), King *et al*. (2013) in the Liverpool area (Figure 3, data set 6), King *et al*. (2017) in the Lunenburg area (Figure 3, data set 7), Barnes and Piper (1978) in Mahone Bay (Figure 3, data set 8), Piper and Keen (1976) in St Margaret's Bay (Figure 3, data set 9), Fader and Miller (2008) in Halifax Harbour (Map 3, data set 10) as well as King (1996) map of recessional moraines on the inner shelf (not displayed on map 3). The inner shelf was almost entirely interpreted as being covered by postglacial sand and gravel by Fader *et al*. (2004). However, the more recent maps distinguish bedrock and till outcrops from patches of sand and gravel and depressions filled with postglacial sediment (Figures 7 and 8). The newer maps also identified glacial diamict present in the form of drumlins alternating with postglacial mud in Mahone Bay and St. Margaret's Bay and facilitated geological interpretation much closer to the shoreline. In the nearshore, recessional moraines sharing the same strike as bedrock ridges (limbs of anticlines and synclines) were differentiated using Olex single beam sonar and non-navigational bathymetric data (Figures 7 and 8). The maps were simplified to match the scale of the present study.

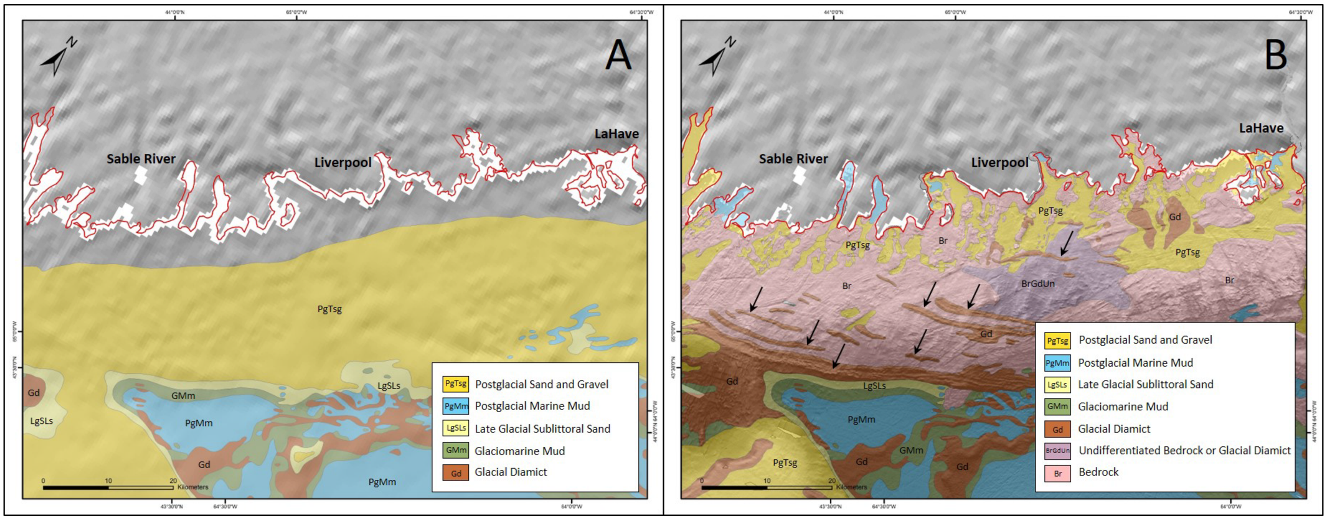

Figure 7: A) Base map (Fader et al., 2004) along the south shore of Nova Scotia. B) Updates to the base map using Piper et al. (1986), King et al. (2013), Olex single beam sonar and non-navigational bathymetric data. Black arrows point to moraines.

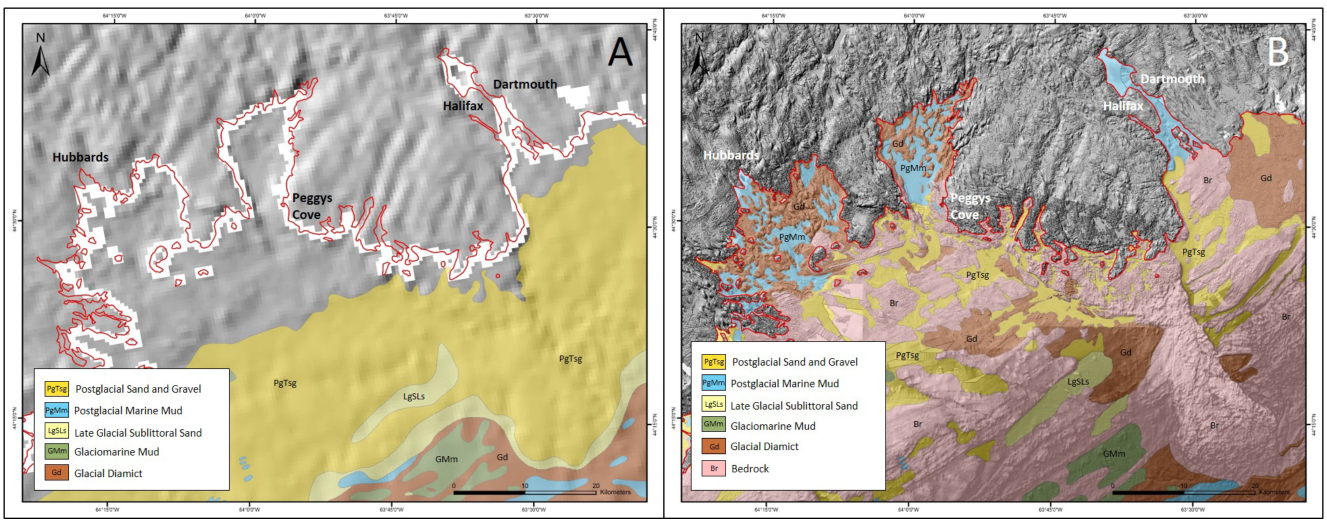

Figure 8: A) Base map (Fader et al., 2004) between Mahone Bay and Halifax. B) Updates to the base map using King et al. (2017) in the Lunenburg area, Barnes and Piper (1978) in Mahone Bay, Piper and Keen (1976) in St Margaret's Bay, Fader and Miller (2008) in Halifax Harbour as well as Olex single beam sonar and multibeam sonar data.

- The Eastern Shore Islands area, between Ship Harbour and Sheet Harbour, was improved using King (2018) (Figure 3, data set 11). Fader *et al*. (2004) interpreted this area as sand and postglacial gravel. The work of King (2018) distinguished bedrock outcrops and shore-parallel moraines from patches of postglacial sediment and brought the interpretation up to the shoreline (Figure 9). King's (2018) map was simplified to match the working scale of this study.

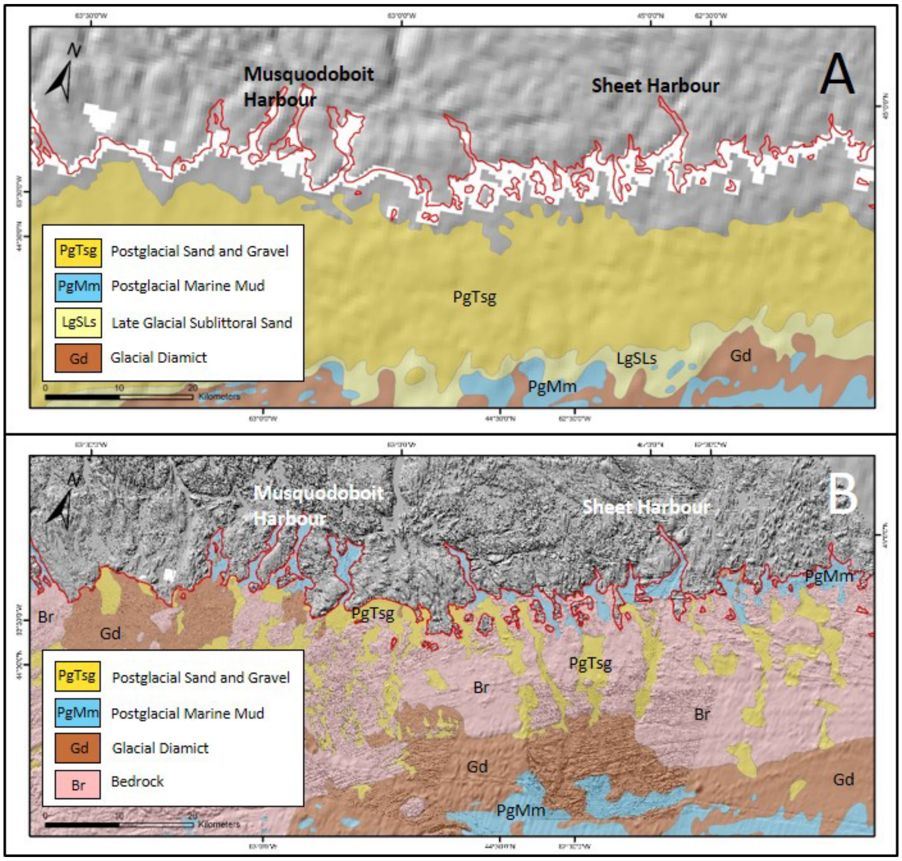

Figure 9: A) Base map (Fader et al., 2004) and B) updates to the base map using King (2018) along the eastern shore of Nova Scotia between Jeddore and Moser River as well as multibeam sonar, LiDAR, Olex single beam sonar and DFO non-navigational bathymetric data (NONNA).

- The Bras d'Or Lake and Great Bras d'Or areas were updated using Shaw and Potter (2008a, b) maps (Figure 3, data sets 12 and 13). These areas were not previously mapped on Fader *et al.* (2004) compilation. Shaw and Potter's maps were both simplified to match the working scale of this study.

- At the eastern extent of the bioregion in the area of St. Ann's Bank, the surficial geology interpreted by King (2014) (Figure 3, data set 14) was employed to distinguish rock outcrop from sediment in an area that was previously identified as entirely sand and gravel (Fader *et al*., 2004). The map of King (2014) was simplified for the purpose of this study (Figure 10).

- The Laurentian Channel area was updated using the map of Cameron and King (2010) (Figure 3, data set 15), used here without any modifications. This map provided details on the distribution of glacial diamict, glaciomarine mud and postglacial marine mud.

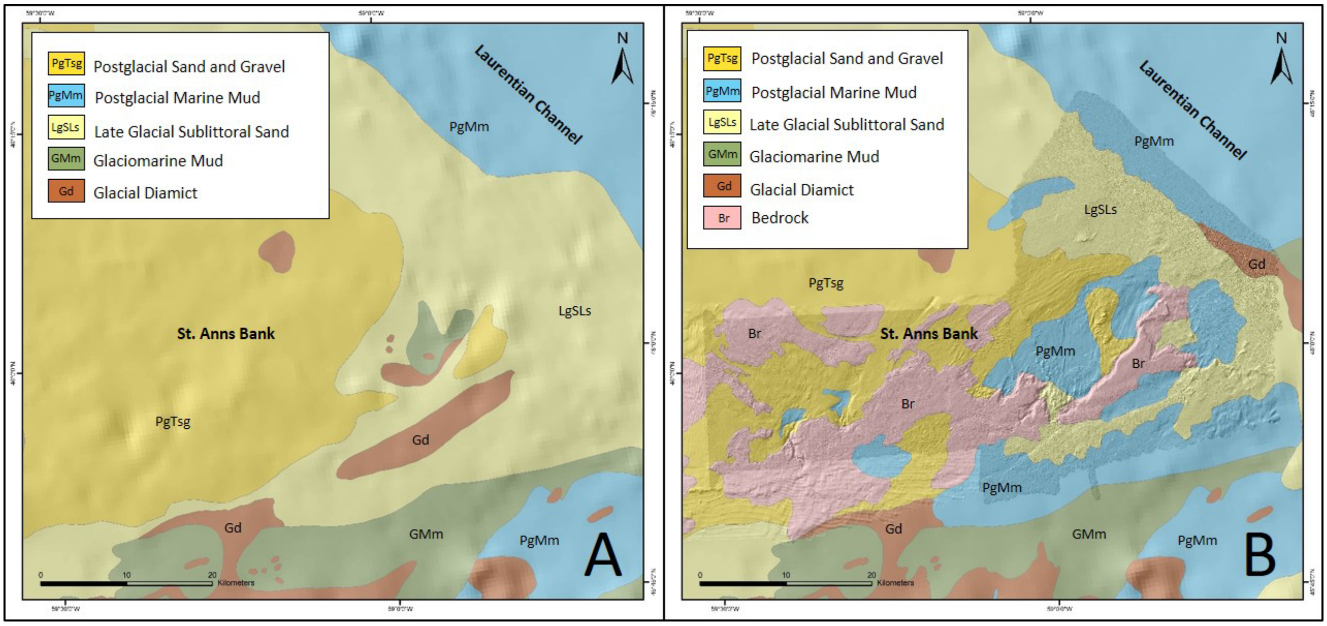

Figure 10: A) The base map (Fader et al., 2004) in St. Ann's Bank area and B) updates based on a simplified version of the King (2014) map modified to match the scale of the present study.

- In The Gully sector on the Scotian Shelf between Sable Island Bank and Banquereau, the work of Cameron *et al*. (2008) (Figure 3, data set 16) provides morphology and sediment type. The Cameron *et al*. (2008) interpretation extends down the upper slope along the canyon showing sediment type and the gully and channel system (Figure 11). The Cameron *et al*. (2008) interpretation was adopted unchanged on the continental shelf but was simplified on the slope.

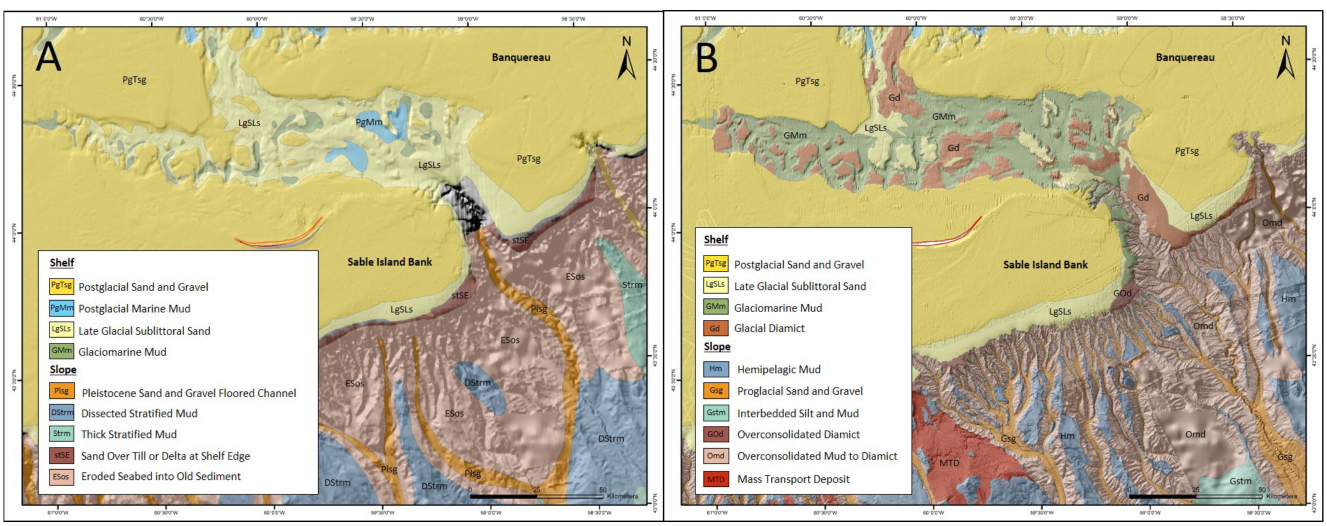

Figure 11: A) Base maps (Piper (1991) on the slope and Fader et al. (2004) on the shelf) in the Gully area. B) Updates based on the interpretation of Cameron et al. (2008).

Along the slope, four other areas were updated using new surficial geology data:

- In the central sector of the slope, the surficial geology maps of Mohican Channel (Figure 3, data set 17), Verrill Canyon (Figure 3, data set 18) and Logan Canyon (Figure 3, data set 19) produced by Campbell *et al*. (2008a, b, c) were overlaid on the original map of Piper (1991). The Campbell *et al*. (2008a, b, c) maps were simplified to match the working scale of the present study. These new maps made it possible to specify the position of the channels and gullies, the MTDs and the nature of the sediments (Figure 12).

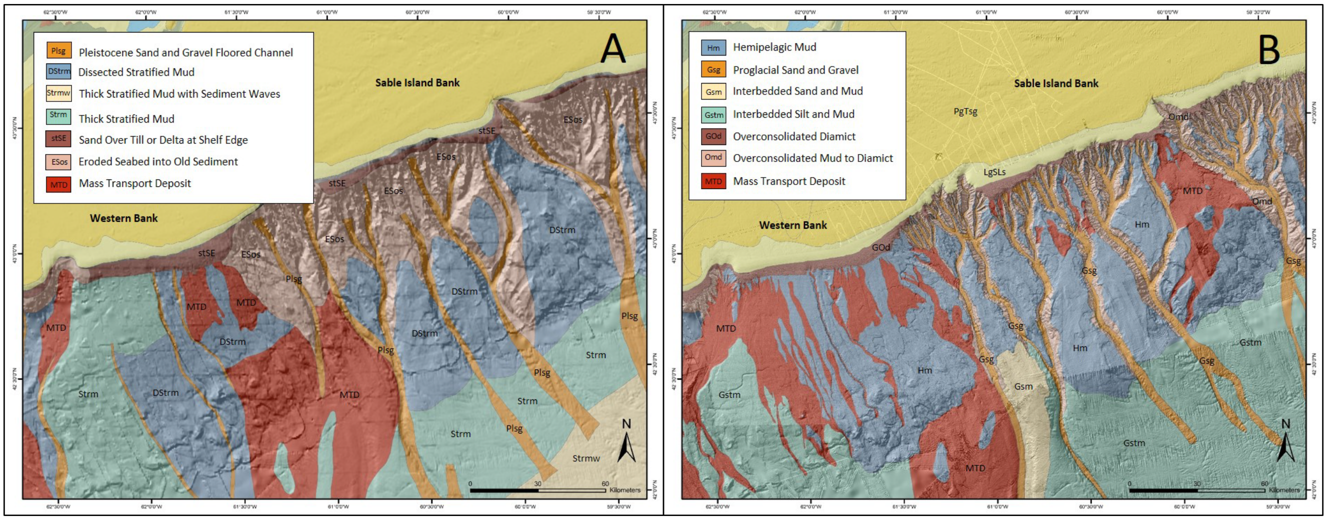

Figure 12: A) Base map (Piper, 1991) in the central upper slope area and B) updates based on the interpretation of Campbell et al. (2008a, b, c) in Mohican Channel, Verrill Canyon and Logan Canyon.

- In addition, the interpretation of Campbell (2013) on the lower slope produced as part of the United Nations Convention on the Law of the Sea (UNCLOS) program was included (Figure 3, data set 20). This new map enabled the identification of mass transport deposits (MTD) which had not been noted on the Piper (1991) map as well as the distinction between sandy mud and silty mud and the position of the many channels (Figure 13). Normandeau *et al*. (2019a, b) refined the extent and age of the MTD on the slope, east and south of The Gully, which helped refine the area of MTD at the surface. These studies, combined with older ones identified from Piper *et al*. (2003) revealed the extent of Holocene MTD and others that are buried. This distinction is important for this surficial geology map, where only the MTD in the top two meters of sediment are mapped along the margin. Therefore, the large MTD on the lower continental slope on Campbell (2013) map are not displayed on this map since they are buried under tens of meters of sediment.

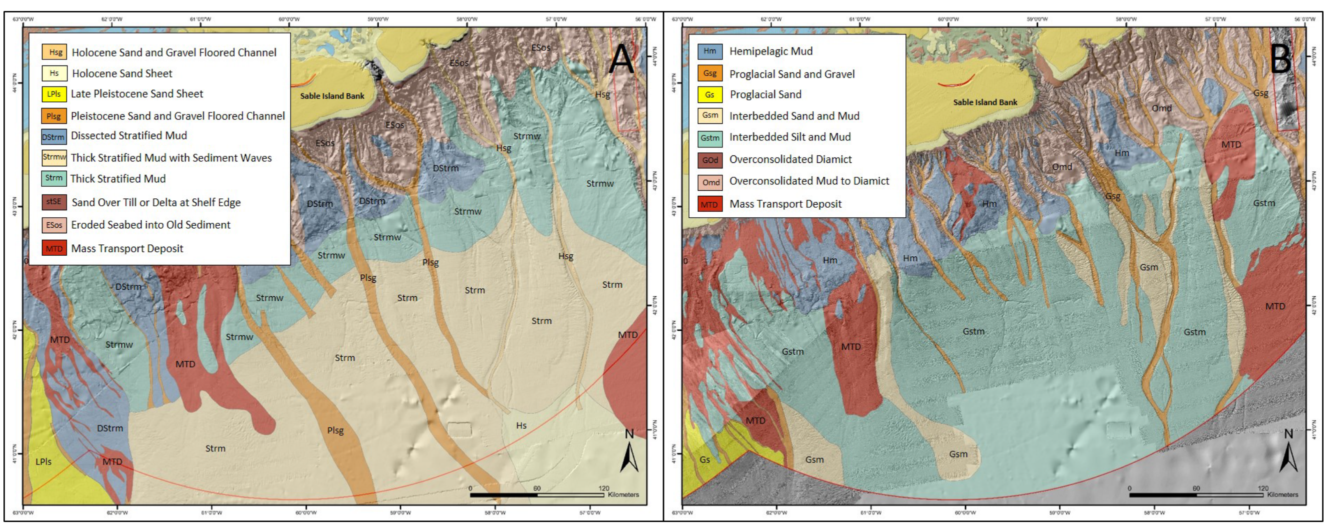

Figure 13: A) Base map (Piper, 1991) in the central lower slope area and B) updates based on the interpretation of Campbell (2013).

3.2 UPDATES BASED ON NEW HYDROACOUSTIC DATA

The acquisition of new hydroacoustic data over recent years enabled the updating of the original surficial geology maps of Piper (1991) and Fader *et al*. (2004) and the reinterpretation of the surficial geology in some areas. Twelve new data sets were used to improve and update the surficial geology of our base maps. These data sets are shown on Figure 4. They include multibeam sonar bathymetry, bathymetric LiDAR, 3D seismic reflection and sidescan sonar data acquired by a variety of institutions as part of different studies and programs. In addition, Olex single beam sonar, the new GEBCO (2021) gridded bathymetry data as well as Non-Navigational Bathymetric Data (NONNA 10 and NONNA 100) from CHS (not displayed on Figure 4) were used to improve the interpretation in some specific areas.

Seven new data sets were used to update the base map on the continental shelf (Fader *et al*., 2004):

- New multibeam sonar and bathymetric LiDAR data acquired by CHS and DFO between 2011 and 2017 in Mahone Bay and St. Margaret's Bay allowed the extension of the interpretations of the base map much closer to the shoreline. It also allowed the identification of drumlins (comprised of till) and depressions filled with postglacial sediments in both bays and to distinguish bedrock outcrop from sediment outside the bays (Figure 4, data set 1). The improvements made are consistent with the Piper *et al*. (1986) interpretations in Mahone Bay and in St. Margaret's Bay, although the details of some polygons were adjusted using the newer and higher resolution data (Figure 8).

- New multibeam sonar data sets acquired on the inner shore just offshore Prospect (Figure 4, data set 2) as well as between Lawrencetown and Ship Harbour (CHS, 2019) (Figure 4, data set 3) allowed us to differentiate areas of bedrock outcrop from sediment in an area of seabed formerly identified as being almost entirely covered in postglacial sand and gravel (Fader *et al*., 2004) (Figure 14). These new data also enabled the identification of moraines.

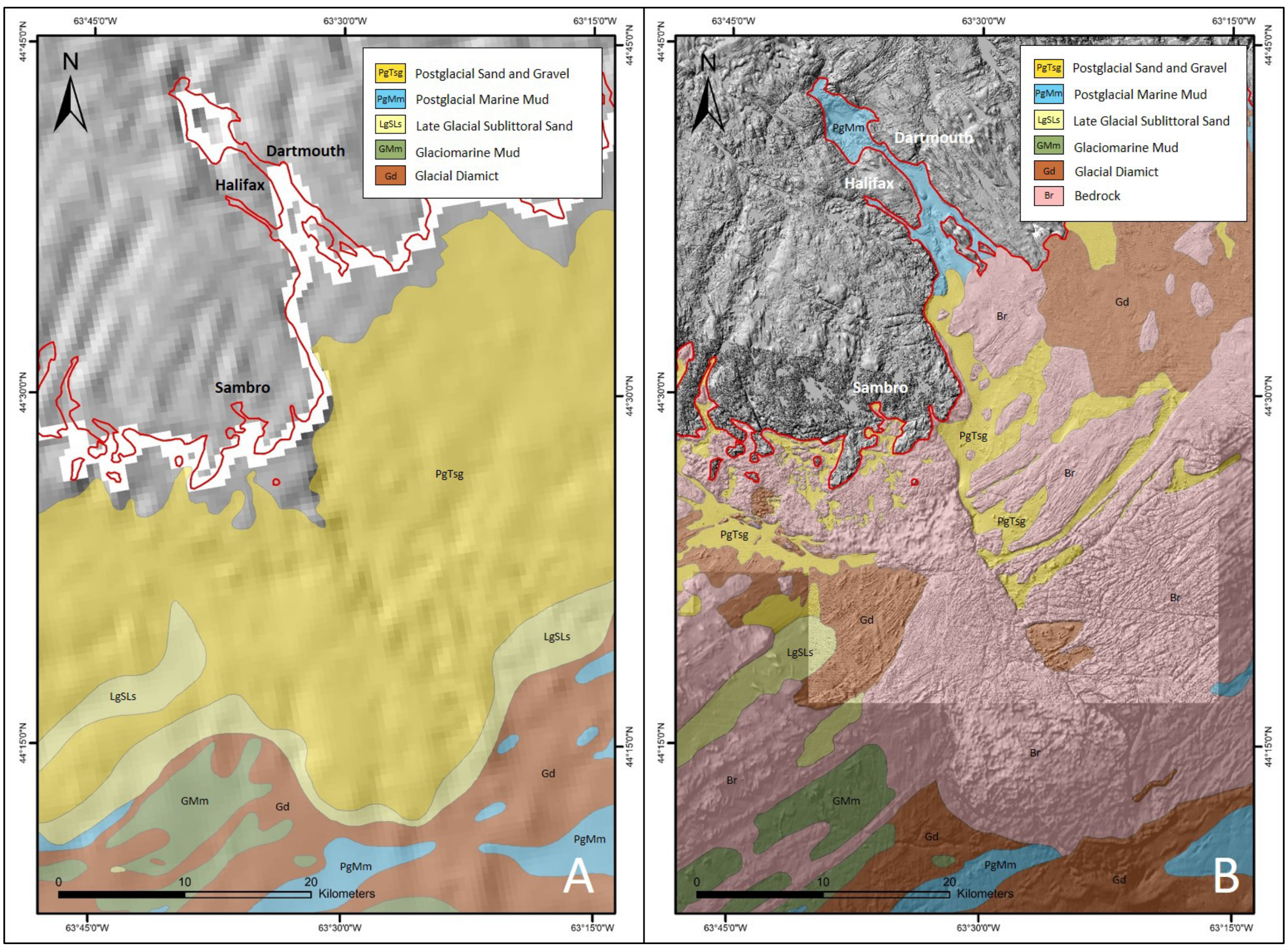

Figure 14: A) Base map (Fader et al., 2004). B) Updates to the base map using LiDAR from the Province, Olex image, bathymetric LiDAR from CHS and multibeam sonar bathymetry.

- Topographic and topo-bathymetric LiDAR with a horizontal resolution of 1 m was acquired in 2018 by the Halifax Regional Municipality (HRM) (Figure 4, data set 4) over the whole HRM area. Even though this data set is terrestrially focused, the nearshore data allowed the interpretation of bedrock and overlying sediment.

- In the Laurentian Channel, multibeam sonar bathymetric data acquired by Normandeau (2017) during the 2017 Coriolis mission (Figure 4, data set 5) improved upon the base map (Fader *et al*., 2004) regarding the position and composition of a grounding zone wedge associated with the Laurentian Moraine. On this moraine, interpretation of the data reveals an iceberg-scoured seafloor characterised by outcropping glacial sediment. Southeast of the moraine, undisturbed seafloor is covered with postglacial marine mud. The extent and distribution of these deposits were confirmed by a seismic profile acquired across the Laurentian Moraine by Normandeau *et al*. (2018).

- All the Non-Navigational Bathymetric Data (NONNA 10 and NONNA 100) from CHS (https://data.chs-shc.ca/map) available in the study area were used to update the base map where possible. These data vary in horizontal resolution (10 m and 100 m). This information enabled bedrock and overlying sediments to be interpreted close to shore along the south-western and eastern shores of Nova Scotia.

- On the continental shelf, variable resolution images of shaded relief of the seafloor derived from Olex single beam sonar enabled changes to Fader *et al*. (2004). The western portion of the shelf, from the Bay of Fundy to Sambro Bank, benefitted from a high resolution image and the eastern portion of the shelf, from Emerald Bank to the Laurentian Channel is covered by a lower resolution image. These new data provided a global portrait of the morphology of the shelf in areas where no data besides GEBCO low resolution bathymetry (GEBCO, 2021) are available. As a result, polygon boundaries of Fader *et al*. (2004) were adjusted based on broad morphology and the interpretation was extended into new areas. The images notably revealed the presence of geomorphic features, such as regional moraines that had not been accurately mapped (Figures 6, 7 and 15) and also highlighted sediment-filled tunnel-valleys on the eastern portion of the shelf. The Olex single beam sonar data also enabled the identification of bedrock, notably on the inner shelf along the south, central and eastern shore of Nova Scotia, all areas that were previously identified as sand and gravel on the base map (Fader *et al*., 2004) (Figures 7, 8 and 15). It is important to note that the interpretation of bedrock on the eastern inner shelf up to the nearshore of Cape Breton Island relies partly on the basis of observations along other parts of the coast where higher resolution data are available. The shelf area between Cape Breton and Laurentian Channel was updated from Fader et al. (2004) using OLEX and all available hydroacoustic data, mainly involving adjustments to the extent of post-glacial mud. Otherwise, the map in the nearshore of Cape Breton is based on interpretation of broad relief visible on low resolution shaded relief images. The new interpretation presented here contrasts with the interpretation of sand and gravel presented by Fader *et al*. (2004) but is consistent with recent maps and studies (Piper *et al*., 1986; Todd, 2009; King *et al*., 2013, 2017; King, 2018) as well as recent bathymetric data sets which show that the nearshore environment of southern and central Nova Scotia is primarily composed of bedrock outcrop and depressions filled with postglacial sediment.

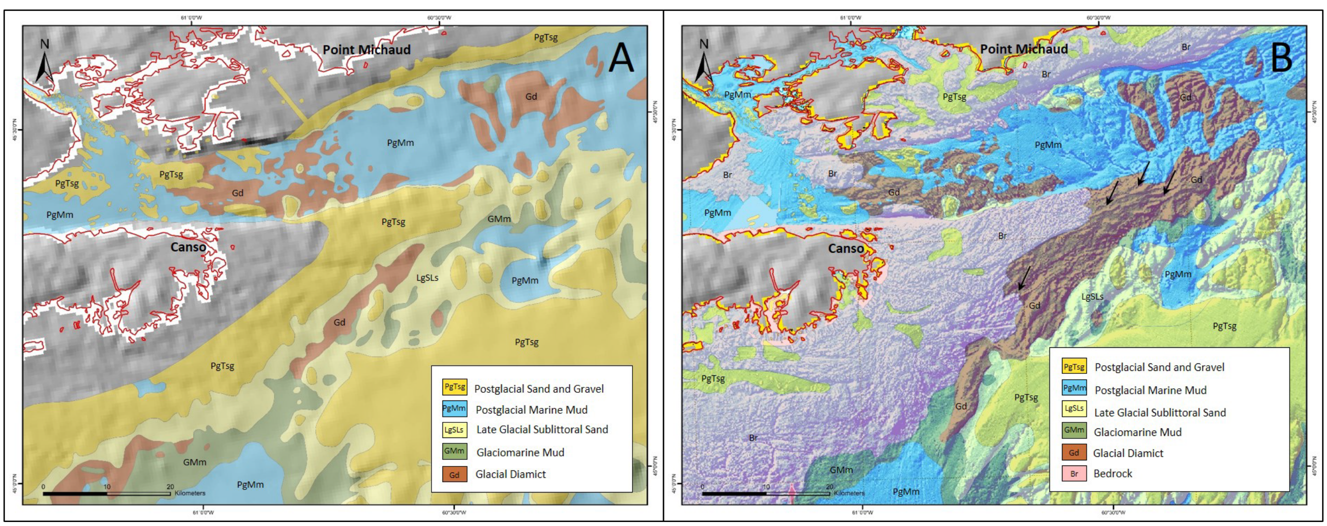

Figure 15: A) Base map (Fader et al., 2004). B) Updates to the base map using an Olex single beam image.

Along the slope, seven new hydroacoustic data sets were used to update the base map (Piper, 1991):

- In the southwest of the study area, bathymetric data acquired by the United States Geological Survey (USGS) onboard the *Ronald H. Brown* in 2009 (Figure 4, data set 6) as well as by the NOAA's *Okeanos Explorer* in 2019 (Figure 4, data set 7) on the upper slope provided information on the position of channels that incise the slope. A third data set acquired by Marine Geoscience Data System (MGDS) mid-slope in the center of the study area onboard the RV *Maurice Ewing* in 1998 (Figure 4, data set 10) enabled interpolation of the gap between the high resolution data on the upper and lower slope. This data set helped to connect the interpretation of Campbell *et al*. (2008a, b, c) in the Mohican Channel, Verrill Canyon and Logan Canyon areas to the surficial geology interpreted on the lower slope (Campbell, 2013) by tracing the channels with more accuracy (Figure 16).

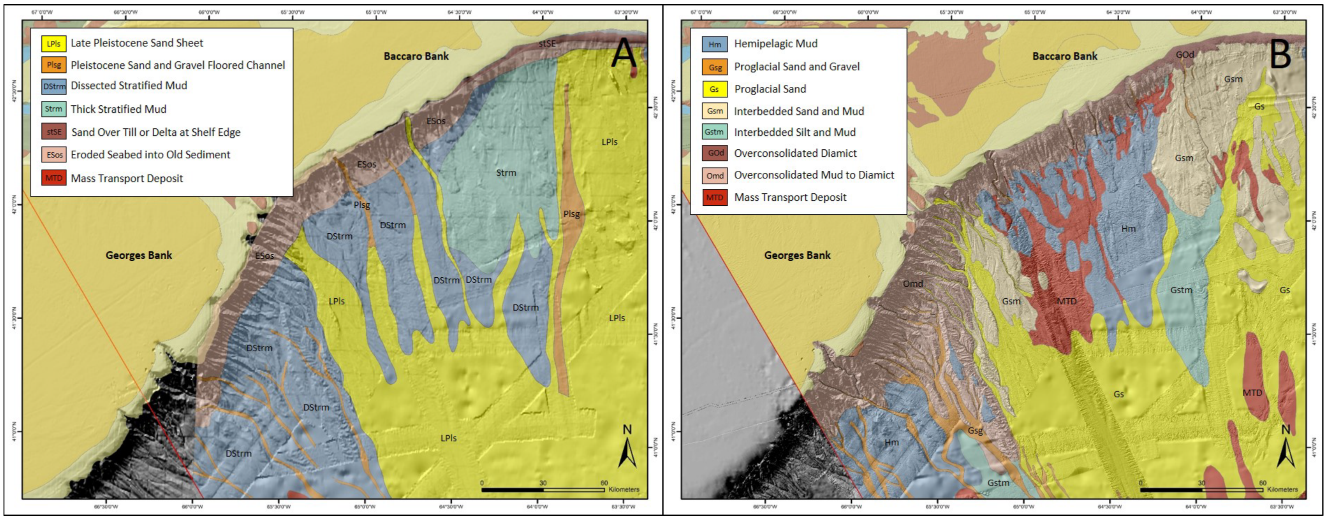

Figure 16: A) Base map (Piper, 1991). B) Updates to the base map using NOAA's Okeanos Explorer multibeam data (NOAA, 2019).

- A digital elevation model of the seabed morphology and an image of seismic amplitude derived from 3D seismic data (Figure 4, data set 8) (Canada–Nova Scotia Offshore Petroleum Board project NS24-S006-003E) provided new information on the position of channels and MTD as well as the type of sediment in the western upper slope area.

- Sidescan sonar data coverage acquired by Hughes Clarke *et al*. (1992) on the mid-slope in the southwest portion of the study area provided information on distribution of channels and MTD (Figure 4, data set 9).

- Bathymetric data across a small area on the eastern slope benefited from a shaded-relief rendering of the auto-picked seabed in an industry-proprietary 3D seismic volume (CNSOBP, 2003) (Figure 4, data set 11) and multibeam bathymetric data on the Laurentian Fan (GSC, 2006) (Figure 4, data set 12) provided information on the position of the canyons and channels that incise the slope (Figure 17).

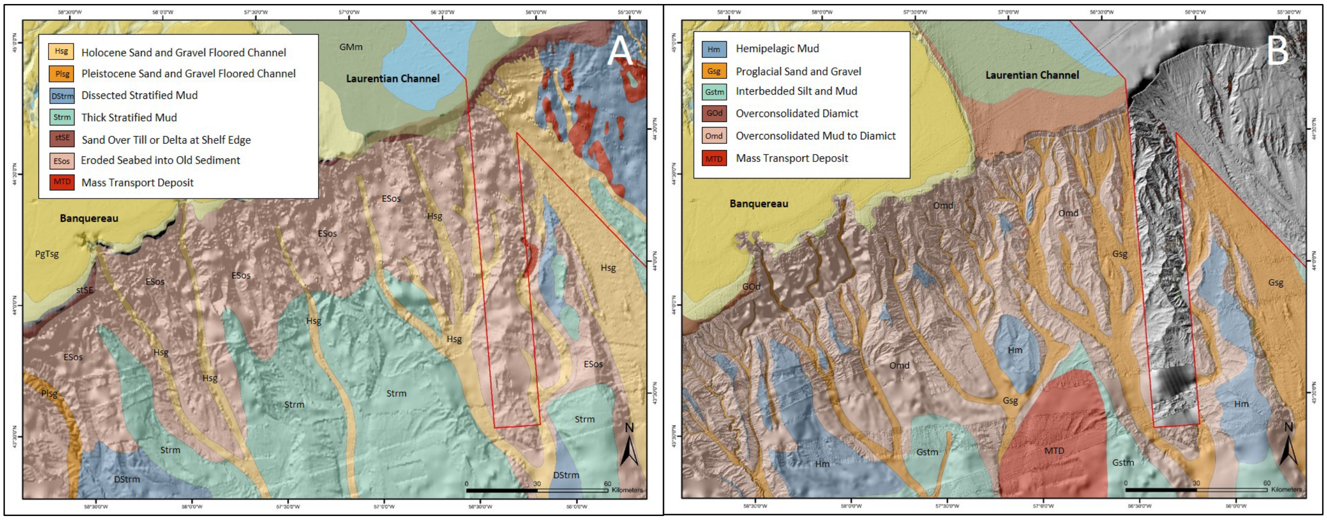

Figure 17: A) Base map (Piper, 1991). B) Updates to the base map using 3-D seismic data from CNSOPB (2003) and multibeam sonar bathymetry (GSC, 2006).

3.3 AREAS THAT REMAIN UNCHANGED

A few areas on the eastern portion of the shelf could not be updated due to the absence of newer data. For most of Emerald Bank, French Bank, Middle Bank, Misaine Bank, Artimon Bank and Banquereau areas, the Fader *et al*. (2004) compilation of maps represents the current state of knowledge on the type and distribution of surficial sediments on the seabed. In those areas, only a few polygons boundaries were adjusted based on broad geomorphology features visible on low resolution Olex images such as the contours of banks and tunnel-valleys. However, the majority of the interpretation remains unchanged. The slope benefits from a more extensive coverage of newer high-resolution data. Only a few sections of the slope could not be updated due to the absence of new publicly-available data. This is the case on the middle slope in the southwestern portion of the study area as well as a section in the southern central limit of the bioregion. In these areas, the present state of knowledge corresponds to the Piper (1991) map.

3.4 UNCERTAINTIES

In certain areas at the junction between the base maps (Piper, 1991; Fader *et al*., 2004) and the more recent maps or data sets, it was necessary to make adjustments in order to combine the information of two maps that are adjacent but where interpretations are different. Therefore, there are uncertainties in filling the gaps between newer data sets and older geology maps mapped at a broader scale. In some cases, geological boundaries had to be extrapolated so the base maps and the new data sets match. The most recent information has been prioritized, being a higher resolution data set benefiting from more precise georeferencing. However, the interpretation can be speculative in these junction areas and a level of uncertainty exists.

Backscatter strength is commonly employed by marine geoscientists as a proxy for seafloor sediment type. Uncertainties remain in the interpretation presented here in areas where backscatter strength data were not available along with the new bathymetric data sets (or imagery). Bathymetric data provide the morphology of the seabed without providing direct evidence of seafloor sediment type. Fortunately, seabed sediment type can often be deduced or interpreted using knowledge of past and modern seafloor processes combined with the presence of bedforms such as sediment waves, dunes, moraines, drumlins, etc.

4. CONCLUSIONS

The purpose of this study was to update the existing surficial geology map over the Scotian Shelf Bioregion into a contiguous and normalized product using recently available and published maps and more recent and higher resolution hydroacoustic datasets. The data used to produce this map included multibeam sonar bathymetry, backscatter strength and sidescan sonar data as well as sub-bottom profiles on the slope. The new map updates many areas and introduces changes to the previous surficial geology maps that covered the SSB (Piper, 1991; Fader *et al*., 2004). For the first time, the surficial geology on the shelf and the slope have been combined onto one single map. Nearshore areas, much of which were previously unmapped, have been interpreted.

The data used to perform the updates on this new map have been collected by a variety of different instruments and are at various resolutions. Therefore, not all the areas enjoy the same resolution and quality of data. For example, where high resolution data are available on the slope, data are generally gridded at 60 m horizontal resolution whereas the shelf data are generally gridded at 10 to 60 m horizontal resolution. This difference in horizontal resolution affects what can be interpreted from bathymetric data. Several areas of the bioregion, mostly on the shelf, remain mapped only using the older, low resolution techniques. Where no newer data were available, the previous surficial geology interpretation (Piper, 1991; Fader *et al*., 2004) remains unchanged.

Shelf and slope areas are considered separately, given the very different processes involved with the genesis of each area. Though geologic processes govern the type and distribution of the map units, an emphasis is placed on the resulting seabed textures with the aim to satisfy seabed-related stakeholders using the data for purposes other than geological interpretation.

On the shelf, eight surficial units have been defined, including one characterizing bedrock outcrop (undifferentiated bedrock type), two specifically associated with glacial cover and retreat, three related to lower sea levels in late- and post-glacial time and two which merge some of the above where their differentiation is challenging.

On the slope, pro-glacial and mass wasting processes dominate. The map units do not differentiate various mass-wasting processes; rather, they focus on the textural characteristics they produced. Map units also include old and exhumed sediments and glacial deposits which exhibit stability due to overconsolidation processes. Deposits originating from glacier margins situated near the shelf-edge fed the upper and mid-slope water depths. These sediments form broad blankets or follow downslope channels and range from mud-dominated to sand dominated.

In conclusion, compiling the available maps and data has proven to be very useful in updating the knowledge on the surficial geology of the seabed within the SSB. The new updated map provides an essential framework for understanding the seabed conditions. In addition, this exercise highlighted the places where high resolution data are lacking and where new data need to be acquired to underpin future geoscience knowledge products.

5. REFERENCES

Amos, C.L., and Judge, J.T., 1991. Sediment transport on the eastern Canadian continental shelf; Continental Shelf Research, v. 11, p. 1037–1068.

Barnes, N.E., and Piper, D.J.W., 1978. Late Quaternary geological history of Mahone Bay, Nova Scotia; Canadian Journal of Earth Sciences, v. 15, p. 586–593.

Brown, C.J., Todd, B.J., Kostylev, V.E., and Pickrill, R.A., 2011. Image-based classification of multibeam sonar backscatter data for objective surficial sediment mapping of Georges Bank, Canada; Continental Shelf Research, v. 31, S110–S119.

Cameron, G.D.M., and King, E.L., 2010. Quaternary geology of the Laurentian Channel and the southwestern Grand Banks of Newfoundland; Geological Survey of Canada, Open file 6451, 1 CD-ROM.

Cameron, G.D.M., and King, E.L., 2008. Seafloor-slope analysis, The Gully, Scotian Shelf, offshore eastern Canada; Geological Survey of Canada, "A" Series Map 2121A, 1 sheet.

Cameron, G.D.M., and King, E.L., 2008. Sun-illuminated seafloor topography, The Gully, Scotian Shelf, offshore eastern Canada; Geological Survey of Canada, "A" Series Map 2122A, 1 sheet.

Cameron, G.D.M., King, E.L., and Campbell, D.C., 2008. Surficial geology and sun-illuminated seafloor topography, The Gully, Scotian Shelf, offshore Eastern Canada; Geological Survey of Canada, "A" Series Map 2123A, 1 sheet.

Campbell, D.C., 2013. Geological justification for foot-of-slope points for the Nova Scotia Margin; Canada's submission to the United Nations Convention of the Law of the Sea for the Atlantic Margin, Confidential report submitted to the United Nations.

Campbell, D.C., and Normandeau, A., 2019. CCGS Hudson Expedition 2018-041: high-resolution investigation of deep-water seabed seeps and landslides along the Scotian Slope, offshore Nova Scotia, May 26– June 15 2018 ; Geological Survey of Canada, Open File 8567, 66 p.

Campbell, D.C., Piper, D.J.W., Mosher, D.C., and Jenner, K.A., 2008a. Surficial geology and sun-illuminated seafloor topography, Mohican Channel, Scotian Slope, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2127A, 1 sheet.

Campbell, D.C., Piper, D.J.W., Mosher, D.C., and Jenner, K.A., 2008b. Surficial geology and sun-illuminated seafloor topography, Verrill Canyon, Scotian Slope, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2128A, 1 sheet.

Campbell, D.C., Piper, D.J.W., Mosher, D.C., and Jenner, K.A., 2008c. Surficial geology and sun-illuminated seafloor topography, Logan Canyon, Scotian Slope, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2129A, 1 sheet.

Canada–Nova Scotia Offshore Petroleum Board (CNSOPB), 2003. Project NS24-E043-002E, 3D Seismic Survey Stonehouse Prospect.

Canada–Nova Scotia Offshore Petroleum Board (CNSOPB), 2013. Project NS24-S006-003E, 3D WAZ Seismic Program Shelburne Basin.

Canadian Hydrographic Service, 2018. Canadian Hydrographic Service Non-Navigational (NONNA) Bathymetric Data; Fisheries and Oceans Canada. <https://open.canada.ca/data/en/dataset/d3881c4c-650d-4070-bf9b-1e00aabf0a1d> [accessed January, 2021].

Courtney, R.C., 1993. Inner Scotian Shelf off Halifax: EM100 swath bathymetry; Geological Survey of Canada, Open File 2803, 1 sheet.

Drapeau, G., and King, L.H., 1972. Surficial geology of the Yarmouth to Browns Bank map area; Marine Science Paper 2, Geological Survey of Canada, Paper 72–24, 6 p.

Dyke, A.S., Andrews, J.T., Clark, P.U., England, J.H., Miller, J.H., Shaw, J., and Veillette, J.J., 2002. The Laurentide and Innuitian ice sheets during the last glacial maximum; Quaternary Science Reviews, v. 21, p. 9–31.

Eamer, J.B., Shaw, J., King, E.L., and 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; Continental Shelf Research, v. 213, p. 104297.

Fader, G.B., 1984. A geophysical survey of the Georges Bank, Georges Basin and Northeast Channel area of the Gulf of Maine; Geonautics Limited and Geological Survey of Canada, Open File 978, 375 p., 21 sheets.

Fader, G.B.J., and Miller, R.O., 2008. Surficial geology, Halifax Harbour, Nova Scotia; Geological Survey of Canada, Bulletin 590, 176 p., 1 CD-ROM.

Fader, G.B.J., King, L.H., and MacLean, B., 1977. Surficial geology of the eastern Gulf of Maine and Bay of Fundy; Marine Science Paper, No. 19, Geological Survey of Canada Paper 76–17, 23 p., 1 sheet.

Fader, G.B.J., King, L.H., and Josenhans, H.W., 1982. Surficial geology of the Laurentian channel and the western Grand Banks of Newfoundland; Marine Science Paper, No. 21, Geological Survey of Canada Paper 81–22, 37 p., 1 sheet.

Fader, G.B.J., King, E., Gillespie, R., and King, L.H., 1988. Surficial geology: Georges Bank, Browns Bank and the southeastern Gulf of Maine; Geological Survey of Canada, Open File 1692, 3 maps.

Fader, G.B.J., Lynds, T., Miller, R.O., Parrott, D.R., Hynes, S., and Sherin, A., 2004. Scotian Shelf regional surficial geology compilation; Geological Survey of Canada, Open File 4671, 7 maps.

Fisheries and Oceans Canada, 2009. Development of a framework and principles for the biogeographic classification of Canadian marine areas; Canadian Science Advisory Secretariat, Science Advisory Report 2009/056, 17 p.

Folk, R.L., 1954. The distinction between grain size and mineral composition in sedimentary-rock nomenclature; Journal of Geology, v. 62, p. 344–359.

GEBCO. 2021. GEBCO 2021 Grid, <https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2021> [accessed January, 2022].

GeoNova. 2021. Data Locator – Elevation Explorer, LiDAR DEM; Province of Nova Scotia, <https://nsgi.novascotia.ca/datalocator/elevation/> [accessed February, 2022].

Gilkinson, K., King, E.L., Li, M.Z., Roddick, D., Kenchington, E., and Hana, G., 2015. Processes of physical change to the seabed and patterns of bivalve recruitment over a 10-year period following experimental hydraulic clam dredging on Banquereau, Scotian Shelf; Continental Shelf Research, v. 92, p. 72–86.

Godfrey-Smith, D.I., King, E.L., and Li, M., 2003. Establishing medium and long-term sand ridge stability and migration on Sable Island Bank using optically stimulated luminescence dating; Abstract, Canadian Quaternary Association (CANQUA) Meeting, Halifax, Nova Scotia.

Halifax Regional Municipality. 2018. Open data files, LiDAR DEM 2 m; <https://www.halifax.ca/home/open-data/open-data-files> [accessed January, 2020].

Hughes Clarke, J.E., O'Leary, D.W., and Piper, D.J.W., 1992. Western Nova Scotia continental rise: relative importance of mass wasting and deep boundary-current activity; i*n* Geologic Evolution of Atlantic Continental Rises, (Eds.) C.W. Poag and P.C. de Graciansky, Springer, p. 266–281.

Jenner, K.A., Piper, D.J.W., Campbell, D.C., and Mosher, D.C., 2007. Lithofacies and origin of Late Quaternary mass transport deposits in submarine canyons, central Scotian Slope, Canada; Sedimentology, v. 54, p. 19–38.

Jenner, K.A., Piper, D.J.W., Campbell, D.C., and Mosher, D.C., 2010. Piston cores and supporting high-resolution seismic data, Scotian Slope, Eastern Canada: data and interpretations; Geological Survey of Canada, Open File 6558, 1 DVD.

King, L.H., 1969. Submarine end moraines and associated deposits on the Scotian Shelf; Geological Society of America Bulletin, v. 80, p. 83–96.

King, L.H., 1970. Surficial geology of the Halifax–Sable Island map area; Geological Survey of Canada, Marine Science Paper, v. 1, 16 pages.

King, L.H., 1996. Late Wisconsinan ice retreat from the Scotian Shelf; Geological Society of America Bulletin, v. 108, no. 8, p. 1056-1067.

King, L.H., and Fader, G.B.J., 1986. Wisconsinan glaciation of the Atlantic continental shelf of southeast Canada; Geological Survey of Canada Bulletin, v. 363, 72 p.

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; Current Research, 2001-D19, Geological Survey of Canada, 18 p.

King, E.L., 2002a. Review and summary of shallow geophysical and geotechnical data applicable to Encana's Abenaki block. Unpublished Technical report to EnCana by the Geological Survey of Canada, 43 p.

King, E.L., 2002b. The nature of seabed sand mobility on Sable Island Bank: What is the stability of the bedforms? Abstract, Offshore Technology Association of Nova Scotia (OTANS) Meeting, Halifax, Nova Scotia.

King, E.L., 2014. Seascapes of St. Ann's Bank and adjoining area off Cape Breton, Nova Scotia; Geological Survey of Canada, Open File 7114, 2 sheets.

King, E.L., 2015. Sable Island Bank glacial and post-glacial landscape evolution as illustrated from eight 3-D vignettes, Scotian Shelf, offshore Nova Scotia; Unpublished report for proponents of the National Park, 15 p.

King, E.L., 2018. Surficial geology and features of the inner shelf of eastern shore, offshore Nova Scotia; Geological Survey of Canada, Open File 8375, 41 p. (1 sheet).

King, E.L., and Li, M., 2003. A multi-faceted approach toward establishing magnitude and processes of sediment mobility in hydrocarbon development areas on the Scotian Shelf; Program and Abstracts, Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting, v. 28, 194 p.

King, E.L., and Beaver, D., 2017. Backscatter strength and shaded seafloor relief, Lunenburg Bay, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, Open File 8176, 1 sheet.

King, E.L., and Beaver, D., 2017. Multibeam bathymetry and shaded seafloor relief, Lunenburg Bay, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, Open File 8177, 1 sheet.

King, E.L., Piper, D.J.W., Mosher, D.C. Campbell, D.C., Li, M.Z., Hynes, S., MacDonald, A., and Birch Hill GeoSolutions, 2005. Eastern Scotian Shelf pipeline-related geohazards: Constraints of sediment mobility and slope stability to offshore upper-slope and shelf-crossing pipelines, Scotian Shelf. Unpublished internal report.

King, E.L., Brown, O., Chapman, C.B., Cameron, G.D.M., Fraser, P., Girouard, P., MacKinnon, W., Piper, D.J.W., and Uyesugi, M., 2005. Hudson 2005023 cruise report: geological investigations in Northeast Channel and the adjacent slope, Scotian Shelf; Geological Survey of Canada, Open File 5058, 94 p., 1 CD-ROM.

King, E.L., Fader, G.B.J., Lynds, T., Hynes, S., and Miller, R.O., 2013. Blue Atlantic pipeline corridor geologic constraints, Scotian Shelf: Desktop study; Geological Survey of Canada, Open File 7147, 82 p.

King, E.L., Hynes, S., and Cameron, G.D.M., 2017. Geology and shaded seafloor relief, Lunenburg Bay, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, Open File 8138, 1 sheet.

King, E.L., Boggild, K., Broom, L., Campbell, L., Fralic, T., Greaves, C., Ingham, P., Manning, D., Nissen, G., Pledge, P., Robertson, A., and Todd, B.J., 2022. Research Vessel CCGS Hudson Expedition 2021126, July 22 to 27, 2021: glacial fan stratigraphy and sediment stability on the southwestern Scotian Slope, offshore Nova Scotia; Geological Survey of Canada, Open File 8829, 97 p.

Kostylev, V.E., Todd, B.J., Fader, G.B.J., Courtney, R.C., Cameron, G.D.M., and Pickrill, R A., 2001. Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs; Marine Ecology Progress Series, v. 219, p. 121–137.

Li, M.Z., and King, E.L., 2005a. Design and initial development of the Sable Island Bank seabed stability GIS database; Geological Survey of Canada, Open File 4932, 32p.

Li, M.Z., and King, E.L., 2005b. Multi-faceted investigation of sediment and bedform mobility on Sable Island Bank, Scotian Shelf; Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting–Canadian Society of Petroleum Geologists–Canadian Society of Soil Science Joint Meeting, Program and Abstracts, v. 30, p. 113.

Li, M.Z., and King, E.L., 2007. Multibeam bathymetric investigations of the morphology of sand ridges and associated bedforms and their relation to storm processes, Sable Island Bank, Scotian Shelf; Marine Geology, v. 243, p. 200–228.

Li, M. Z., King, E.L., and Prescott, R.H., 2012. Seabed disturbance and bedform distribution and mobility on the storm dominated Sable Island Bank, Scotian Shelf; *in* Sediments, Morphology and Sedimentary Processes on Continental Shelves, (Eds.) Li, M.Z., Sherwood, C. and Hill, P., Special Publication of International Association of Sedimentologists, Blackwell Science, Berlin, p. 197-228.

Li, M.Z., Shaw, J., Todd, B.J., Kostylev, V.E., and Wu, Y., 2014. Sediment transport and development of banner banks and sandwaves in an extreme tidal system: upper Bay of Fundy, Canada; Continental Shelf Research, v. 83, p. 86–107.

Li, M.Z., Wu, Y., Hannah, C.G., Perrie, W.A., Shen, H., and King, E.L., 2021. Modelling seabed disturbance and sediment mobility on the Canadian Atlantic Shelf; Geological Survey of Canada; Open File 8805, 50 p.

MacLean, B., and King, L.H., 1971. Surficial geology of the Banquereau and Misaine Bank map area; Marine Sciences, Paper 3, Geological Survey of Canada Paper 71–52, 19 p., 1 sheet.

MacLean, B., Fader, G.B.J., and King, L.H., 1977. Surficial geology of Canso Bank and adjacent areas; Marine Science Paper 20, Geological Survey of Canada Paper 76–15, 11 p., 1 sheet.

Marine Geoscience Data System (MGDS), 1998a. Multibeam collection for EW9806: Multibeam data collected aboard Maurice Ewing from 02-Jul-98 to 13-Aug-98, Halifax, Canada to Halifax, Canada; NOAA National Centers for Environmental Information. <https://www.ngdc.noaa.gov/ships/maurice_ewing/EW9806_mb.html>, [accessed January 2020].

Marine Geoscience Data System (MGDS), 1998b. Multibeam collection for EW9805: Multibeam data collected aboard Maurice Ewing from 16-May-98 to 01-Jul-98, Halifax, Canada to Halifax, Canada; NOAA National Centers for Environmental Information. <https://www.ngdc.noaa.gov/ships/maurice_ewing/EW9805_mb.html>, [accessed January 2020].

Mosher, D.C., Piper, D.J.W., Campbell, D.C., and Jenner, K.A., 2004. Near-surface geology and sediment-failure geohazards of the central Scotian Slope; American Association of Petroleum Geologists Bulletin, v. 88, p. 703–723.

Mosher, D.C., Campbell, D.C., Gardner, J.V., Piper, D.J.W., Chaytor, J.D., and Rebesco, M., 2017. The role of deep-water sedimentary processes in shaping a continental margin: The Northwest Atlantic; Marine Geology, v. 393, p. 245–259.

National Oceanic and Atmospheric Administration (NOAA), 2019. Multibeam collection for EX1905L1: Multibeam data collected aboard NOAA Ship OKEANOS EXPLORER (R337) from 06-Aug-19 to 20-Aug-19, North Kingstown, Rhode Island to Halifax, Nova Scotia; NOAA National Centers for Environmental Information, <https://www.ngdc.noaa.gov/ships/okeanos_explorer/EX1905L1_mb.html> [accessed January, 2021].

National Oceanic and Atmospheric Administration (NOAA), 2021. National Centers for Environmental Information, Bathymetric Data Viewer. <https://maps.ngdc.noaa.gov/viewers/bathymetry/> [accessed January, 2021].

Normandeau, A., 2017. 2017CORIOLIS expedition: geological investigation of seabed seeps and deglacial processes in the Sydney Basin, offshore Nova Scotia, June 24–July 6, 2017; Geological Survey of Canada, Open File 8301, 39 p.

Normandeau, A., and Campbell, D.C., 2020. Recurrence of turbidity currents on glaciated continental margins: a conceptual model from eastern Canada; Journal of Sedimentary Research, v. 90, p. 1305–1321.

Normandeau, A., Hayward, S.E., Jarrett, K.A., Jauer, C.D., MacKillop, K., MacIntyre, M., Patton, E., Robertson, A., Thiessen, R., White, M., Faulkner, M., and Wohlgeschaffen, G., 2018. CCGS *Hudson* expedition 2018042: marine geohazards and natural seeps off southeastern Baffin Island, Nunavut; Geological Survey of Canada, Open File 8488, 89 p.

Normandeau, A., Campbell, D.C., and Cartigny, M.J.B., 2019a. The influence of turbidity currents and contour currents on the distribution of deep-water sediment waves offshore eastern Canada; Sedimentology, v. 66, p. 1746–1767.

Normandeau, A., Campbell, D.C., Piper, D.J.W., and Jenner, K.A., 2019b. Are submarine landslides an underestimated hazard on the western North Atlantic passive margin?; Geology, v. 47, p. 848–852.

Normandeau, A., Campbell, D.C., Piper, D.J.W., and Jenner, K.A., 2019c. New evidence for a major late Quaternary submarine landslide on the external western levee of Laurentian Fan; Geological Society, London, Special Publications, v. 477, p. 377–387.

Normandeau, A., Piper, D.J.W., Shaw, J., Todd, B.J., Campbell, D.C., and Mosher, D.C., 2020. The seafloor of southeastern Canada; *in* Landscapes and Landforms of Eastern Canada, (Eds.) Slaymaker, O. and Catto, N., Springer, p. 453–471.

Parrott, D.R., Todd, B.J., Shaw, J., MacGowan, B., Lamplugh, M., Griffin, J., Hughes Clarke, J.E., and Webster, T., 2009. Shaded seafloor relief, Bay of Fundy, offshore Nova Scotia / New Brunswick ; Geological Survey of Canada, Open File 5834, 1 sheet.

Philibert, G., and Todd, B.J., 2022. Scotian Shelf geoscience information within Network Candidate Sites (NCS) of Fisheries and Oceans Canada; Geological Survey of Canada, Open File 8888, 27 p. https://doi.org/10.4095/329978.

Piper, D.J.W., 1978. Geology of coastal bays in Labrador and Nova Scotia; Progress report to the Department of Energy, Mines and Resources, Research Agreement 113–4–78, 61 p.

Piper, D.J.W., 1979. Coastal geological studies, Nova Scotia and Labrador, 1978–1979; Progress report to the Department of Energy, Mines and Resources, Research Agreement 147–4–79, 26 p.

Piper, D.J.W., 1991. Surficial geology and physical properties 6: deep water surficial geology; *in* Scotian Shelf, (Eds.) Ross, D.I., Lewis, C.F.M., Howie, R.D., Cant, D. and Bates, J.L., Geological Survey of Canada, East Coast Basin Atlas Series, p. 121, 1 sheet.

Piper, D.J.W., and Keen, M.J., 1976. Geological studies in St. Margaret's Bay, Nova Scotia; Geological Survey of Canada, Paper 76–18, 18 p.

Piper, D.J.W., and Campbell, D.C., 2002. Surficial geology of the Scotian Slope, eastern Canada; Geological Survey of Canada, Current Research 2002-E15, 10 p.

Piper, D.J.W., and Brunt, R.A., 2006. High-resolution seismic transects of the upper continental slope off southeastern Canada; Geological Survey of Canada, Open File 5310, 77 p.

Piper, D.J.W., Mudie, P.J., Letson, J.R.J., Barnes, N.E., and Iuliucci, R.J., 1986. The marine geology of the inner Scotian Shelf off the south shore, Nova Scotia; Geological Survey of Canada, Paper 85–19, 65 p.

Piper, D.J.W., Cameron, G.D.M., and Best, M.A., 1988. Quaternary geology of the continental margin of eastern Canada; Geological Survey of Canada, Map 1711A, scale 1: 5 000 000.

Piper, D.J.W., Mosher, D.C., Gauley, B.J., Jenner, K. and Campbell, D.C., 2003. The chronology and recurrence of submarine mass movements on the continental slope off southeastern Canada; *in* Submarine mass movements and their consequences, (Eds.) Mosher, D.C., Shipp, R.C., Moscardelli, L., Chaytor, J.D., Baxter, C.P.D., Lee, H.J., Urgeles R., Springer Dordrecht, (pp. 299-306).

Piper, D.J.W., Macdonald, A.W., Ingram, S., Williams, G.L., and McCall, C., 2005. Late Cenozoic architecture of the St. Pierre Slope; Canadian Journal of Earth Sciences, v. 42, p. 1987–2000.

Piper, D.J.W., Shaw, J., and Skene, K.I., 2007. Stratigraphic and sedimentological evidence for late Wisconsinan sub-glacial outburst floods to Laurentian Fan; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 246, p. 101–119.

Schnitker, D., Belknap, D.F., Bacchus, T.S., Friez, J.K., Lusardi, B.A., and Popek, D.M., 2001. Deglaciation of the Gulf of Maine; *in* Deglacial history and relative Sea-level changes, Northern New England and adjacent Canada (Eds.) Weddle, T.K. and Retelle, M.J., Geological Society of America, Special paper 351, p. 9–34.

Shaw, J., and Potter, D.P., 2008a. Surficial geology and sun-illuminated seafloor topography, Bras d'Or Lake, Cape Breton Island, Nova Scotia; Geological Survey of Canada, "A" Series Map 2115A, 1 sheet.

Shaw, J., and Potter, D.P., 2008b. Surficial geology and sun-illuminated seafloor topography, Great Bras d'Or, Cape Breton Island, Nova Scotia; Geological Survey of Canada, "A" Series Map 2116A, 1 sheet.

Shaw, J., Piper, D.J.W., Fader, G.B.J., King, E.L., Todd, B.J., Bell, T., Batterson, M.J., and Liverman, D.G.E., 2006. A conceptual model of the deglaciation of Atlantic Canada; Quaternary Science Reviews, v. 25, p. 2059–2081.

Shaw, J., Todd, B.J., and Li, M.Z., 2012. Seascapes, Bay of Fundy, offshore Nova Scotia/New Brunswick; Geological Survey of Canada, Open File 7028, 1 sheet.

Shaw, J., Todd, B.J., Li, M.Z., Mosher, D.C., and Kostylev, V.E., 2014. Continental shelves of Atlantic Canada; *in* Continental Shelves of the World: Their Evolution During the Last Glacio-Eustatic Cycle, (Eds.) Chiocci, F.L., and Chivas, A.R., Geological Society of London Memoir No. 41, p. 7–19.

Todd, B.J., 1999. Browns Bank survey 1998: cruise report and scientific results; Geological Survey of Canada, Open File 3666, 91 p. 8 CD-ROMs.

Todd, B.J., 2005. Morphology and composition of submarine barchan dunes on the Scotian Shelf, Canadian Atlantic margin; Geomorphology, v. 67, p. 487–500.

Todd, B.J., 2007a. Backscatter strength and sun-illuminated seafloor topography, German Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2106A, 3 sheets.

Todd, B.J., 2007b. Sun-illuminated seafloor topography, German Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2107A, 3 sheets.

Todd, B.J., 2009. Surficial geology and sun-illuminated seafloor topography, German Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2148A, 3 sheets.

Todd, B.J., 2013. Shaded seafloor relief, Georges Bank, Fundian Channel, and Northeast Channel, Gulf of Maine; Geological Survey of Canada, Open File 5896, 1 sheet.

Todd, B.J., and Shaw, J., 2006. Sun-illuminated seafloor topography, Browns Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2086A, 1 sheet.

Todd, B.J., and Valentine, P.C., 2010. Shaded seafloor relief, backscatter strength and surficial geology, German Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, Open File 6124, 3 sheets.

Todd, B.J., and Shaw, J., 2012. Laurentide Ice Sheet dynamics in the Bay of Fundy, Canada, revealed through multibeam sonar mapping of glacial landsystems; Quaternary Science Reviews, v. 58, p. 83–103.

Todd, B.J., and Valentine, P.C., 2012. Large submarine sand waves and gravel lag substrates on Georges Bank off Atlantic Canada; *in* Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats, (Eds.) Harris, P.T. and Baker, E.K., Elsevier, Dordrecht, p. 261–275.

Todd, B.J., and Courtney, R.C., 2014. Backscatter strength and shaded seafloor relief, Georges Bank, Fundian Channel and Northeast Channel, Gulf of Maine; Geological Survey of Canada, Open File 7243, 9 sheets.

Todd, B.J., and Valentine, P.C., 2015. Surficial geology and shaded seafloor relief, Georges Bank, Fundian Channel, and Northeast Channel, Gulf of Maine; Geological Survey of Canada, Open File 7657, 1 sheet.

Todd, B.J., Fader, G.B J., Courtney, R.C., and Pickrill, R.A., 1999. Quaternary geology and surficial sediment processes, Browns Bank, Scotian Shelf, based on multibeam bathymetry; Marine Geology, v. 162, p. 165–214.

Todd, B.J., Boyce, A.A., Chapman, C.B., Kostylev, V.E., Rainey, W.A., Spencer, P.L., and Uyesugi, M.S., 2001. Expedition report 2000-047: CCGS *Hudson*, southern Scotian Shelf; Geological Survey of Canada, Open File 3911, 93 p., 12 CD-ROMs.

Todd, B.J., Valentine, P.C., Kostylev, V.E., and Pickrill, R.A., 2001. Habitat mapping of the Gulf of Maine; Geological Survey of Canada, Open File 3995, 1 sheet.

Todd, B.J., Shaw, J., and Courtney, R.C., 2006. Backscatter strength and sun-illuminated seafloor topography, Browns Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2085A, 1 sheet.

Todd, B.J. Fader, G.B.J., and Shaw, J., 2006. Surficial geology and sun-illuminated seafloor topography, Browns Bank, Scotian Shelf, offshore Nova Scotia; Geological Survey of Canada, "A" Series Map 2093A, 1 sheet.

Todd, B. J., Shaw, J., Parrott, D. R., Hughes Clarke, J. E., Cartwright, D., and Hayward, S. E., 2011. Backscatter strength and shaded seafloor relief, Bay of Fundy, sheets 1–17, offshore Nova Scotia - New Brunswick ; Geological Survey of Canada, Open Files 7008–7024, 17 sheets.

Todd, B. J., Shaw, J., and Parrott, D. R., 2011. Shaded seafloor relief, Bay of Fundy, sheets 1–17, offshore Nova Scotia - New Brunswick; Geological Survey of Canada, "A" Series Maps 2174A–2190A, 17 sheets.

Todd, B.J., Shaw, J., and Valentine, P.C., 2016. Submarine glacial landforms on the Bay of Fundy–northern Gulf of Maine continental shelf; i*n* Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient, (Eds.) Dowdeswell, J.A., Canals, M., Jakobsson, M., Todd, B.J., Dowdeswell, E.K., Hogan, K.A., Geological Society of London Memoir, No. 46, p. 429–436.

United States Geological Survey (USGS), 2009. Multibeam collection for RB0904: Multibeam data collected aboard NOAA Ship RONALD H. BROWN (R104) from 16-May-09 to 24-May-09, None to None; NOAA, National Centers for

Environmental Information, <https://www.ngdc.noaa.gov/ships/ronald_h_brown/RB0904_mb.html>, [accessed January 2020].

Wade, J.A., 1990. The stratigraphy of Georges Bank Basin and relationships to the Scotian Basin; *in* Chapter 5 of Geology of the Continental Margin of Eastern Canada, (Eds.) Keen, M.J. and Williams, G.L., Geological Survey of Canada, Geology of Canada Series No. 2, p. 171–190.

Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments; Journal of Geology, v. 30, p. 377–392.