GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7147

Blue Atlantic Pipeline Corridor Geologic Constraints, Scotian Shelf: Desktop Study

E.L. King, G.B.J. Fader, T. Lynds, S. Hynes and R.O. Miller

Technical Report for Accent Engineering Consultants Incorporated

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1.0 Report organization

1.1 Zonation of Corridor

In this report the pipeline corridor has been divided into segments based largely on regional morphology/surficial geology (Fig. 1.1, Enclosure 1). Each area will be assessed and discussed in terms of the published surficial geological maps, sample data base, seismic reflection and sidescan sonar information and interpretation, seabed features and hazards, seabed processes, a summary geological history, and an assessment relative to the presence of constraints to pipeline route selection and construction.

To support this discussion and interpretation, maps of the corridor are presented that show surficial sediment distribution, sample and survey control for seismic and sidescan sonar information, multibeam bathymetric interpretation (where available), zonation of features including a dynamic assessment of sediment transport and distribution of hazards. Each area will be discussed using the above available information with an emphasis on the seabed and immediate subsurface in assessment of attributes and hazards to pipeline route selection, laying and stability.

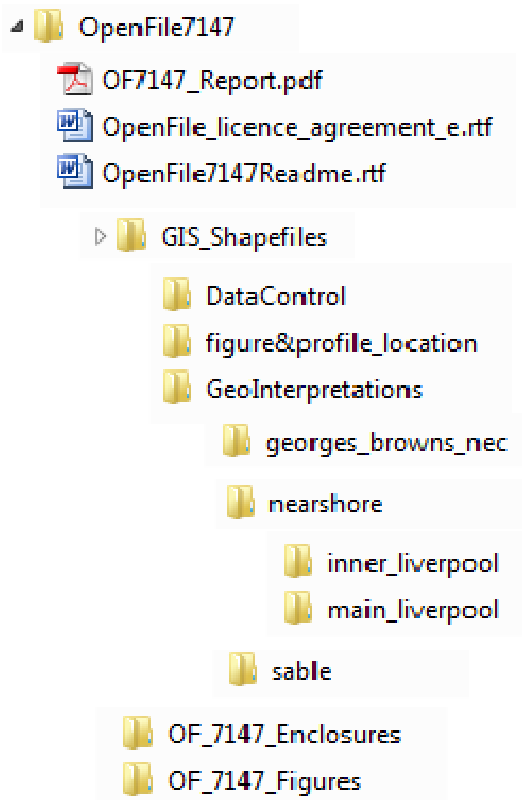
1.2 Organization and viewing of the report and ESRI ArcView projects

This report is subdivided into descriptions and discussions of the corridor zonations noted above (Fig. 1.1). The presentation begins in the east and proceeds westward. Generally an overview of the morphology and geography is followed by notes on previously existing compilations of the surficial geology and sometimes a brief geological history. Where multibeam bathymetry was accessible, a compilation and interpretations of the various geologic and morpho-dynamic elements are presented. Where it was not available existing and updated modifications and specifically tailored maps for this study were usually compiled. The nearshore area involved voluminous compilation and new mapping techniques so this section also provides detailed background and methods presentations. Most sections provide a final summary of factors deemed pertinent to pipeline routing and commonly routing suggestions (or at least avoidance issues) are included.

Much of the corridor data were compiled into numerous GIS maps, where data suitability and availability warranted. These are presented in this report both as illustrations and original GIS data. It is important to note that the illustrations are necessarily overviews and do not contain much of the information available upon further inspection of the multitude of themes. To do so would require many more illustrations and it defeats the primary advantage of GIS products which enable the user to interactively query and present information. The report text points the reader to specific GIS themes and makes note of the type of information at his or her disposal. However, this is not always the case and casual and specific browsing of the GIS products is highly recommended.

The GIS product is contained in the Environmental Systems Research Institute, Inc (ESRI) ArcView® product, Version 3.XX. The report text and illustrations are not reproduced in hard copy. Rather the multitude of colour, scales and sizes of illustrations is best examined with the ability to overview, zoom and pan. Hardcopies can, of course, be generated at the user's will. Note that some illustrations are reproduced at non-standard paper sizes. The report is presented in Adobe Acrobat® .pdf format, Version 5.

The GIS projects were originally organized (for Industry reporting) to be directly accessible from a CD as many dozens of separate themes, several projects are presented. However, this Open File version post-dates ArcView 3.xx versions. Most folders contain the original project files (.apr) but these are obsolete for many users. For example, the “data_coverage” folder contains “corridor_gsca_geophys.apr”, and a sub-division of several geographic areas, each with corresponding ArcView project files, according to the following folder layout. The user is obliged to discover data/interpretations via ESRI ArcCatalogue or the report figures and enclosures and “assemble” datasets into a custom project in a current GIS application.



Numerous geologic sections and bathymetric profiles from multibeam data are also presented, both as figures and enclosures. The exact locations of these profiles are included in the ArcView project “elpaso3_figs.apr” in the folder “figure&profile_location” in several themes according to geographic area.

Report and illustrations layout is presented in several alternatives. The report comprises 21 sections. The text of the entire report (without illustrations) is in Adobe Acrobat (version 5) format, entitled “OF7147_Report.pdf”. The illustrations for each section are under separate files entitled “Sectionxx_figs” where xx represents the section number. Some sections have relatively large file sizes. Several of the key illustrations, the maps and geological and bathymetric profiles, are compiled into one PDF file entitled “Enclosures.pdf”. These are largely duplicates of some of the illustrations. As with the illustrations, the pan and view capabilities of the Adobe Acrobat reader allow the reader to examine details not otherwise visible in hard copy.

Hard copy printout of the text-only file and screen view of the “Enclosures” and various section illustrations PDF files is perhaps the optimum method of viewing the report.

2.0 Introduction

2.1 Background and Corridor Location

This report presents an assessment of the geological conditions within a proposed pipeline corridor, primarily on the western Scotian Shelf and outer Gulf of Maine (Fig.2.1). The corridors connect the outer Scotian Shelf on Sable Island Bank, Western Bank and Emerald Bank to the shoreline of southwest Nova Scotia passing through LaHave Basin and /or Roseway Basin (Fig. 1.1 and Enclosure 1). The corridor continues seaward across the inner shelf through Roseway Basin to the southwest, crossing Browns Bank and Northeast Channel, splitting into two corridors along the northern and southern flanks of Georges Bank, and terminating at the Hague line (international border) on Georges Bank. A revision to the corridor on April 15, has enlarged it to include an area to the south, north and west of Sable Island on Sable Island Bank, and the Canadian sectors of Georges Basin, Sewell Ridge and Crowell Basin. Further revisions to the corridor were discussed in late May conference calls and the areas between LaHave and Roseway Banks, including the northeastern area adjacent to LaHave Bank, have been de-emphasized. This is largely resulting from the nature of the geology in these areas and a preference for landfall in Shelburne versus Liverpool. Further later revisions were made on Sable Island Bank to de-emphasize the outer bank east of Sable Island. In addition, the western boundary of the corridor was expanded westward to include an area of deeper waters west of West Bar, thus enabling avoiding the shallow bar areas known to experience higher sediment mobility.

This assessment is a desk-top scoping study of an evaluation of seabed characteristics within the proposed corridors. It will interpret, assess, define and map areas of pipeline constraints. The assessment work was separated into two components, one concerned with seabed conditions in pipeline corridors crossing the nearshore of the Scotian Shelf extending from Shelburne to Liverpool (between the shoreline and approximately 120 m water depth) and a second component which includes the shelf crossing corridors and outer shelf, basin and bank edge areas. Both are presented together in this report.

2.2 Data Base

The data base for evaluation will consist of existing surficial geological maps and reports both published and unpublished; bottom sediment sample information; piston core and photographic information; high-resolution seismic reflection profiles that includes small airgun systems and Huntec DTS data; echosounder profiles; bathymetry data bases; and various sidescan sonar systems. Multibeam bathymetry has been collected in various areas of the proposed pipeline corridor (Fig. 2.2 and Enclosure 2). Not all of this data is within the public realm and some is proprietary to the petroleum industry. For this study multibeam bathymetry on Georges Bank, southern Georges Basin, Northeast Channel and Browns Bank has been reinterpreted. The nature of the interpretation emphasizes morphology and sediment dynamics in a presentation termed a morphodynamic assessment. This compliments backscatter assessments (proxy for sediment texture) and sediment distribution maps.

2.2.1 Existing Surficial Geological Maps

In the 1970's and 80's a systematic study of the surficial geology of the Scotian Shelf was conceived and designed by L. H. King. The first map area chosen was the Halifax to Sable Island map area of the central Scotian Shelf. These studies utilized echograms collected by the Canadian Hydrographic Service for charting the offshore to determine and discriminate surficial sediments at the seabed. Thousands of samples were collected to groundtruth the acoustic signatures on the echograms and bottom photographs were used to supplement the database. The maps were prepared at the same scales as the existing published hydrographic charts for the shelf. Additionally, airgun seismic reflection systems were used for deeper penetration and definition of bedrock. Submersible dives were conducted in type areas and cores of sediments were collected to determine stratigraphy, lithology, depositional setting and age. The samples were processed for grain size and textural parameters and the gravel was assessed for lithology. The surficial maps are true stratigraphic maps that express the surficial sediments in a formational framework. Figure 2.3 provides an overview index of these maps.

For purposes of this study the surficial geological maps used are: Surficial Geology of the Halifax to Sable Island Map Area, by King, 1970; Surficial Geology of the Yarmouth to Browns Bank Map Area by Drapeau and King, 1972, Surficial Geology of the Eastern Gulf of Maine and Bay of Fundy by Fader et al., 1977; and the Surficial Geology of Georges Bank by Fader et al. 1988. Figure 2.4 show a composite of the whole shelf area surficial geology and Figure 2.5 (Enclosure 3) shows the present (full detail) offshore map over the entire corridor area.

Since the publication of these maps and reports, new information has been collected in some areas, but for many others, the existing maps represent the present state of knowledge on the distribution and character of surficial sediments at the seabed. Huntec DTS and sidescan data was not collected for production of the early maps and was used on a regional study of the Quaternary history of the shelf after 1975 which has been synthesized in King and Fader (1986). Piston cores were collected at critical locations to define the glacial history of advance and retreat. Later studies in the area focused on the mineral potential of the Scotian Shelf supported by Mineral Development Agreements between Nova Scotian and the federal government and surveys of relevance to this study were conducted in the nearshore of the south shore inner shelf and on Browns Bank utilizing a modern suite of geological and geophysical technologies.

Upon completion of the regional surficial mapping program of the Scotian Shelf in the early 1980s, the program moved to the Grand Banks of Newfoundland. During this transition, new technologies for seabed mapping were developed and the maps of the Grand Banks benefited from the application of high-resolution Huntec DTS and the widespread use of sidescan sonar systems. The westernmost maps on the Scotian Shelf, for the Gulf of Maine and Georges Bank, did however, benefit from limited collection of Huntec and sidescan information. These maps incorporated more information on seabed features in the form of interpreted symbolization, thickness assessments and bedform metrics. The survey of Georges Bank was in support of boundary delineation between Canada and the United States and was a systematic grid survey.

2.2.2 Multibeam Bathymetry

In the late 1980s, multibeam bathymetric mapping systems began to be used in both hydrographic charting and marine geological studies. The first application of this technology in Atlantic Canada was through the use of boom-mounted transducers in Halifax Harbour from the CGS Smith with the publication of a colour coded, shaded relief terrain model of the seabed morphology. Over the following decade many new systems were developed and applied to specific areas offshore Canada.

For areas of the Scotian Shelf covered by this study, multibeam bathymetry exists for the outer shelf edge and continental slope along Sable Island Bank, Browns Bank, three areas of Northeast Channel, Georges Bank and a nearshore area off Liverpool along the south shore inner shelf (Fig. 2.2). An additional survey was conducted by David Piper, GSCA, north of Browns Bank over an area of very rugged topography and interpretation of that data has constrained initial pipeline corridor selection to

the south across Browns Bank. Recently collected multibeam data from German Bank to the north of the corridor is also not relevant to this study. Smaller multibeam surveys have been conducted on Western Bank as part of a trawling impact experiments and many other areas in an around Sable Island have been surveyed to study sediment transport and seabed stability. The relevant multibeam bathymetric images will be discussed in greater detail in later sections.
The ideal model for seabed mapping that has been developed by the Geological Survey of Canada over the past decade, is to conduct multibeam surveys first. Using the terrain information and backscatter data from the multibeam, groundtruth surveys are designed with seismic, sidescan, sample and video data collection.

2.2.3 Huntec DTS

Of all the systems used for assessment of surficial sediments offshore, the Huntec Deep-Towed Seismic Reflection System (DTS) gives the best mix of penetration, resolution and characterization of the sediments on the Scotian Shelf. It is a boomer seismic system and deep-towed to position the boomer closer to the seabed. It is also heave compensated for improved presentation and coherency of reflections. The system has approximately 0.25 m resolution and can penetrate the seabed over 100 m. Figure 2.6 (and Enclosure 4) show coverage across the corridor.

It characterizes the glacial till of the Scotian Shelf as a unit of incoherent reflections and can differentiate tills on the basis of the degree of internal backscatter and coherent reflections. Tills also vary in their morphological character and this can be used as another distinguishing feature. The Emerald Silts, glaciomarine sediments, appear as continuous-discontinuous coherent reflections with varied amplitude and reflection spacing. They interbed with the tills at the seaward flanks of the large moraines on the shelf. Holocene muds (LaHave Clay) are thin, acoustically transparent units with weak continuous reflections at the base. The Sable Island Sand and Gravel unit ranges from a veneer to thick deposit of a variety of reflection characteristics. It can be acoustically stratified or appear sometimes without internal reflections. Gravels are normally thin and difficult to detect on seismic especially where they overlie bedrock. Boulder fields show as hyperbolae above the seabed. The Sambro Sand is also a thin unit of muddy sand but resembles the Sable Island Sand where thick on seismic profiles.
Other high resolution seismic reflection data included in this report is sparker data from the Nova Scotia Research Foundation deep-towed sparker. It has less resolution than the Huntec system and is not motion or depth compensated.

2.2.4 Sidescan Sonar

Three sidescan sonar systems were interpreted and reviewed in this study: Klein, BIO and Simrad systems. They vary in frequency between 73, 100 and 330 Khz. These systems have greatly improved over the years and the data is highly variable. Most were operated on 100 m range. More recent systems use neutrally buoyed systems that physically remove motion effects from the data and provide high quality information. This is particularly important for the recognition of boulders on the seabed. All of the above systems sonograms were evaluated for this report. Figure 2.6 (and Enclosure 4) show coverage across the corridor.

2.2.5 Airgun Seismic Reflection Data

For the original interpretation of the bedrock geology of the study area, the report and map of King and MacLean, 1976 served as the basis. This was largely produced from an interpretation of 1, 5, 10 and 40 cubic inch air gun profiles collected in a grid across the study area combined with borehole rock samples and drill cores. Most of these systems provided a measure of the total thickness of the surficial sediments but do not differentiate each of the surficial formations. The resolution of these systems is approximately 10 m. A limited number of seismic reflection profiles were reinterpreted and assessed for this study. Figure 2.6 (and Enclosure 4) show coverage across the corridor.

2.2.6 Samples, Cores and Photographs

Compilations were made of the existing sample database for the corridor. Most of these samples were used to define the surficial units on the original maps and were collected with van Veen, medium-sized grabs. A limited number of piston cores were collected in the muddy basinal areas of the study area. Bottom camera stations were occupied with EG&G Model 605 benthic cameras and were also part of the surficial mapping program. Some of these photographs are used throughout this report. More recent photographs and video information has been collected in the areas of multibeam bathymetric coverage on Browns, Georges and German Banks and additional surveys are in progress. Figure 2.7 (and Enclosure 5) show coverage across the corridor.

2.2.7 Echograms and Bathymetric Data

Echograms provided the acoustic characterization for the surficial geological maps in the original series. Figures 2.8 and 2.9 show the data coverage. Only a few were consulted for this study. For the nearshore bathymetric component of the study, hydrographic plotting sheets were digitized and the data were processed to produce shaded relief maps of topography. Methodologies are described in the section concerning the nearshore landfall.

In summary, regional GSCA data coverage is provided in figures, enclosures and ArcView project themes; Figure 2.6 (and Enclosure 4) shows the geophysics coverage within the pipeline corridor area. Figure 2.7 (and Enclosure 5) shows the GSCA sample stations. Data coverage in general is included in the GIS maps on this CD (ArcView project “corridor_gsca_geophys.apr”). The geophysics data is differentiated according to data type and includes cruise and day/time information. The station data types are also differentiated in the project (themes “Corridor_sample_data.shp” and Georges_samples_clipped.shp”). Grainsize data subdividions of gravel, sand, silt, and mud percent components are included in theme “GSCA Grainsize”.

2.3 Regional Physiography

The offshore areas of this pipeline corridor fall within the Appalachian Region and the Atlantic Coastal Plain geomorphic provinces (Fig. 2.10). The division between these provinces on the Scotian Shelf occurs south of Nova Scotia at the 0-edge of the Coastal Plain strata on the north flank of the inner shelf basins. The Atlantic Coastal Plain lies between the erosional edge (zero-edge) of the Mesozoic to Cenozoic sediments and the continental shelf edge. The Appalachian region to the north of this line largely occurs over hard metamorphic and crystalline terrain on the inner shelf, and is the area with the most difficult pipeline crossing terrain. It is a submarine seaward extension of the Atlantic Uplands, a continuation of the Appalachian Region.

The Bay of Fundy and the eastern Gulf of Maine fall within the Carboniferous-Triassic lowlands area of the Appalachian region. Areas north of the Fundian Moraine (Sewell Ridge and Crowell Basin) also fall within this physiographic zone.

2.4 Geomorphic Elements

Within the broader geomorphic regions are geomorphic elements - the local topographic and morphologic features which give the shelf it shape and expression of banks and basins. The Scotian Shelf can be classified into three broad geomorphic zones: inner shelf, middle shelf and outer shelf.

The inner shelf consists largely of a seaward dipping peneplain developed across hard resistant lithologies. It is incised with former drainage channels in some places overdeepened by glaciation. Isolated basins are common. Bedrock outcrops frequently and the area down to about 100 m water depth is largely gravel covered with the exception of the south west inner shelf which regionally has a predominance of sand. Boulders and boulder fields are common, bedrock ridges trend coast-parallel and eroded, small bouldery linear moraines have recently been found to be numerous.

The middle shelf consists of broad open mud filled basins with small intervening banks of sand and gravel. The middle shelf on the western Scotian Shelf north of Browns Bank consists of large areas of bedrock outcrop, interpreted to have been formed by subglacial meltwater erosion. On the eastern middle shelf (north of Banquereau) it consists of a highly dissected topography with deep channels and many isolated broken banks.

The outer shelf is an area of large offshore shallow and flat banks with intervening, slightly deeper areas called saddles. Deep middle shelf connecting canyons cut through the outer shelf such as Northeast Channel and The Gully to the continental slope. These channels are thought to represent former fluvial channels that have been eroded by subsequent glaciers that repeatedly crossed the Scotian Shelf and were focused with ice streams in the former subaerial system.

Although the Gulf of Maine and its Canadian northeastern extension, the Bay of Fundy, are not considered part of the Scotian Shelf, they represent a western continuation of the Scotian Shelf that is of similar shape, geological history, and sedimentation pattern. In the Gulf of Maine, the middle shelf zone is much broader and occupies the greatest area. It consists of large, deep and broad basins such as Georges, Crowell and Jordan, separated from one another by boulder strewn and iceberg furrowed moraines. Much of the Gulf of Maine is similar to the northern flank of the middle shelf zone of the Scotian Shelf where west to east aligned morainic ridges border small muddy basins. This middle shelf zone opens to the Bay of Fundy which shallows and narrows to the northeast. An outer shelf zone of large shallow banks, Georges and Browns, buttresses the Gulf of Maine from the North Atlantic. These banks are separated from each other by Northeast Channel, which cuts across the shelf to the continental slope.

In this pipeline corridor area, the corridor crosses all of the geomorphic divisions of the Scotian Shelf, cuts some divisions at normal incidence and parallels other geomorphic features. In the choice of pipeline routes it is desirable to cross the inner shelf normal to the trend of the coastline to minimize the rough and rugged terrain of this zone. The basins and saddles of the shelf offer a minimum of constraints to pipeline route selection in contrast to the inner shelf and gravel covered bank areas.

2.5 Bedrock Geology

The bedrock geology of the corridor is extracted from a map and report by King and MacLean (1976), and evidence gathered from subsequent studies of the area, surficial mapping projects and evaluations in this report. The inner shelf is dominated by acoustical basement outcrop. It is an offshore extension of the Meguma Group and related rocks consisting of Cambrian Goldenville Formation greywacke, quartzite and slate and the overlying Ordovician Halifax Formation composed of slate. This area coincides with the inner shelf geomorphic zonation of the Scotian Shelf. The outcrop of bedrock on the inner shelf was underestimated in the original mapping program but through the use of multibeam bathymetry and selected studies in the nearshore with sidescan sonar systems, it is clear that bedrock is widely exposed at the seabed.

A Mesozoic-Cenozoic section occurs beneath Georges Basin, Georges Bank, Northeast Channel, Browns Bank and all other areas of the pipeline corridor south of the 0-edge of the Coastal Plain. It comprises Jurrasic, Cretaceous and Tertiary rocks. These rocks generally dip seaward at angles of less than 1 degree. In contrast, the Jurassic rocks are gently folded in Georges Basin. Erosion of Coastal Plain strata in Northeast Channel has exposed Jurassic and Cretaceous rocks at the bedrock surface, generally beneath thick surficial sediment cover, and the Tertiary sediments have overstepped Cretaceous rocks in the Browns Bank region. Cretaceous rocks form the bedrock in LaHave and Emerald Basins largely as a result of subsequent erosion and removal of overlying Tertiary rocks. The remainder of the area offshore to the shelf edge is underlain by Tertiary rocks, largely consisting of siltstone and mudstone.

2.6 Surficial Geology

The surficial geology along the pipeline corridor will be discussed in detail in the sections on individual segments of the corridor but here we will present an overview of the distribution, history and character. Approximately 50% of the seabed of the Scotian Shelf is considered relict, that is, exhibiting characteristics developed by processes not presently active. The surficial formations are named after type locations on the Scotian Shelf where they were first identified (King, 1970). Table 1 briefly describes their principal characteristics. Figure 2.4 shows the distribution of sediment types across the Shelf and Figure 2.11 is a cross-section of sediments along a line extending from the coast of Halifax, Nova Scotia to Sable Island Bank.

The Scotian Shelf Drift and Emerald Silt form a small portion of the sediment units exposed at the seabed but cover a much larger area in the subsurface (Fig.2.12). Both of these sediment formations originated during glaciation while the other surficial sediments, Sambro Sand, LaHave Clay and Sable Island Sand and Gravel were formed by reworking and redistribution of sediments during marine inundation of the shelf, and to a lesser degree, modification by present day storms and bottom currents.

Scotian Shelf Drift occurs as thick ground moraine, parabolic-shaped drumlins, large morainic ridges up to 50 m in height, and smaller linear moraines. These sediments are very similar to the tills that cover the surface of Nova Scotia. They are exposed at the seabed only over 10% of the area of the Scotian Shelf. The surface of the till is very rough with many boulders, and it is criss-crossed by linear iceberg furrows and marked by circular pits produced by icebergs which grounded on the seabed. These surface features formed during the time when ice sheets were breaking up across the shelf. Large linear moraines of Scotian Shelf Drift form extensive ridges that are most prominent on the landward flanks of Emerald and LaHave Basins but occur across the entire Scotian Shelf. These moraines border and confine many small mud filled linear basins on the northern flank of the middle shelf.

Emerald Silt is interspersed with or overlies Scotian Shelf Drift and in places is overlain by clay or sand. Emerald Silt sediments are rhythmically banded, greyish brown to green, silts and clays that were deposited in environments proximal and distal to glacial ice margins. Emerald Silt is exposed at the seabed on the margins of basins or depressions. There it is interspersed with Scotian Shelf Drift, indicating that deposition of the sediments occurred near the grounded margins of receding glaciers.

The surface of the Emerald Silt is generally smooth but relict iceberg furrows and circular depressions (pockmarks formed by venting gas) occur in some areas. Emerald Silt also underlies sand and gravel on some of the bank areas as isolated remnants in fluvial and glacial meltwater channels.

Sambro Sand is a thin layer of muddy sand that overlies Scotian Shelf Drift and Emerald Silt on the fringes of the banks and in the saddles between large outer shelf banks such as Emerald and LaHave, and LaHave and Baccaro. It was deposited adjacent to former beach and shoreline zones as the ocean waters inundated the shelf following the retreat of the glacial ice.

LaHave Clay is a silty clay to clayey silt that overlies Scotian Shelf Drift and Emerald Silt in the basins and depressions of the Shelf. It is a greyish brown, relatively loosely compacted material. Much of the LaHave Clay originated from glacial materials on the bank areas that were eroded and winnowed during the marine transgression, transported to the shelf basins and deposited. Its surface is generally smooth and flat but some basin areas contain depressions (pockmarks, ranging from 1 - 400 m in diameter) formed by venting gas. Sedimentation is minimal at present over most areas. Many areas are criss-crossed with linear trawl marks resulting from the dragging of bottom fishing gear. The persistence of the trawl marks attests to the lack of significant modern deposition and modification by currents.

Sable Island Sand and Gravel sediments are coarse-grained materials which are actively moving on many areas of the shallow areas of the banks where strong currents and waves affect the seabed. The sediments are largely devoid of silt and clay due to their original formation at the high energy shore face of the transgressing sea. Bedforms (sand ribbons, sandwaves, sand ridges, megaripples, ripples in gravel, comet-shaped marks); are all features produced by non-cohesive sediment transport mechanisms. Long-term sediment transport processes have moved sand from west to east on many of the bank areas both during the post-glacial transgression by the sea and in modern times. This may explain the large accumulations of sand around Sable Island. Sable Island Sand and Gravel covers the largest area of the Scotian Shelf.

2.6.1 Surficial Geological History

Three most recent major processes have been responsible for shaping the present seabed of the Scotian Shelf:

- terrestrial river erosion that developed during periods when the shelf was exposed above sea level
- repeated glaciations and
- massive flooding by the sea (called the marine transgression)

Glaciation eroded the bedrock by ice scouring and meltwater erosion, thus creating large basins and isolated depressions and depositing linear ridges (moraines) of bouldery sediment together with glaciomarine sediments in the basins. Flooding of the previously exposed seabed (present offshore areas in less than 110 m water depth) during the later part of the last glaciation (about 15 000 years ago) smoothed the seabed and sorted previously deposited glacial materials producing a series of drowned beaches across the banks and inner shelf areas.

Continental scale glaciations began in the northern hemisphere of North America during the period known as the Quaternary (beginning approximately 2.5 million years ago). There is limited evidence for earlier glaciations during the previous Tertiary period. Glaciers repeatedly advanced and retreated across the continental shelf to the shelf edge. During this time, sea levels were lower and water was shallow or absent over large areas of the shelf which was contiguous with the adjacent land (Nova Scotia). It is believed that each successive glacial episode eroded and incorporated materials from previous glaciations and inter-glacial periods into its depositional products (King and Fader, 1986).

Although glaciers probably crossed the continental shelf many times during the Quaternary, most of today's sediments were deposited by glacial ice during the Wisconsinan period, which began approximately 70,000 years ago. During this period, it is believed that ice advanced to the shelf edge over all of the Scotian Shelf (Piper et al., 1990). Beneath the ice, deposition of glacial material took place in some areas while erosion extended to bedrock in other areas, especially those closer to the coast. Much of the till (material directly deposited by ice) was deposited during ice retreat when glacial sediment was concentrated in areas adjacent to the margins of the ice. Till was deposited in the large linear and lobate-shaped moraines in the shelf basins and on their flanks where the retreating and thinning ice sheet remained temporarily grounded on progressively shallower parts of the seabed. Further seaward, gravelly and sandy glaciomarine muds were deposited in the basins and interspersed with moraines, particularly on the basin flanks.

During the final breakup of the ice sheets, large icebergs floated throughout the basins of the Scotian Shelf and collided with the tops of most of the moraines and other shallow areas. This produced large linear iceberg furrows from wind and current generated iceberg movement. In areas where the icebergs became unstable and rolled over impacting the seabed, circular depressions termed "iceberg pits" (Fader and King, 1981) were formed. These features remain on the surface of the till, largely unaltered since their formation.

The relative degree of erosion directly by ice, versus erosion by subglacial meltwater from beneath the glaciers, is a matter of current scientific debate. Theories have been proposed by Shaw (1996) that emphasize glacial meltwater as the responsible agent. Large channels that may have formed both by ice and meltwater are exposed at the present seabed north of Banquereau and also occur in the subsurface beneath Sable Island Bank. At the beginning of glacial retreat, following the maximum advance of the glaciers, periodic large meltwater floods may have been released from beneath the glaciers. These large volume water flows would have been concentrated in some areas forming subglacial rivers that could have eroded very deep channels.

Marine transgression, or flooding of the continental shelf since the last glaciation, largely defined the sediment character on many parts of the Scotian Shelf, particularly the banks. Following the retreat of the glaciers, relative sea level was much lower than today, due to the large volumes of water taken up as glacial ice, and bank areas not covered by late glacial ice, were exposed as large islands. The coastline at the time extended up to 30 km farther offshore than today. On the inner shelf, the former sea level is estimated to have stood at a depth of approximately 70 m below that of the present day (Stea et al., 1994), while farther offshore evidence indicates relative sea levels as low as 110 m below present (Fader, 1989). This difference between the low sea level stand in the nearshore and the offshore reflects the rising sea level as the ice sheets melted, thinned and progressively retreated toward the coast, and delay in rebound of the earth's crust as the weight of the glacial ice was removed.

The Scotian Shelf can be described as predominantly relict, that is, exhibiting characteristics that developed in the past, with little modern modification. The recovery of sea level to its present position flooded the shallow bank and nearshore areas, producing a series of drowned beaches across their surfaces. This marine flooding sorted and redistributed sediments. On these former beaches where the wave energy was high, previously deposited till and glaciomarine sediment were reworked and the fine-grained components, silt and clay, were removed and transported to the adjacent basins or over the edge of the continental shelf to deep water. The encroaching sea initially advanced across the shelf at a relatively rapid rate and eventually slowed, as the sea level neared its preglacial former position.

In recent time, the sands and gravels on the shallow bank areas have been further modified by currents and waves, particularly those generated during large storms which generally move northeastward along the eastern seaboard of North America (Amos, 1989). As a result of thousands of years of net sediment transport to the northeast, large sand ridges, sand waves and other smaller sandy bedforms have formed on many shallow bank areas. In particular, Sable Island Bank, Middle Bank and Banquereau exhibit very large sand features at the eastern ends attesting to long term northeasterly sediment transport and periodic high energy conditions. In the deeper basinal areas of the shelf, conditions are much less dynamic and the seabed character has changed little over the last several thousand years.

3.0 Summary of potential hazards to a pipeline

3.1 Pockmarks

Pockmarks (cone-shaped gas venting depressions) only occur in cohesive muddy sediments. They are largely confined to the basins of the shelf but some have been found in isolated small depressions in the Gulf of Maine and in others areas of the eastern Scotian Shelf. Those that have been studied show the presence of hard seabeds at their base likely the result of the formation of calcrete deposits. Some have enhanced benthic communities because of chemosynthetic relationships with bacteria and higher trophic levels. The mud is required to record the passage of gas. The gas for the pockmarks on the Scotian Shelf is considered to be petrogenic gas as most of the pockmarks occur only over Coastal Plain sediments known to contain hydrocarbons.

Based on 35 years of research on pockmarks on the Scotian Shelf we suggest that the pockmarks in the basins are actively venting. We also suggest that gas vents from other areas of the shelf but the passage is not recorded in granular sediments. The rate of formation is however not known. Therefore, pockmarks could represent problems for pipeline construction and maintenance. The present distribution is easily mapped. Evidence also suggests that pockmarks can be started through anthropogenic activity on the seabed. This is another consideration for trenching in pockmark territory. The distributions of pockmarks are not dense enough that pipeline routes through fields could avoid them. This needs to be assessed if pipelines are planned through pockmark fields. Perhaps total avoidance is the safest route. Basins can be skirted to avoid the densest distributions and largest pockmarks.

3.1.1 Boulders

Boulders are common on glaciated shelves and the Scotian Shelf is no exception. They occur on the inner shelf, on moraines and on the outer banks. They are largely absent from only two areas: muddy LaHave Clay and the Sable Island Sand. Where the seabed is thin and overlies gravel lag, gravel boulders sometimes protrude through. They come in all sizes and range to over 10 m in diameter, these are referred to as megaboulders.

They are more widespread on the inner shelf where they have been liberated from the till in the transgressing sea. In the nearshore they are found on bare bedrock as well are in former gravel ridges and in many moraines. A recent discovery of small ribbed moraine in many areas of the nearshore shows the boulders concentrated on parallel small 3 m high ridges.

Few boulders occur in the Emerald Silt unit. The Sambro Sand can have large boulders as it is a reworked till and Emerald Silt. Where the Sambro Sand overlies Emerald Silt boulders are less common. Boulders occur on the banks in regions devoid of sand. Many of these are well rounded – shaped through passage in the transgressing sea.

Boulders are very common on till (Scotian Shelf Drift). They vary in size but are concentrated in berms of iceberg furrows and pits. Most of the till surfaces on the Scotian Shelf are covered with iceberg furrows and pits. The troughs of iceberg furrows can be flat with cobble. These should be investigated as good locations for pipelines.

Most importantly is the recognition of boulders and an ability to assess their distribution for the selection of pipeline routes. Multibeam systems have severe shortcomings in the recognition of boulders. Sidescan sonar is the preferred method. Slow towed, high frequency sidescan sonar systems have an ability to detect objects down to a few decimetres in diameter.

3.1.2 Sand Bedforms

Sand bedforms (megaripples, sand ribbons and sand waves as defined by Amos and King, 1984) are widespread on the Scotian Shelf. Bedforms in shallow water generally less than 80 m in depth are usually active. Those in deeper water can sometimes be relict. Their heights can vary up to 10 m with wavelengths varying to km. It is important to understand sandwave activity and movement in the selection of pipeline routes. A large field of sand waves in northern Northeast Channel appear to be partially relict. An important point regarding bedforms is that it is often assumed that areas of large bedforms indicate high energy. If they are relict than this is not true. Adjacent plain bed areas are assumed to be of lower energy but can in reality be areas with much stronger currents. Such is the case in Northeast Channel where the areas of till have thin sand ribbons moving in flow parallel pathways across the seabed. The areas of sandwaves are thus occurring in lower velocity regimes.

In the nearshore across the dominant bedrock outcrop area, bedforms are common. Ripples form in pebbles and cobble gravel by oscillatory waves, likely in large storms. Sand waves and megaripples are common. Most of these bedforms have heights of less that 1 m and offer good locations for transit of pipelines across the inner shelf.

3.1.3 Moraines

There are four types of moraines across the pipeline corridor: ground moraine, end moraines, ribbed moraines and broad moraines (a form of smeared end moraine – the Browns Bank Moraine for example). All of these features consist of till with boulders. Some have steep slopes and others have iceberg furrows and pits on their surfaces. The moraines that occur on the banks, for example part of the Fundian Moraine and the Browns Bank Moraine, have gone through the marine transgression during the Holocene. This sorts the materials and leaves the moraines covered in gravel with large boulders. Their cores of till remain intact.

A similar situation exists on the inner shelf but most of the moraines are smaller features, ribbed moraines, a few m in height but continuous for km. These are also boulder covered features.

Some drumlins have recently been found on the inner shelf. Several generations of drumlins, reflecting changing ice centres have been detected west of Halifax on the inner shelf. The area off Lunenburg has been found to have fields of drumlins as well, and others may occur further to the west especially in areas adjacent to drumlin fields onshore.

3.1.4 Bedrock Exposure

Bedrock (pre-Quaternary in age) is only exposed in a few areas on the outer shelf. Georges Bank is one such area and bedrock occurs in the south at the seabed. The bedrock of the middle and outer shelf is really consolidated sediment and is sandstone, mudstone and siltstone. This is in sharp contrast to the bedrock of the inner shelf, which is metamorphic and crystalline hard and indurated material.

On the inner shelf bedrock is often exposed as linear ridges and the seabed in some of these areas is very rough and irregular with steep slopes. This morphology is dependent and directly related to the structure of folds, faults and joint patterns within the bedrock. In other areas the bedrock surface can be smoothed and almost polished by the passage of glaciers. In those areas it often exhibits boulders and cobbles on its surface. On a broad regional scale of 10s to 100s of metres the bedrock surface can be fluted with regional broad grooves reflecting former ice directions and rock drumlins are also formed. This can be seen in the multibeam data in the nearshore off Liverpool.

3.1.5 Summary of potential hazards

Figure 3.1 shows an overview of the locations of some of the potential pipeline hazard features described in the following section.

In summary the major constraints to the selection to pipeline corridors are: bedrock exposures, boulders, rough and hummocky moraine, sand bedforms, pockmarks and steep slopes. Seabeds of LaHave Clay and Emerald Silt, with the exception of pockmarks, present little difficulties for pipeline routing. The inner shelf in general is a hostile zone for pipeline crossing. Areas do occur where buried channels and smooth seabed occurs. Moraines in these zones can be crossed but final confirmation of till versus bedrock needs to be assessed using seismic reflection systems and sidescan sonar. Boulders vary is size and occur on all surficial formations with the exception of LaHave Clay. Boulders of southwest Nova Scotia are generally larger that those on the eastern shelf. This reflects lithologies of the on land and inner shelf areas.

In Northeast Channel and on both adjacent banks, Georges and browns, strong currents and resulting sediment transport is occurring. Bedforms can range to 10 m in height. Care must be exercised in determining relative trade-offs in routing as till areas of Northeast Channel are swept by the strongest currents without the formation of sandwaves. The sandwaves present in depressions indicate lower velocities and could be relict in some areas.

This report and associated maps provides a framework of materials and processes, both relict and modern, that can be used to determine routes for survey within the broad corridor. Emphasis of the follow-up surveys should be on the features identified as hazards and the problematic formations.

4.0 Sable Island Bank, shallow area

Figure 4.1 shows the geography and names on Sable Island Bank.

4.1 Geologic Background and previous work

The Marine Sciences series offshore geological maps show limited information in bank areas. This reflects the inability of the acoustic tools of that time to characterize sand and gravel-dominated areas. L.H. King (1970) first differentiated a gravel lag and overlying sand body (Sable Island Sand and Gravel Fm.) and recognized a terrace at 115 to 120 m water depth, attributed a post-glacial low sea-level stand and coastal processes during the late Wisconsinan-Holocene transgression of the shoreline across the entire bank. Scott, et al. (1987) developed a relative sea-level rise history since about 7000 years before present (7 ka) and recognized a flat horizon at the base of the locally thick Sable Island Sand Body (SISB), which they attributed to the post-glacial transgression. This became known as the "R-1" horizon but with further refinements of the stratigraphic model (E.L. King, 2001) it has since been renamed. In this report it is simply designated "low-stand surface 1" in geologic profile illustrations.

With sidescan and deep-towed boomer and high resolution sparker tools understanding of the bank deposits and processes increased greatly. Boyd et al. (1988) recognized a buried channel complex on the northern bank and interpreted a sub-glacial meltwater (tunnel valley) origin. McLaren (1988) and Amos and Miller (1990) both developed glacial and post-glacial stratigraphic frameworks but differed in their interpretation of glacial processes and timing and in sea level related deposition and reworking of the sand-dominated body (SISB) over the flat transgression surface. McLaren mapped the thickness of the SISB and part of this is included in the ArcView project. Amos and Miller's chronology from borehole data showed that the R-1 lag and organic clay indeed represented the post-glacial transgression. This appeared incompatible with a glacial (meltwater dominated moraine and outwash) origin for the SISB, as McLaren and Boyd maintained, so they inferred a simple sea-level rise history for the overlying Sable Island Sand Body. L.H. King (1994) also adopted the moraine interpretation and this was strengthened in E.L. King, (2001). With sea level rise the upper surface was further reworked into a shoreface-connected sand ridge field (Hoogendoorn and Dalrymple 1986), its base marked by another regional horizon (since referred to as R-0). The ridges have been recently mapped in greater detail and this is included in this report.

The present thinking on the geological evolution of the bank (King, 2001 and unpublished data) has a limited glacial ice cover (ca. 22 to 18 ka) extending to the outer shelf-break (designated "earlier glacial sand") followed, with retreat of the ice, by the first post-glacial marine regression-transgression cycle producing the marked erosion surface, designated "low-stand surface 1", upon which a thin (< 3 m) clay blanket (designated "pro-glacial clay") was deposited immediately preceding a final glacial advance (ca. 15 ka) which deposited the SISB as a meltwater-dominated terminal moraine (ubiquitous channels on northern side) and an associated wedge-shaped depositional apron south of this (marked "pro-glacial sands" in profile illustrations). This was followed by another transgression/low-stand designated "low-stand surface 2" in the profiles (locally shallow water only, not shoreline), during and after which sand ridges and progradational sand sheets developed in progressively shallower areas with progressive sea-level rise. The pipeline corridor falls in the western reaches of this sand ridge province. Internal stratigraphy in the sand sheets and sand ridges shows a variable history of transport magnitude and direction but the most recent movement was dominantly to the east. Short term morphological studies and dating of the ridges and superimposed bedforms has been addressed at GSCA and elsewhere in the past decade and is the subject of one section in this report. Generally, the large forms are “dynamically stable” on the sub-decadal time scale while small surficial bedforms move a thin layer of the sands on a short-term basis (as often as every major storm).

The GSC – Atlantic is in the process of assembling a detailed regional geological framework on Sable Island Bank including surficial and sub-bottom sediment types and properties, features and geohazard catalogue, stratigraphic mapping with an aim to better identifying foundation soils and processes associated with glacial and sea-level change history and an increased modern sediment mobility/dynamics understanding. Potential geohazards on the bank include: sediment mobility (directions, magnitudes, periodicites), buried clays (in old tidal or glacial channel-fill or in exhumed paleo-lagoonal deposits), shoreface pits developing in these clays, potential for boulder fields, and shallow gas. Parts of the database and knowledge gained from these studies can be readily applied to an assessment of the geologic conditions along the proposed Blue Atlantic pipeline route on Sable Island Bank. Much of the database information is provided for the corridor area in an ArcView project entitled “sablecorridor_gsca” and reference is made to several themes within in the follow sections. Data coverage is lacking locally and some of the themes represent compilations from a GSC compilation which is in need of updating (Amos et al. 1988) so feature or sediment type distributions are necessarily incomplete. Several geologic sections derived from seismic profiles are included to provide indications of sediment type, thickness, configuration which should also prove useful for interpretation of the data gathered along the proposed route. The locations of these sections is shown in Fig. 4.2 and ArcView theme “Sib_geoprofile_locat” .

4.2 Morphological provinces

The northern part of the bank, north of Sable Island and its East and West Bars, the seabed slopes consistently northward, interrupted occasionally by low amplitude sand ridges. The relatively planar seabed belies a chaotic sub-bottom of countless in-filled channels of varying scale (Figs. 4.3 and 4.4, Profile 86-035p49and50 and Profile 87-042-11. These channels both sourced and eroded the SISB (Sable Island Sand Body) but only occur on its north flank. They have been planed off with the latest transgression of the sea. This surficial and subsurface configuration changes abruptly to the south at the toe of a complex of large sand sheets which developed mainly through northward prograding as the SISB drowned in the rising sea. The SISB, comprising the terminal moraine, superimposed prograding sand sheets, and Sable Island itself creates a large positive relief over the planar, slightly inclined “low-stand surface 1”horizon. (Figs. 4.5 and 4.6, profiles 89-039-13 and 86-035-51). Figure 4.7 shows an isopach map (ArcView theme “McLaren_isopach_ba”) indicating thick sands over this flat horizon, making up Northern Spur and West Bar, where it reaches 40 m in the corridor area. It is thickest in the shallowest water but thins abruptly to the north (Fig. 4.6 profile 86-035-51), marking the edge of the prograding sand sheets. To the south, the seabed inclines gently southeastward on what was a proglacial apron deposit. Superimposed and cut into this are sand ridges of varying lengths and heights (ArcView theme “and_ridge&bedforms_ba2”) and a dominant NE-SW crestline orientation. South of these, where the SISB thins considerably, it was reworked into low and broad sand ridges, likely under low sea level conditions. Beyond this, extending 25 km to the shelf break a wide zone comprises gently inclined sandy seabed with very broad undulations reflecting but smoothing out an underlying early post-glacial topography (Fig. 4.8 profile 78-068-7).

4.3 Conditions along shallow bank corridor

Sand is, by far, the dominant sediment type on Sable Island Bank. Only a small percentage of the numerous GSCA grab samples on the bank recovered any gravel (ArcView theme “Gsca_grainsize”. Gravel sized shell fragments are one component of some samples. The dominating features of the bank are the sand ridges which vary in length, spacing, height, and complexity of pattern. Figure 4.2

(ArcView theme “and_ridge&bedforms_ba2”) shows their general pattern while Figures 4.9 and 4.10 (ArcView themes “Bedform_crest_height” and “Bedform_app_wavelengths”) show their heights and widths respectively, including those of superimposed, smaller-scale bedforms. These have been measured on a bank-wide basis (Campbell, 2001) from the GSCA database of seismic profiles database (with data-collection spanning over 20 years). Measurements are from seismic profile tracings; heights less than about 0.5 m are imprecise and true wavelengths are shorter. Multibeam images show that many of the sand ridges have smaller scale superimposed low-relief bedforms at an acute angle to the ridge (Fig. 4.2, inside multibeam limits). These are either relict remnants of sandwaves or flow-parallel sand ribbons, which may be more active. These dynamics are not well understood. See the following section on sediment dynamics. The highest sand ridges are in the Cohasset/Panuke area; elsewhere they are low but the larger are equally broad. The majority of measurements are from small, superimposed bedforms. The largest ridges are up to 14 m high and wavelengths over 2 km are uncommon. Figs. 4.11 and 4.12 (profiles 85-019-36 and 86-041-3) show the sand ridges in profile, with the undulating topography of the basal “low-stand surface 2”. Note that this surface occasionally crops out in the troughs. Here there is significantly more shell hash and gravel (eroded and winnowed) and this is inferred for the subsurface horizon also.

Other bedforms have been noted in the corridor. Sand ribbons (relatively high current, flow parallel) have been noted near COPAN and in the thin sands north of Sable Island (Fig. 4.7 and ArcView theme “Ribbons_ba”).

4.4 Sediment dynamics

Seabed sediment dynamics will have an influence on decisions of burial or depth of burial of the pipeline on the bank. GSCA has undertaken studies to address the historical and present rates and directions of sand mobility on Sable Island Bank (Amos and Judge 1991, Li et. al. 1997, Li et. al. 1999). This has involved a number of approaches. Techniques involved radioactive tracer studies, repetitive sidescan surveys, repetitive profiler surveys, comparisons of older maps and profiler data with Canadian Hydrographic Service data, repetitive multibeam surveys, coring and dating, current meters, and insitu seabed condition measurements from an instrumented platform, RALPH (Heffler, 1996). RALPH has developed over time to have a full suite of sensors which generally collect short bursts of data at timed intervals, deployed over a period of weeks or months. Sensors include seabed photography, digital video seabed photography, optical backscatter (sediment turbidity), sector-scanning pencil beam seabed profiler (measures small-scale bedforms), sector-scanning fan-beam sonar (acute angle sidescan with 40 m radius), a variety of wave and water depth sensors and associated processing software. Figure 4.13 shows the instrument and typical derived products. These various studies have been conducted largely in the Cohasett/Panuke (COPAN) former hydrocarbon production site located SW of Sable Island, an area immediately south of Sable Island (South Sable), and smaller scattered areas on the bank. Some study designs and initial results are presented in scientific papers and open file reports but some results remain unpublished. Many findings can be applicable to the shallow parts of the corridor area and a summary of pertinent findings follows.

The question of migration rates of the ridges was briefly addressed by Hoogendoorn and Dalrymple (1986) and Dalrymple and Hoogendoorn (1997). They suggested relatively high rates of migration were a possibility. With laying of the first pipeline in the area, this became an important engineering issue, recognizing the potential for sufficient migration of the large forms to create spanning. This was addressed by various workers, Tuscan Enterprises (1985), Jacques/McClelland Geosciences Inc. and Amos (1986) and Ingersol and Ryan (1997). However, long-term comparisons suffered from imprecise instrument navigation making reoccupation of identical sites difficult. Nevertheless, the general consensus upon pipeline laying was that small scale sand bedforms transported a relatively thin “mobile layer” of under 1 m on a storm by storm basis. The estimates for migration rates varied greatly ranging from 0.04 m per year to 5 m per year.

This uncertainty sparked more concentrated research at GSCA in the last 3 to 5 years. State-of-the-art repeat multibeam surveys are being used to build up longer time series of high-resolution data (Li et. al. 1999, Li et al. 2002). This work is still in progress. The magnitude, frequency, path, duration, and conditions of spin-up vs. spin-down of the storm and relation to occurrence, frequency and thickness of the modern mobile layer and the bank-wide variability of this remain a research thrust at GSCA. Much of this study focuses on the in situ RALPH data collection and analysis. Figure 4.13 shows some of the data and analysis methods for RALPH data. This type of study applies mainly to the smaller bedforms and to the relatively common storm magnitude. Generation of wave-formed ripples up to a few decimetres in amplitude occurs regularly and small megaripple generation and destruction or degradation has been observed under moderate storms. Larger transport events are recognized in the sub-bottom stratigraphy (eg. the “old ridge migration unconformity” horizons in the geologic profiles) but their timing remains largely unknown. They are bracketed only by recorded sea level rise history (back to 7ka) and sparse C-14 and other dates. These generally indicate major ridge-forming/building/altering on the millenium time scale. The constraints with this type of study remain the mixing of “old” dates from shell reworking. Events of intermediate magnitude likely are responsible for generation of intermediate-sized bedforms (sandwaves, ribbons etc.). These are similarly poorly time-constrained but surveys conducted within time spans of years and sometimes months commonly show different patterns of intermediate-sized bedforms (megaripple-scale; 10 to 50 m wavelength, 20 to 50 cm height). Attempts to constrain the periodicity of these events is presently under study at GSCA, mainly through repetitive geophysical (sidescan images and high resolution profiles), multibeam surveying and correlating these with storm data/predictions.

One approach with repetitive multibeam surveying is to compare many adjacent seabed bathymetric profiles generated from gridded multibeam data in the COPAN and South Sable areas from surveys spanning several years. Offsets of individual crests or troughs recognized from one survey to the next were measured. Preliminary findings indicate that horizontal “migrations” of sand ridge crests or troughs which exceed 25 m over a two year time frame represent only 5 percent of the measurements and occur in both “stoss” and “lee” directions on the ridges. Migrations over 15 m occur in 10 % of cases. The relative proportion of easterly versus westerly (or SE vs. NW) migration of sand ridge elements can vary from one survey to the other but on the longer time span they are about equal (normal distribution). This suggests that changes are quite dynamic and in a general equilibrium (ie. back and forth). Perhaps more concrete in terms of seabed changes are the (unmeasured) appearance-disappearance of small-scale superimposed bedforms. These are the bedforms in the range of 10 to 25 cm height and 20 to 40 m wavelength. These bedforms are in the measurement range of megaripple or perhaps sand ribbon scale (Amos and King, 1984) but the possibility arises that this does not reflect the bedform size at its storm equilibrium; they may have had greater heights, more compatible with sandwaves. While some multibeam surveys were largely devoid of these bedforms, earlier surveys showed their presence and intermediate surveys showed much smaller amplitude forms. In other areas the survey-to-survey similarity in this size feature was remarkable. The serial surveys are not closely enough spaced in time to establish the frequency of this variability nor the associated storm magnitude threshold. A similar change in megaripple scale bedforms is noted in repeat sidescan surveys.

In the shallowest areas (eg. 10 to 15 m on West Bar) a consistent migration of large sandwave crests was noted, varying from nil to over 30 m over a three year span (Li et. al. 2002). Over a time span of several years the south Sable Island shoreface (20-30 m) shows only minor pattern changes in relatively low-amplitude bedforms. This might bode well for stability of buried structures but a thin upper layer might be very dynamic.

Numerous measurements of the degree of cross-sectional asymmetry of the ridges have also been measured (from seismic traverses). Such symmetry should reflect the migration direction with, for example, asymmetry to the east suggesting easterly net transport. While the greater proportion is asymmetric to the east (or to the south), a large proportion (nearly 40%) is asymmetric to the west (or north). This is interpreted to reflect both transport direction and an affect of progressive erosion of the troughs since sand ridge inception, which does not result in significant net movement of the sand ridge on the long term. Such an interpretation is consistent with the dynamic back and forth situation suggested for the shoreface connected sand ridges from the short-term repetitive multibeam analysis.

Though outside the corridor area, Figure 4.14 shows the ridges south of Sable Island in relation to the underlying stratum. Early eastward sand migration is evident at the base of the sand ridge unit, probably related to a different regime under lower sea-level conditions. The following example shows, however, that, as the larger ridges developed this eastward migration apparently decreased. The large Harcourt-Cameron Ridge, stretching into fairly deep water depths (>50 m), had to have initialized in a shoreface under considerably lower sea-level. It began on a topographic perturbation (in the south) and, with progressive sea-level rise, has evolved length-wise to the present shoreface. It is significant to note that the sand body making up this ridge persisted through time, not by migrating of the crest, but by progressively cutting into the basal material. The sand in the near shoreface is perched upon a ridge of pre-sand ridge sediment, not by virtue of build-up but by virtue of trough erosion. Most of the smaller ridges show this trough erosion to well below the level of their bases directly under their crests. Provided these observations hold for all the shoreface connected ridges (ie. the smaller), it would suggest little migration of the morphological form since its inception and has implications for assessing the observations of ridge migration on the shorter term.

The following is a summary regarding sediment dynamics and significance to pipeline routing on Sable Island Bank. Based on ongoing GSCA studies, observations on the short (3-5 year) time span from repetitive multibeam analysis and the regional stratigraphic and morphologic compilations for the sand ridges suggests that with relative sea level rise, the traces of these ridges migrated with the coastline, that is, troughs and crests extended parallel to their long axes while becoming deeper and higher respectively. Concurrently (on the long-term time scale) a relatively small component of lateral ridge migration occurred (mainly in an eastward and southward direction) as indicated by internal prograding reflectors but, at least in the areas of a simple ridge system (less than 40 m water depth) this might not have exceeded a half wavelength of migration. Movement of the superimposed mid-scale bedforms is more frequent, and an associated “mobile layer” of 0.5 to 1 m probably occurs on a large storm basis and can occur anywhere on the ridge form (crests as well as troughs). The frequency of regeneration of mid-scale bedforms is largely undocumented but shorter than several years. Periodic observations under small storm conditions from instrumented observations record generation and re-generation of current and wave ripples up to megaripple size. It is important to note that little migration of the major sand ridges with does not necessarily imply little sand mobility through the system. A constant replenishing or cycling of sediment may involve significant bypass of sediment without major morphological alteration. However, this information could prove useful in designing burial depth of a pipeline with regard to prevention of subsequent exposure and seabed erosion causing spanning; the potential for this is a lesser concern than indicated in earlier studies.

4.5 Other potential hazards

In terms of other processes possibly relevant to pipeline routing, buried channels that occur very close to the seabed may present some foundation due to different in-fill material. Immediately below the “low-stand2” surface in the geologic profiles (Figs. 4.3, 4.4, and 4.6) the sub-glacially eroded channels are nearly ubiquitous and have a large range in scale. Many are inferred, based on seismic character and depositional environment, to be sand-filled, with little reason to suggest a different geotechnical character than the surrounding sands. Others are likely mud-filled and it is assumed would have different strength character. Most are beneath over 1 m of sand so any geotechnical issue may be minimal. Figure 4.15 (ArcView theme “Shallow_buried_channels_ba”) shows the distribution of those with an interfluve (uppermost bank) less than 5 m below the seabed Most are north of Sable Island and any covering sand is generally thin here as well. The ArcView theme can be queried to identify individual depths of burial. Those channels in the sand ridge field SW of the island may be tidal (or proglacial) and more likely in-filled with sands.

In the shoreface south of Sable Island, silt rich horizons which represent relict lagoonal deposits stemming from a much larger Sable Island are presently being exhumed with continued transgression of the sea (Amos et al. in prep.). These paleo-lagoonal deposits are not registered as sub-surface horizons in seismic profiles. Their extent is largely unknown. There is a possibility that they crop-out locally in the pipeline corridor because presumably the whole expanse from Northern Spur to East Bar was formerly an island with lacustrine deposits. (Lacustrine deposits are inferred from seismic north of the island.) Apart from exposing sediments of different geotechnical character at the seabed these horizons are subject to formation of erosional pits up to several hundred metres across and up to 2 m deep. Preliminary analysis of repetitive multibeam and sidescan coverage indicates the pits may be dynamic (infilling and eroding). As such they are a potential hazard to structures on the seabed.

Shallow gas distribution (shallower than 20 m bsf) is shown in Figure 4.7 (ArcView theme “Shallow_gas_less20 m_deepba.”). Occurrences are sparse and likely quite diffuse. The only area with significant sub-surface gas is in the extreme NE end of the corridor, at the northern bank edge. Here small “point sources” scattered in the subsurface are interpreted to represent free gas. Nothing is know about seep activity at the seabed but such shallow occurrence is considered unlikely if it is not regularly replenished. This phenomenon is common along the entire northern bank edge.

Gravel is not common on top of the SISB, south of the bank crest and the large clasts (>5 cm) are unlikely. Gravel areas are, however noted north of Sable Island (Fig. 4.16, ArcView theme “Seabed_gravel_ba “). Boulders are noted outside the corridor in the eastern Northern Spur area but not within the corridor. This is most likely a function of sparse data coverage; some boulders are likely north of Sable Island where the Holocene sand thins to expose the underlying transgression-modified horizon “lowstand-2” noted in the geologic profiles. Only one GSCA grab sample recovered minor gravel and this is in the vicinity of the gravel mapped from sidescan.

4.6 Pipeline route Assessment – This Study

Sediment type is dominantly sand and nearly everywhere the uppermost (Holocene age) sand unit occurs in metres (or more) thickness and should afford the possibility of pipeline burial. The sand is generally thin north of Sable Island and east of Northern Spur, where numerous buried channels, some inferred to contain silt and clay in-fill, occur within 5 m of the seabed (some very shallow). This might present a foundation issue. Sediment mobility still the subject of research activities by GSCA. It is locally high; this suggests that pipe burial is prudent, but studies to date suggest that disturbance deeper than about 1 m over several years and perhaps a decadal time span, is improbable. Mobility of large bedforms in the shallowest water (<15 m) is greater. Large bedforms studied in 25 to 40 m water depth may be active, but in a dynamic sense, such that large scale migration of the forms (beyond 15 m per year) is improbable so significant pipeline spanning is unlikely. The potential pipe route is oriented normal to most of the sand ridges.

5.0 South Sable Island Bank

The ArcView project, theme "Multibeam_limits_ba" shows that the pipeline corridor skirts along shelf-break multibeam coverage. At the immediate shelf-break and below, the multibeam shows ubiquitous bank edge relict iceberg scours and large pits and occasional sandwaves. However, the corridor boundary consistently falls in water depths shallower than these features. Without exception the multibeam indicates a featureless sand seabed within the (narrow) zone that lies within the corridor.

Additional geophysical data coverage along the Sable Island and Western Banks corridor consists of very sparse sidescan and generally older (low resolution) reflection seismic. Figure 5.1 (profile 78-068-7) indicates a continuous sand blanket cover of 2.5 to 6 m thickness over a probable relict ice-scoured surface. Sidescan coverage east of Dawson Canyon shows zones of sand ribbons with inferred flow directions to the NNW-SSE. These ribbon fields have been registered on two cruises spanning several years. Otherwise, isolated shell beds (likely disarticulated) are present locally. Relatively large expanses of gravel are also indicated (ArcView theme "Seabed_gravel_ba"). East of Dawson Canyon, two sidescan traverses show that trawl marks are very common. Ribbons, again, normal to bathymetric contours, are also common, varying in scale, spacing and textural contrast. Also present, locally, are long and wide patches of coarser material (shells or coarse sand?) in wave-formed ripple fields (ca 1 m wavelength). The patches have curvilinear edges, sometimes regular enough to resemble sandwaves with the important difference that the ripples occur in flat troughs with relatively steep ca 1 m high banks, and that the sand areas express little or no height. They may be relict bedforms whose coarse trough material only remains. This is sensitive to wave action and is periodically remobilized. The slope inflections at the trough edges are probably gentle enough that they do not present a pipeline issue.

Sediment samples along the bank-edge corridor are largely sand. Only about 6% of samples contain 50% or more gravel. One area of exception is a small area on the southern spur of Emerald Bank where several samples contain a significant mud component (50 to 96%) (see ArcView theme "Gsca_grainsize"). This is anomalous with respect to the offshore geology map which depicts sand.

The "spotted" disarticulated shell beds referred to as specks (Amos and Nadeau, 1988) are common (ArcView theme "Specks_ba."). These, where most dense, can cover over 30% of the seabed. They can be randomly distributed, round deposits several tens of metres across but variations include relatively regular patterns whereby the specks are aligned in areas transitional to very low-relief bedforms (not typical ribbons or megaripples). The specks also are manifest as irregular shapes with irregular pattern or more organized alignments. Their origin is not well understood but current-related erosion/winnowing from vertical vortices is one possibility. Another hypothesis (Amos, pers. comm.) is that the shell deposits result from periodic sub-surface gas expulsion, with flotation/concentration of shell material up through the sediment column, such that they are bank/sand pockmark equivalents. This would presumably very disruptive of any primary depositional sub-surface structure. However such sub-bottom horizontal stratification, though weak, is occasionally observed in areas of specks. Further field observations of these features is planned in the near future.

5.1 Pipeline route Assessment – This Study

The seabed is relatively flat-lying and free of obstructive features (shallower than relict iceberg scours). Sediment mobility is largely unknown so the presence of occasional sand ribbons, which indicate high current regimes raises some concern, especially as they are oriented normal to the pipe route. Wave action periodically reworks fields of wave ripples. The edges of these rippled fields are upwards of 1 m high and can have steep slopes (perhaps 1 in 5). Bank-edge currents are commonly high, despite deep water depths but the route generally is situated landward of this. A sand cover of metres thickness affords relatively straightforward burial conditions for most of the route.

6.0 Western, Emerald Bank, South

The pipeline corridor continues along the Scotian Shelf edge to the south of Western and Emerald Banks until encountering the broad saddle of the outer shelf between Emerald and LaHave Banks to the south of Emerald Bank. This part of the shelf is covered by the surficial map and report of King, 1970 (Fig. 2.5 or ArcView theme "Corridor surficial geology.shp"). It is important to note that the outer part of both Emerald and Western Banks are mapped as significant gravel occurrences near the shelf edge, unlike Sable Island bank to the east. Modern detailed studies have been conducted on both Emerald and Western Banks as part of trawling impact studies over the past decade. These clearly show large areas of gravel with boulders and sand in transport across the gravel lag surfaces.

The area between Western and Emerald Banks is called Western Gully and at the seaward zone of this feature, the Sambro Sand occupies a wider area of seabed. Western Gully probably acted as an outlet for glaciers from the north and ice streams likely moved across its surface many times. They transported glacial sediments to the shelf edge and therefore boulders are likely present on the shelf edge south of Western and Emerald Banks. Seismic reflection surveys conducted in Western Gully to assess the potential for seabed aggregate showed a series of truncated till tongues and Emerald Silt deposits along the axis of Western Gully. This supports the interpretation of ice movement completely across these banks to the shelf edge.

7.0 Saddle between Emerald and LaHave Banks

The saddle area between Emerald and LaHave Banks, south of Emerald Basin is a large regional area of Sambro Sand as depicted on the surficial map of King, 1970 (Fig. 2.5 or ArcView theme “Corridor surficial geology.shp”). The seabed consists of muddy sand with gravel. It is an area that has not been studied in detail with modern mapping systems. However, based on knowledge of geological characteristics of similar outer shelf saddle areas, we interpret that the Sambro Sand is a veneer deposit overlying interbedded tills and glaciomarine Emerald Silt. The Sambro Sand can attain thicknesses of up to 80 m in this region, but it likely only a thin veneer deposit. It is not known if active sand bedforms are present on its surface. A GSCA sidescan survey was conducted in the area for purposes of telecommunications cable-laying. Figure 7.1 shows an interpretation of these data, with rough distributions of potential hazards. These include boulders, trawl marks, and rough ground associated with relict iceberg scours.

In relation to the selection of pipeline corridors across this region, emphasis should be placed on determining how thick the Sambro Sand is and how many boulders occur across its surface. It is possible that many boulders occur in the immediate subsurface as well and could have an effect on the pipeline despite presenting a flat muddy sandy seabed. Where the Sambro Sand overlies till there is a tendency to have the greatest concentration of boulders within the Sambro Sand. Where it overlies Emerald Silt boulders are much less frequent. The relative distribution of Emerald Silt versus till in the subsurface of this saddle is not known. Therefore, detailed surveys should be planned across this area if pipeline routes over Emerald Silt in the subsurface are preferred to avoid buried boulders.

8.0 LaHave Basin

8.1 Location

The pipeline corridor crosses LaHave Basin in the southwestern area of the Basin. No multibeam bathymetric data exists for the area of LaHave Basin. At the northern flank of LaHave Basin are two moraines: the South Shore Moraine and the Pennant Point Moraine. These morainic areas are complex distributions of till, Emerald Silt and LaHave Clay. Another moraine termed the LaHave Basin Moraine trends east-west across the centre of LaHave Basin. It is mostly buried below LaHave Clay but crops out in a few isolated areas. Where the till outcrops it is often surrounded and or flanked by Emerald Silt.

8.2 Previous Surficial Geology

The previous published surficial geology of the region is covered by the surficial geology map Yarmouth to Browns Bank (Fig. 2.5 or ArcView theme “Corridor surficial geology.shp”). It depicts the seabed of most of LaHave Basin as consisting of LaHave Clay, silty clay facies. In the southern area of LaHave Basin the unit is a clayey silt, slightly coarser. Areas of northern, eastern and western LaHave Basin are ringed with outcrop of Emerald Silt. The LaHave Basin Moraine crops out in several places within the centre of the Basin suggesting it is a partially buried ridge. LaHave Clay is likely thin over the trend of this moraine. Figure 8.1 shows site-specific information on the sediment types at the seabed and immediately below in this region of Scotian Shelf. Figure 8.2 provides the index for the column sections.

8.3 Pockmarks

Pockmarks are widespread in LaHave Basin with a similar distribution to those in adjacent Emerald Basin (Fig. 8.3). Figure 8.4 shows pockmarks on a seismic profile. They tend to occupy the central and northern areas of the Basin. Based on a study of echograms from the region, it is estimated that they have a density of distribution of approximately 45 pockmarks per square km. They range to 60 m in diameter and to 9 m in depth. A few large pockmarks range to 400m width and 20m in depth. The pockmarks all appear to be developed over coastal plain sediments suggesting that the origin of the gas is Tertiary to Jurassic bedrock and that the gas is likely petrogenic and not biogenic. Thus the pockmarks may be active.

9.0 South Shore and Pennant Point Moraines

9.1 Location

The South Shore and Pennant Point Moraines are two sub-parallel multiple morainic ridges that occur on the northern flank of LaHave Basin and would have to be crossed in a pipeline route to the northwest. The southernmost moraine, the South Shore Moraine has several breaches where Emerald Silt occurs at the seabed. Most of these areas are located in the northeastern area of LaHave Basin and to follow these in a route selection, would likely place the route too far to the northeast. Both the South Shore and Pennant Point Moraines converge and merge at the northwest corner of LaHave Basin. This is an area to the south and east of Liverpool. A pipeline crossing LaHave Basin and heading for Liverpool would be required to cross this area of northwestern LaHave Basin.

The moraines are a series of southwest/northeast trending ridges exposed at the seabed (Fig. 2.5 or ArcView theme “Corridor surficial geology.shp”). Intervening depressions contain Emerald Silt and LaHave Clay with the LaHave Clay dominating the sediment at the seabed of the region. A narrow band of Sambro Sand connects to the inner shelf zone of exposed bedrock. The Sambro sand here likely represents modified till as a gravely, muddy sand.

In the western area of LaHave Basin, the South Shore and Pennant Point Moraines change direction and swing to a north/south orientation. They effectively separate the main depositional area of LaHave Clay in the main part of LaHave Basin from a small western area of the Basin, also covered with LaHave Clay. The South Shore Moraine joins with an eastern projection of Roseway Bank suggesting that the ice that formed the moraine was grounded on the seaward flank of Roseway Bank at the same time forming the ice margin in northern LaHave Basin.

A pipeline route crossing LaHave Basin and heading for Liverpool would cross the moraines in north LaHave Basin normal to their orientation minimizing the length of the route across them. In contrast, a pipeline corridor crossing LaHave Basin heading for Shelburne Harbour would trend westerly in western LaHave Basin and cross the moraines in the area where they are oriented north/south. This zone of morainal territory is wider that the northern route. In this case the Pennant Point moraine is buried beneath more Emerald Silt than the adjacent South Shore Moraine but the South Shore Moraine is more exposed.

10.0 Inner Shelf Geological Constraints Assessment

10.1 Introduction

A landfall geological constraints assessment for the proposed pipeline landfall area along the southwest Nova Scotian coast was carried out for the area between Port LaTour and Liverpool based on initial definition of offshore corridors. Along this zone a landfall between Liverpool and immediately west of Shelburne was identified as a prime target for landfall, governed mainly by approach constraints from the offshore. The Port L'Herbert, Port Joli and Mouton Head areas are less "attractive" because they have issues with wildlife or park protections. However some existing geologic compilations are included here for this area, partly to justify choices of the other areas but also to highlight feasibility based on geological/morphological constrains on their own merits. The nearshore study, unlike much of the offshore, required considerable effort in terms of compilation of raw data. This included compilation from relatively non-conventional techniques, namely from shaded relief images of low-resolution bathymetric data. For this reason, reporting is more detailed, including methodology, incorporation of previous compilations, and feature/hazard descriptions and discussions.

10.2 General Geologic/Morphologic Conditions

Most of the nearshore zone shallower than about 80 m water depth presents geology-related challenges to pipeline routing for several reasons. The area is generally characterized by relatively rugged bedrock outcrop terrain (granites and metamorphosed sediments) at or immediately below the seabed (commonly termed the scary zone), which involves an estimated 70% in some embayment approaches. Glaciation of the area has left isolated but locally expansive till and proglacial (cohesive diamict deposits, locally of several metres thickness. The roughness and high sediment distribution variability partly reflects the glacial style of erosion and deposition in this hard bedrock and partly that the zone has undergone marine transgression and coastal reworking immediately following glaciation. This eroded and "washed" much of the glacial sediment, leaving an abundance of gravel with cobbles and boulders, often as thin blankets overlying the till and/or bedrock. The result is a highly variable topography, highly variable sediment thickness and distribution and relatively "difficult" terrain or sediment types (moraines, till, gravel - boulders). Partially mapped paleo-glacial (buried) valleys cut in bedrock, oriented normal to the coast and normally infilled with glacigenic sediment can be ideal pipeline routes through this terrain.

10.3 Previous studies

10.3.1 St Margaret's Bay to Sable River (Piper et al. 1986) study

The St. Margaret's Bay to Sable River coastline (including Liverpool) has been investigated previously from field investigations in the years between 1978 and 1980 aboard 12 m rented fishing vessels. The main geological results from these have been published (Piper et al. 1986) but their work also involved collection of data salient to pipeline routing which was not incorporated into the published data. They conducted limited 3.5 kHz sub-bottom profiling (generally incapable of penetration through sands/gravels thicker than ca 0.5 m), very limited NSRF deep-towed sparker (better penetration) and sampling program comprising grab and cores. They also conducted magnetometer surveys with an aim to distinguishing the bedrock types; Granite/granodiorite of the Devonian age South Mountain Batholith and metasediments of the Meguma Group comprising the Goldenville (quartzite-dominated) and Halifax (slate-dominated) Formations. The Liverpool and Port Mouton areas are floored with windows of the granitic plutons protruding up through the Meguma metasediments. These generally give way to the Meguma Fm. which dominates the seabed slightly beyond the headlands and seaward. The bathymetric compilation confirms dominant Meguma rock outcrop and subcrop beyond the headlands.

The Piper study (Piper et al. 1986) included bedrock, sediment thickness, and surficial geology maps. Preliminary (and commonly more detailed) versions of parts of these maps are in the preceding progress reports (Piper, 1978 and 1979). Some of these maps were incorporated into the GIS database because they offered the possibility of 1. Control for the revised surficial geology maps, and 2. Location of basins with sediment fill and possible buried channels carved in bedrock and these might serve as pipeline route alternatives. It was discovered that some of the published boundaries were not presented in the detail or accuracy of the original (much smaller scale) maps. Nevertheless, most map features had a registration error of under 300 m.

Most notable of the potential pipeline routes (previous to the offshore bathymetric compilation) were a continuous channel extending from inner Liverpool Harbour to about 25 km offshore and scattered but apparently isolated sediment-filled basins in the Port Mouton area. The nearshore bathymetric compilation concentrated on these areas in an attempt to establish their degree of continuity in the offshore.

The surficial geology maps differentiated bedrock outcrop, till, various facies of the Sable Island Sand and Gravel Fm. (sandy and gravelly), and the basinal La Have Clay Fm. These maps also demonstrated relatively continuous sediment cover, with little till offshore Liverpool.

Some core data were collected under this study; of seven coring attempts in the Port Mouton and Liverpool Bay area, only four long cores managed to penetrate Holocene age muds. These were in the basin areas and sediment comprise silt or silty sand, generally with a greater sand component in the upper centimetres. In all other areas a sand bottom prevented core penetration.

10.3.2 Inner Liverpool Harbour, Haggis Geophysical/Public Works Canada Study

A geophysical survey of Liverpool harbour and its immediate approaches was undertaken by Haggis Geophysical and Edward L. King and Associates (PWC, 1992) in the summer of 1992 for Public Works Canada to assist in assessing the feasibility of proposed improvements to shipping channel depths and alignments. Sub-bottom profiling equipment included a 20-tip sparker with an 11-element hydrophone array and a catamaran-mounted double-coil electromagnetic acoustic source boomer using the same array. This was deployed aboard a PWC vessel “Scotia Surveyor”, using a laser-positioning system for navigation. Immediately before and following the seismic program an extensive marine borehole program was carried out by Maritime Testings (1985) Limited and preliminary results were made available during seismic interpretation and compilation.

Liverpool Harbour is underlain by metamorphic rocks of the Cambro-Ordovician age Meguma Group comprising dominantly quartzose schists in this area. As with the near offshore, glaciation left a patchy cover of glacial till. Borehole data indicate a very competent unit of variable extent and thickness comprising boulders, cobbles, and often sand and gravel which lies directly on the bedrock. This is either the local till or its marine reworked (winnowed) products. It was termed the “Cobble Unit” in the report. The marine areas were then reworked in a beach zone with post-glacial sea level fluctuations (mainly rising). Continuing rise in sea level locally left littoral (sub-marine beach related) deposits. This is represented by an overlying grey, sorted, sometimes stratified, usually fine sand with shells and some organics with strengths ranging from loose to dense (“Sand Unit” in the report). As sea level increased, a more ponded deposition of organic and microfossil rich silts and clays became more confined to the basinal areas, fed largely by the Mersey River and fine, winnowing products from headland (till) erosion. Borehole samples are green, soft, sandy to silty unit with abundant organic content (the "Organics Unit" in the report). Local reports of sunken logs, together with the apparent presence of a near seabed accumulation of natural gas as interpreted from the seismic profiles, indicates that the logging and pulp and paper industry has left its mark in the uppermost depositional history as well. The gas mode of occurrence is different than most. It is present immediately below the seabed as opposed to a more common situation whereby an upper zone of 1 to 3 or 5 m below sea floor exhibits little gas. It is believed to originate from the development of anoxic conditions generated in a thin, decomposing, nearly purely organic surficial layer deposited from the effluent and logs related to the nearby pulp and paper industry.

The pipeline routing salient information from this inner Liverpool report is provided in Environmental Systems Research Institute, Inc (ESRI) GIS format as an “ArcView”, project file entitled “Lvpl_Harbour_GSCA”. It includes borehole (Theme “Lvpool_bh_locat”), seismic trackline control (Theme “Lvpool_shiptrack”), point elevations to the bedrock surface from the interpreted seismic profiles, including minimum elevations where interpretation was inconclusive or limited by till or shallow gas acoustic attenuation, a thickness map (in m) of the combined sand and silt/clay/organics units (Theme “Lvpool_thk_elev_data”), isopachyte maps of total sediment thickness (Theme “Lvpool_bdrk_elev2”), isopachyte maps of the thickness of the upper sand and mud/organics unit (Theme “Lvpool_sand&org_thk “), and finally, a sketchmap of the general geologic conditions including bedrock outcrop, cobble unit outcrop, sand sheet occurrences and areas of thick sand and finally areas of shallow gas (Theme “Lvpool_1geo_summary”). Figure 10.1 presents much of this information, excluding the isopach maps, ship’s tracks, and thickness and elevation control points.

Routing-specific summary: From a study of inner Liverpool Harbour, borehole and seismic investigations identify the following sequence of soils: A quartzose schist bedrock with an overlying cobble and boulder rich unit, an overlying grey, shelly sand unit, and in turn, an overlying organic sand/silt unit. Not all units were encountered at every site due either to excessive thicknesses or local absences. Shallow gas dispersed in the sediment is present over much of the central harbour immediately below the seabed. It prevents any acoustic sub-bottom condition investigation and probably arises from the pulp and paper activities. The GIS product delineates the borehole and seismic control, bedrock elevations and contour map, a sediment thickness map of the overlying sand and silt/clay/organics and a summarizing geological zonation map which identifies conditions relatively benign to pipeline laying with the exception of the surficial gas.

10.3.3 Liverpool Approaches geophysical and multibeam surveys, GSCA

A series of geophysical, sampling and bathymetric surveys were conducted by GSCA (Geological Survey of Canada-Atlantic) together with PWGSC (Public Works and Government Services Canada), Transport Canada, and Environment Canada between 1994 and 1998 in the Liverpool Harbour approaches (Parrott et.al. 1994, 1995, 1999 and 2000). These included multibeam, sidescan, and boomer coverage. The aim of the study was to provide both background geological conditions for the area and to identify the offshore dredging spoils derived from Liverpool Harbour and to establish the stability of these dredge spoils.

They identified bedrock outcrop, sand and gravel but also mud/organics from sidescan. Repetitive sidescan surveys identified the dredge spoils and enabled pre-and post- dump changes. The changes on the seabed are probably related to dumping and include thickness and distributional variation in fine sands and coarser sediments. There was evidence of bedforms and thus periodic sediment mobility.

Multibeam images identified bedrock, sands and gravels, series of medium and small-scale moraines, and local thick sand deposits.

A large amount of nearshore high resolution seismic and sidescan data from the Parrott study was largely uncompiled in terms of surficial geology and seabed features relevant to pipeline routing. Accordingly, a surficial geology and compilation was included in the present study and is included in the GIS product (Themes Parrott_outer_liverpool_poly", "Parrott_outer_liverpool" and "Lpool_moraines"). This served to provide high resolution control for the lower resolution bathymetric images compilation.

The anthropogenic constraints to pipeline routing into Liverpool are mainly related to the dredging of the inner harbour and the offshore dumping of these dredge spoils. They were not addressed in further detail.

Routing-specific summary: Of direct significance to pipeline routing are primarily the maps of surficial sediment distribution and buried valleys. A more or less continuous sand and gravel seabed is present from the outer harbour to the southern edge of data coverage (8 to 10 km offshore Coffin Island). This becomes muddy in the Harbour and (according to the Haggis study) mud with organic and abundant shallow gas in the inner harbour. Locally this sand and gravel sits on till which is boulder-strewn may be considered "difficult pipeline terrain". The till is sculpted into a mid-scale moraine which multibeam data indicate is breached locally, affording a pipeline route. The multibeam also show numerous smaller-scale "ribbed moraines" in a "washboard" pattern (ca 100 m spacing, up to 2 m high). These are also strewn with boulders. The area of multibeam coverage indicates the ribbed moraines can also be avoided though they are likely present, though unmapped farther offshore. Bedrock outcrop is common but can be largely avoided with a selected route based on multibeam surveying.

10.3.4 Port LaTour-Shelburne and Lockeport approaches geological/morphological characterization, GSCA-COGS pilot project

An ongoing GSCA pilot study in the Shelburne and Lockeport approaches addresses a lack of existing maps by utilizing Canadian Hydrographic Service (CHS) water depth data (from original survey field sheets) which, when presented in formats similar to multibeam data, have been demonstrated to enable geomorphic characterizations of the seabed useful for pipeline route selection. Thus, the limited, immediately available existing data set indicates Liverpool and Shelburne regions as target areas.

Recent GSCA experience from other parts of Scotian Shelf had indicated that digital terrain rendering of relatively sparse bathymetric data compilations (100 to 500 m point spacing) from existing Canadian Hydrographic Service (CHS) could be used to enhance the existing surficial geological maps (King and others, 1970's). This improvement stemmed mainly from the greatly improved ability to visualize and correlate surface morphology and features not so readily accomplished with the older mapping technique. This is despite that the original maps utilized original echosounder records that displayed much higher spatial resolution and sub-bottom information. The higher spatial resolution available from nearshore CHS surveys (closer line spacing than in offshore) had the potential to augment existing maps or, as in the case of SW Nova, fill in areas nearly entirely unmapped to date (The Piper et al. study continued only to Sable River).
The CHS data set presents a rather coarse representation but provides an overview which, to reproduce even with present multibeam technology, would require many thousands of survey kilometres. A joint GSCA- Center of Geographic Studies (COGS) pilot study to fill in some of the unmapped nearshore area of SW Nova was initiated in January 2002 as a student term project focusing in the Shelburne and

Lockeport approaches. This is ongoing compilation and has been enhanced, modified and incorporated into this nearshore study for pipeline route assessment.

10.4 Methods

New compilations specific to this study included completing of the mapping technique established in the GSCA-COGS pilot study and extending this to the Liverpool approaches. For reasons noted in the introduction, the intervening area was excluded from the compilation.

The seabed geologic/morphologic characterization technique involved compilation of bathymetric spot depth data, rendering this to quasi-3-D images, superposition of any known surficial (upper 5-10 m) geologic data and from these two approaches, compilation of a seabed characterization/ surficial geology map. Data were compiled into the GIS package by Environmental Systems Research Institute, Inc (ESRI), “ArcView” The project file is entitled “Blue_Atlantic_nearshore_GSCA.apr”

Compilation Technique; Bathymetric Data: The technique involves digitizing spot depth data from the original 1: 12 000 and 1: 36 000 scale CHS field sheets. This was accomplished first through scanning, vectorization and scaling and georeferencing in a CAD package. All maps were UTM projection, Zone 20 referenced to a NAD 83 datum. Georeferencing accuracy varied somewhat but was typically to within 5 metres and always within 15 m. This is considered better than the spot depth placements on the field sheets which are typically hand-drawn and the digits cover a diameter typically from 25 to 150 m. The digitized depths were placed centrally on these digits with an overall accuracy of about ±20 m. Any horizontal inaccuracies are likely insignificant in relation to vertical precision which on most parts of the field sheets was one fathom (ca 2 m). This was better in the nearshore, in shallower than 20 m where the CHS charts typically presented fathom/foot designations. Occasionally where fathom/feet designations were very dense over shoals, the depths were rounded to the nearest fathom. This was a time saver and is justified on the basis that isolated shoals were usually avoidance areas for a pipeline.

The relatively low vertical precision (1 ftm) causes considerable artifacts in the final shaded relief images. This is especially evident across the relatively smooth, flat or gently inclined seabed areas where it imparts a terraced appearance. The profiles also show this. Also, adjacent survey lines apparently were not corrected for sea level datum entirely as line-parallel ridges or troughs are evident. Where relief is greater this is less problematic. The positions of all bathymetric data points from the CHS field sheet compilation are included as a Arc View themes (“Chsbathy_spot_depth”, Chsbathy_spot_depth2” and “Chsbathy_spot_depth3”) to facilitate evaluation of the derived shaded relief images and geologic maps. Access of the CHS data to GSCA for producing these images is for scientific purposes, including geological and habitat mapping. The images or the x,y,z data derived from the CHS field sheets is to be considered confidential from the client’s perspective.

Shaded relief images were compiled largely on a field sheet by field sheet basis, largely because spatial resolution was typically similar across a sheet but not from sheet to sheet (especially in the onshore to offshore sense). The shaded relief image generation program was unable to differentiate large interpolated or extrapolated areas with little or no coverage (e.g. headlands, islands, undigitized portions of maps). Therefore these areas were “masked” manually with black background. With subsequent mosaicing of the various field sheet images in arc View, considerable overlap of black background with areas of good data became apparent. The result was that no one view provides all shaded relief image data and “hidden” information requires sliding of the individual image themes to upper “layers” in the Arc View program. One alternative solution, gridding and imaging of all data at one resolution, was not considered viable because it produced serious degradation of image quality (less resolution in nearshore and too much single data point weighing in the offshore, lending an artificial “hill and hole” topography). The shaded relief images generated from the CHS bathymetric depths are presented as several separate images in the Arc View project. These are: Livpol-near.tif, Livpol-skerry.tif, 9461.tif, 2657.tif, 2870.tif, 2905.tif, 2658.tif, 2658-2.tif, and 1215.tif . All have accompanying tif world files.

10.5 Geologic/morphologic Presentation

The CHS field sheet-derived bathymetric data are presented as shaded relief images (also known as hill-shade relief images) generated from gridding of the raw data points at presentation resolutions compatible with the geographic spacing of the raw data points. In practice, this involved three resolution ranges; one for the 300 to 500 m spacing (generally 1:36 000 scale) offshore sheets, a mid-resolution for the 1:12 000 scale sheets (typically under 100 m spacing) and a third for the closer spacing of inner harbours and shallow shoals (typically less than 20 m water depth). The images are all presented at the same vertical exaggeration of 50 times and with a “sun” illumination angle of 45 degrees from horizontal and from 45 degrees west of north (i.e. from the NE). The gridding resolution was generally defined to between one quarter and one half the original data spacing. Gridding was always by the kriging method (exponential weighting of neighbouring points). This results in a display which is not too “pixelated” but still honours much of the correlatability of data points. This correlatability breaks down occasionally, and is manifest as individual peaks or lows, derived from emphasis on only one original data point. Another presentation artifact arises from the fact that generally in water depths greater than 20m (sometimes 11 m) CHS field sheet data are presented in even fathom intervals (ca. 2 m). Especially in smooth but slightly inclining areas this 2 m jump results in an artificial terraced appearance. A further artifact arises apparently from incomplete or erroneous sea-level datum correction along individual survey traverses. This is manifest as a linear trough or crest in the same orientation of a single traverse.

10.6 Compilation Technique

Geologic Data: One purpose of the bathymetric shaded relief rendering is to enable a seabed morphometric and, where possible, an inferred or interpreted geologic map. This requires some “control” data which, if they can be correlated to specific seabed morphologic character could then be interpolated and extrapolated. Geophysical along-track data coverage is provided in various Arc View themes (“Nearshoresiesitec_pts”, “Nearshoresiesitec_lines”, “Nearshoresidescan_lines”, “Nearshoresidescan_pts”, “Nearshorereflection_lines”, “Nearshorereflection_pts”, “Piper_sable to lvp_tracks”).

- Geologic data came from several sources:
- Sediment Grab and short core (piston or gravity) samples
- Borehole data (inner Liverpool Harbour only)
- CHS field sheet bottom type qualifier annotations
- High resolution reflection seismic (boomer, sparker and air gun) profiles
- High resolution sidescan
- Limited multibeam data (enabling higher resolution morphological to lithologic inferences)

All polygon, line and point data are in latitude and longitude base units in the Arc View project. The sample data (mainly GSCA) are presented in percent gravel, sand and mud, with a Folk grainsize classification name, just as for all the offshore samples (Theme “Gsca_sample_grainsize_data”).

Locations and sample types are included in the theme "All_ed_sample". The Liverpool Harbour borehole positions are provided in Themes "lvpool_bh_lable" and "lvpool_bh_locat". The CHS field sheets included occasional bottom-type qualifiers. These include: rock, gravel, stone, sand, mud, and stones with gravel. These annotations are included in the GIS project and significantly supplement the GSCA-collected samples. A hard-copy multibeam image offshore Liverpool was, in combination with a sidescan image, interpreted in terms of surficial geological units and seabed features and is included in Themes "Parrott_outer_liverpool_poly", "Parrott_outer_liverpool" and "Lpool_moraines".

Much of the geophysical data were interpreted and compiled in a spreadsheet in terms of outcropping and sub-cropping sediment type and features. This included the following categories:

Bedrock outcrop
Sediment type, by formation
- Till outcrop:
  - Till outcrop (1)
  - Thin till (less than 1 m), (2)
  - Till subcrop (less than ca 1 m sediment cover), (3)

Emerald Silt outcrop and subcrop:
- Outcrop (2)
- Subcrop (less than 1 m below seabed),(1)

LaHave Clay outcrop:
- Outcrop (1)
- Less than 1 m thickness (2)

Surficial sediment texture
Sand at seabed:
- Sand outcrop (1)
- Thin sand (where differentiated on profiler data), (2)

Sand & Gravel patches at seabed
Gravel at seabed
Boulders at seabed
- Very dense (3)
- Dense (2)
- Scattered (1)

Bedforms
Megaripples
- Well defined (1)
- Low relief (2)

Sediment thickness parameters
Soils greater than 10m
Soils greater than 5m (2 m for cruise 78005, offshore Liverpool)
Other possible pipeline routing hazards
shallow gas
pockmarks
trawl or anchor marks
Comments

The spreadsheet was set-up (Fig. 10.2) such that day/time and position columns had corresponding columns with integer values (ranging from 0 to 3) to indicate the presence or absence or some other qualifier of the sediment or seabed feature type. Generally all day/time positions were assigned a null (0) value which was then edited to a "1" value, indicating its presence at that position. No layback corrections were applied given the regional approach to the mapping project. In some cases a >1 value was assigned to indicate either a further qualifier, e.g. present but in shallow sub-crop, or present but thin, or scattered, medium, or dense boulder occurrence.

These categories were included only where all the data types (sidescan, high resolution seismic) existed and where the data were of sufficient quality. Some cruises were lacking sidescan data and thus parameters such as boulder densities, surficial sand vs. gravel differentiation, and bedform presence (and type) were much less straightforward or reliable. Cruise 95-030 and 95-149 provided the most complete and best quality coverage.

These interpretations of the geophysical data were incorporated into ArcView and can be accessed in the GIS project (Theme: “Allcruise_interp_new”). This theme can be queried for locations of any of the above sediment types or features. A number of themes have been generated through such queries to enable ready visualization of the information. These include the following themes: Bedrock outcrop points, Till outcrop_points, Thin till outcrop points, Clay outcrop points, Gravel outcrop points, Sand outcrop points, and finally, San&grav outcrop points. Each theme is colour-coded in the ArcView project.

Data Limitations: Typically sidescan or profile raw data depicted sediment type (till, bedrock outcrop, sand patches) in higher resolution than was recorded in the spreadsheet. For example, bedrock outcrop commonly had isolated protruding highs with intervening sand, gravel, bedforms etc. The dominant aspect was recorded. Transitional areas (e.g. sand changing to gravel or patches of sand and gravel or an homogeneous mixture of sand and gravel) were similarly characterized according to the dominant aspect. Bedrock outcrop was, perhaps, weighted more heavily (i.e. reported even if only small area of outcrop on the sidescan/profiler) given the preference to avoid in a pipeline route.

A note of caution using these interpreted data: not all data sets included the appropriate type of data (or sufficient quality) to include in the spreadsheet data files. For example, Huntec profiler data may have been interpreted for clay and till presence but sidescan sonograms were not available (or not accessed) for proper evaluation of the presence of gravel versus sand or boulder presence. Thus, ArcView queries which yield null values (for presence or absence) may reflect sidescan or profiler data not interpreted.

10.7 Potential Pipeline hazards

The following section provides and overview of geological conditions observed in the nearshore, deemed of potential hazard to pipeline routing. Many are similar to the offshore but comments here are specific to observations from this area.

Bedrock outcrop probably presents the primary concern for routing of a pipeline in the nearshore. It is nearly ubiquitous, presents very high and irregular topographic relief relative to the other bottom types, commonly crops out in long, prominent ridges extending many kilometres, comprises well lithified, hard lithologies (mainly granites and metasediments) and generally has a boulder-scattered surface. Figure 10.3 shows typical expressions of bedrock from the sidescan and high resolution profiler data. Bedrock type, jointing pattern, and regional mophological trends can, to varying degrees, be inferred from the sidescan and/or compiled shaded relief images.

Till is also quite common at the seabed in the neashore. It is commonly buried by pro-glacial and early post-glacial muds but outcropping till has been shown to be common, both in the Shelburne and Liverpool study areas. Morphologically, the till generally occurs as ground moraine, a blanket, often with considerable relief and irregular pattern and of variable thickness over bedrock, and as morainic ridges of greatly varying dimensions. The smallest morainic ridges are the so-called “ribbed”, “Rogen”, “DeGeer” or “washboard” moraines which occur as expansive fields of ridges up to km in length, 50 to 200 metres spacing, decimetres to metres high and metres to tens of metres across. They are only locally recognized in the Liverpool area where multibeam data confirms their ridge morphology. Here the field extends to the tidal zone. They are known to be ubiquitous offshore from Yarmouth and across German Bank so their presence elsewhere is likely. They are generally too small to be registered in the CHS data compilations though where identified on the multibeam, they are exhibited as an anomalous character in the CHS data shaded relief images compiled in this study.

Relatively small moraines have been well expressed from the CHS data compilation and their crest traces are provided in the GIS product (Theme “Moraine-crests” and, off Liverpool, “Moraine_or_bedrock_crests” and “Parrott_outer_liverpool”). Figure 10.4 shows a typical example. These were largely unrecognized as moraines until this study. Their differentiation from teardrop-shaped glacial drumlins requires this type of 3-D visualization. Drumlins, though locally ubiquitous in the nearshore zone farther east (eg. Lunenburg to Halifax) have presently not been recognized as common features. As drumlins are closely related to glacial ice streaming, they are not so prevalent in SW Nova Scotia, in comparison to, say the Lunenburg area. However there is a general glacial imprint to the till terrain (especially fluting) and this is common in drumlinized terrain. Drumlins are widespread to the west in the Yarmouth area, probably resulting from glacial streaming out of the Bay of Fundy. Mid-scale moraines (several to 10 m high) are common and many have been mapped in the compilation. Figure 10.4 shows crest traces of such moraines. Larger moraines were discovered on the flank of Roseway Basin (Fig. 10.5). These resemble those mapped slightly farther offshore in the original King et al. maps. They are relatively discontinuous compared to the large offshore moraines (e.g. Browns, Fundian, and Thruxton Moraines) and occur as local nests of individual ridges, sometime in an en echelon pattern. They are commonly perched on top of bedrock topographic highs which acted to pin the glacier margin or grounding line for a time allowing a till buildup. This was noted in a very few locations in this compilation study. For this reason it would be prudent to take care with multibeam and profiler data interpretation of the route alternatives. The en echelon pattern affords the possibility of routing a pipeline around may of these boulder-strewn features. Geotechnical properties of the till are not adequately known in the area. It presents a stable foundation for pipeline placement but the associated boulders and undulating topography can be a hazard.

Gravel, cobbles and boulders will certainly present pipeline issues locally. Figure 10.6 shows an example of their setting. The definition of gravel, cobbles and boulders is used loosely in this study because of the low resolution nature of investigation techniques. Generally, if sidescan images present a strong backscattering signature it is recognized as gravel with the presence of cobbles and some boulders inferred. This relationship is well established elsewhere through video and photograph control. Geologists generally utilize the Folk classification of grainsize whereby gravel is 2 to 64 mm diameter, cobbles 64 to 256 mm and boulder larger than this. Recognition of boulders from sidescan instruments typically employed at GSCA is only those that are larger than about 0.5 m and then, only under “good” conditions (fair weather and stable towing configuration, high enough frequency source, proper tow-depth etc.) Boulders are widespread in the zones shallower than approximately 100 m water depth. The post-glacial transgression of the sea has winnowed the glacial deposits, at least on their upper surface, leaving a near ubiquitous gravel/cobble/bouldery seabed which only locally was later buried. Furthermore, the latest till (ablation till) in Nova Scotia is commonly more boulder-rich than the underling lodgement till. The boulders are inferred to comprise both the Meguma Fm. metasediments and the granites. Local observations on land indicate that there is not necessarily a relationship between boulder type and underlying bedrock type and true glacial erratics are very common. The boulders vary in size and density as interpreted from sidescan sonar data. These data were generally able to resolve boulders smaller than 1 m in diameter. The largest boulders occur in areas of bedrock outcrop and in areas of till outcrop and can be house-sized. Apart from clearly identifiable boulders, with strong reflectors and associated acoustic shadows, the till can present a very rough surface, comparable in relief to boulders. Yaw of the sidescan towfish commonly distorts this bouldery-till roughness so more precise resolution is difficult. Locally the boulders are concentrated; this seems to be the case on the moraine crests as the sidescan data indicate. They are less dense on the moraine flanks and only scattered in the areas of glacimarine (Emerald Silt) sub-crop. An attempt at differentiating boulder densities was made. The boulder density category boundaries are relatively subjective and apparently difficult to project long distances from the sidescan data control. Figures 10.7 to 10.9 show typical sonograms from the three density categories. The most dense are in the order of 10 to 20 recognized boulders per square 1000 metres (ten to twenty per km^2), while the scattered category is typically 1 to 5 per 1000m2 (1000 to 5000 per km^2). A common phenomenon in coastal Nova Scotia is erosion of till forms (typically drumlins), associated with continued (though slow) sea-level rise. The result of this is typically a single-clast layer gravel-cobble “pavement” on top of the relatively un-modified till. This situation, together with areas with subsequent sorted sand cover are inferred for large areas of the nearshore.

The Liverpool Harbour borehole project (Maritime Testing (1985) Limited) encountered a cobbly unit interpreted as the winnowed remnants of till. This study might provide useful background or specific geotechnical data on the boulder/cobble/gravel transgression unit.

The ubiquity of boulders in the nearshore area is anticipated to be a primary concern for pipeline routing.

Shallow gas and pockmarks are locally common. Shallow gas occurrence was considered in Section 3.1, providing an overview in the offshore areas. Shallow gas in sediment is also a common phenomenon in the muds of inner harbours of SW Nova Scotia. This usually occurs as large areas of continuous gas masking at depths of 2 to several metres below seabed in sub-bottom profiles. Associated pockmarks are often present but not common. The gas is likely methane-dominated as petrogenic gas is unlikely given the bedrock type. The Liverpool Harbour shallow gas occurrence is probably anomalous, due to the anthropogenic influence of pulp and paper industry effluents. It is present immediately at the seabed. The concentration of gas is largely undetermined; typically sediment cores recovered in areas with this acoustic signature ooze sediment and gas bubbles due to overpressures developed when brought to atmospheric pressure.

The sidescan compilation of pockmark occurrences in northern Roseway Basin revealed about 13 per km^2. This density is probably underestimated and biased to include only the larger features and those which have a textural difference in their base which gives rise to enhanced sidescan registration. This compares to up to 200 per km^2 reported the offshore basin. Depths of these pockmarks is up to several metres. Up to 300 (small) features per km^2 were encountered in Shelburne Harbour, north of McNutt’s Island (Fig. 10.10).

Trawl marks were recognized from sidescan sonograms in a wide range of water depths in the nearshore study. Note that their recognition can depend on a contrast in sediment texture on the seabed in addition to any micro-relief the scour created and as such the sidescan may not register all features. Of note was intensive scallop raking over the harder ground (till) areas of Shelburne Harbour, including well into the harbour. These may simply be dredging-related or rake test sites. Also, individual drag marks were recognizable across most of the muds (LaHave Clay) in Roseway Basin. These likely represent the cumulative total of occurrences as their healing/infilling is anticipated to be at very low rates in this area of low sedimentation rate. Conversely, the areas of sand and bedforms may be periodically active enough to obliterate trawl marks. Trawl marks do not present a physical barrier to pipe laying put provide an indirect indication of benthic fishing activities. Their documentation can only supplement/confirm fisheries activity reports but have the advantage of providing, to some degree, a cumulative record.

Sediment mobility is indicated locally. Bedforms registered on sidescan sonograms were documented in this compilation. These were classified as either "well defined" or "low relief". The low relief features are usually manifest as elongate strips of coarser (usually gravelly) sediment alternating with sandy strips (Fig. 10.7). They express no relief on the high resolution profilers and are likely less than 25 cm in amplitude. The well-defined features are generally shorter wavelength, more continuous crest-lines, less textural contrast (mainly in sand) and a sidescan signature arising more from morphological variation than seabed texture (Fig. 10.11). The latter indicates higher amplitudes (still well under 1 m). The patterns suggest most forms are flow transverse and the size/wavelength is generally that typical of megaripples though the low amplitude forms suggest a non-equilibrium with present current-wave conditions. The question of sediment mobility in the nearshore is largely unaddressed in this study. There is obvious pertinence in terms of current/wave combination mobilization threshold (presumably during storms), sand flux (and thus spanning or burial of a pipeline), periodicity of mobility, degree of fairweather reworking and degrading etc. Inferences based on the sidescan images would suggest a low periodicity for the low relief features, leaving ample time for degradation. The well-defined class is probably much more frequently activated. The bedforms are generally located in the vicinity of topographic perturbations such as bedrock outcrops and till moraines. Presumably these topographic features enhance current flow locally, mobilizing the seabed.

10.8 Results of Nearshore compilation

In general the large coastal embayments/harbours and headlands have a similar topographic expression in the nearshore. The headlands tend to be bedrock controlled projections with little sediment cover and the embayments often have an associated seabed topographic depression, often with a sub-surface bedrock expression and greater sediment cover. These features cut across (normal to) the nearshore zone and provide the most viable pipeline route alternatives with respect to both avoidance of bedrock and the advantage of softer sediments and lower sediment mobility.

10.8.1 Surficial Geology maps derived from shaded relief and (limited) geophysical data

The geophysical, sample and multibeam data alone are far to sparsely spaced to generate meaningful surficial geology maps. Superpositioning (in GIS) of the interpreted sediment type information from geophysical data (sidescan, high and medium reflection seismic) reveals that the shaded relief maps indeed can be used to extrapolate surficial sediment types and till and bedrock outcrop areas well beyond the geophysical tracks. This study evolved into a pilot project to establish the feasibility of generating surficial geological maps from these data together with the CHS bathymetry-derived shaded relief images. This is considered largely successful, given the limited nature of the data. The following provides a description and discussion of the resulting maps and derived profiles and some notes on their limitations for purposes of pipeline route selection.

The relatively flat-lying areas are variously muds (LaHave Clay Fm., locally with high organics content) or thin sands or thin sand and gravel (SISG Fm.), generally with underlying Emerald Silt. Here, the sample data helped differentiate the sands and gravels from the muddy areas. The sands are difficult to differentiate in the shaded relief maps from the areas of gravel, with the exception of the areas of till outcrop, where a gravel lag (concentration of gravel on upper surface) is inferred. In general it should be assumed that areas of till outcrop have a medium to high density of boulders. The differentiation of till outcrop from bedrock outcrop is more subjective.

10.8.2 Comparison with Piper et.al. (1986) map

There is general agreement in the mapping philosophies of Piper et. al. (1986) and the new compilation. Both are largely based on stratigraphic units and a similar history model. The Piper maps (Arc View Theme “Piper_nearshr”) include a more detailed sub-division of the Sable Island Sand and Gravel Fm. not possible in the new maps. Where the maps overlap (in the Liverpool and Port Mouton areas) there is overall agreement but considerable difference in detail. This apparently arises from the different underlying data sets, the continuity afforded by the shaded relief images, and the difficulties in differentiating till from bedrock, especially where it is thin. A thin bouldery till over bedrock is best differentiated based on sidescan data and this was largely lacking for both map compilations. Extent of bedrock in the new compilation is commonly over-emphasized in comparison to the Piper map. The extent of thin till is probably under-represented in both maps because the (limited) multibeam coverage (Liverpool approaches) indicates plentiful small-scale ribbed moraines (till) perched on bedrock and this is difficult to identify, even on sub-bottom profiler and sidescan data.

10.8.3 Compatibility with offshore maps

The nearshore maps were compiled to be compatible with the offshore Marine Sciences surficial geology series. Arc View theme “Corridor_surficial_geology” presents this map within the corridor area. The nearshore geological maps generally follow the stratigraphic unit mapping philosophy of the offshore maps. The offshore maps depict most of the nearshore map area simply as Sable Island Sand and Gravel Fm. This recognizes that the whole area has been transgressed and winnowed to some degree, which is confirmed in this study. However, the newer mapping tools enable a great enhancement over the old echosounder profiles which rarely provided sub-bottom penetration through the thin sand and/or gravel. The morphological and geophysical data combined allow for much greater differentiation of the units immediately under the sand and gravel. Thus, sand and gravel are indeed present over most of the map area (including much of the bedrock “outcrop”) but commonly in such a thin layer as to have little effect on the seabed morphology. Because of this, although the actual distribution of this sand and gravel is readily identified from sidescan data, it is not so readily extrapolated beyond data coverage. The GIS-based maps produced in this study provide a combination of surficial veneer information (along ship’s tracks) and the geological conditions inferred from morphology and limited geophysical control.

The new mapping involved some modification of the offshore maps and some incorporation of the offshore map boundaries into the nearshore area. In the Liverpool area the existing Piper et al. maps and sub-bottom data were also at our disposal (in Arc View) for comparative purposes. The major modification of the offshore maps was to eliminate any depiction of the Sambro Sand Fm. in vicinity of 100 m water depth. This formation was largely defined on the basis of a silt component in seabed samples which is not present in the (higher energy) Sable Island Sand and Gravel Fm. (King, 1970). The silt was interpreted as a deeper water derived component in relation to the –100 m post-glacial sea-level lowstand. In the SW Nova area the marine low-stand appears to be at about this level, as gravel (from the transgression) becomes nearly ubiquitous shallower than this. (Note that there is some disagreement with the depth of low-stand on other parts of the Scotian Shelf, where the marine low-stand has been shown to be shallower than ca 100 m. However, lacking sufficient sample data, only a sand versus gravel designation could be made.

The digital version of the nearshore maps are considerably enhanced compared to the offshore equivalents; shaded relief information is available, as are interpretations of the original geophysical data as well as numerous site-specific notes "imbedded" in the maps (Theme "Outcrop_pattern_pts"), concerning factors such as the specific variability, the stratigraphic relationships, or the confidence level of interpretation. The ArcView Theme "Allcruise_interp_new" can be queried for locations of various features and sediment types.

10.9 Liverpool region geological map

Morphological provinces: The area offshore Liverpool exhibits several morphological provinces, generally in a coastal to offshore sense, each reflecting different dominant geological deposits, processes or features. Figure 10.12 shows the shaded relief image.

The inner harbours are often characterized by Holocene age (post-glacial) mud confined to the more energy-sheltered (wave and current) embayments and basins. The headlands are generally bedrock-controlled and the embayments have been more depositional sites. The headland morphology continues seaward; bedrock dominates but thin erosional remnants of till are inferred. With higher energy levels in the immediate offshore, muds give way to sands and gravels. The NNW-SSE "fabric" or linear trends of the bedrock morphology continue to about 10 km seaward of the headlands. This reflects primarily the erosional effects of multiple glaciations following bedrock weaknesses and older fluvial systems. It gives rise to a large-scale glacially "fluted" terrain. This "fluting" occurs at scales of several hundred metres to kilometres spacing between ridges and troughs expressing metres or 10's of metres relief. Some of this fluting may be artifact due to incomplete survey line to survey line sea-level datum correction as trackline orientation is nearly parallel. However, the multibeam data confirm this scale of fluting. Beyond ca 10 km the morphology is dominated by linear or curvi-linear bedrock and end-moraine elements which generally parallel the coastline trend and bathymetric contours. Note that this change in morphology occurs near the change in CHS bathymetric data density and this is reflected in the shaded relief image, which perhaps serves to over-emphasize this otherwise transitional change. Linear elements at two or three different orientations are present. The crestlines of many of these linear elements have been mapped (Theme "Moraine_or_bedrock_crests"). The geophysical control indicates that most of the ridges are bedrock-controlled but that many have till moraines perched on the ridge crest. The bedrock acted as a pinning front or "dam" for the ice front (or ice base) providing the time and space for till deposition. This zone of rough topography, hard bedrock lithology, and little sediment cover is sometimes termed the "skerry zone". Beyond this, at about 25 to 30 km from the coast, the skerry zone gives way to the inner-shelf basins, generally with much thicker sediment cover. The transition is generally at the (buried) contact with much younger (Mesozoic) bedrock that has been more effectively sculpted by the glaciers and where glacial deposits are thick. (This transition also occurs at a change in CHS data density.)

10.9.1 Geological conditions

A summary of the geological conditions in inner Liverpool Harbour is provided in the ArcView project "Blue_Atlantic_nearshore_GSCA" as discussed in Section 10.3.3. The Piper et. al. (1986) study identified a sediment-filled channel in the outer Harbour (Theme "Piper_sable to mouton_thickness5") and this is clearly continuous with the channel in the inner harbour (a data gap of only 500 m). If the gas-charged muds present a pipeline problem, relatively thick sands (overlying a cobble unit) flanking the channel (on both sides of the harbour) present an alternative route.

An ArcView theme (Theme "Lpool_geol_ll.") presents the final geologic map. Figure 10.13 shows an overview of the map, but with much of the information in the ArcView project not included (e.g.

shaded relief images, some geologic boundaries, etc.). In a zone from the headlands to10 km seaward, the geological map shows abundant bedrock outcrop (probably with patchy thin till, as noted above). The large areas without bedrock outcrop correspond quite closely to the basinal infill as mapped by Piper et al. (1986 and Piper 1979), (Theme “Piper_sable to mouton_thickness5”) and Figure 10.12, comprising mainly Emerald Silt (glacimarine muds) which have been washed, during the transgression, to leave sand and gravel remnants at the seabed. These areas present the most benign pipeline route conditions, though some amount of scattered boulders is inferred. The sidescan mosaic offshore Liverpool shows high concentrations of boulders mainly associated with the thin till remnants and lesser in the sand and gravel areas. It was anticipated, previous to the bathymetric compilation, that one or several of the basins extended seaward, through the skerry zone, a relatively common phenomenon in the Lunenburg area (Piper et al 1986), thus affording a possible pipeline corridor. This proved not to be the case.

In the skerry zone (ca 10 to 25 km) offshore Liverpool, the geological map shows mainly undifferentiated bedrock and till (one colour). Apart from the geophysical control, the cross-cutting orientation of at least three systems of ridges and valleys is interpreted as reflecting both morainic deposits and bedrock dominated terrain. This undifferentiated zone has, nevertheless, been sub-divided into two seabed zones reflecting a higher relief ridge and valley morphology in the outer part, associated with numerous moraines, and a lower relief but apparently bedrock dominated terrain on the inner part. The inner zone is designated “pockets or ridges of thin till over bedrock” while the outer zone (same colour) is simply designated undifferentiated bedrock and till. The geophysics traverse indicates considerable till in moraines perched on bedrock ridges but the till is not continuous and bedrock protruding through the till, both in the valleys and on the ridge crests is common. As noted above, the linear ridge-crests have been mapped (Theme “Moraine_or_bedrock_crests”) but most are designated undifferentiated till or bedrock..

A geophysical transect across the most “difficult conditions” was analyzed for percentage of various seabed types. The ca. 25 km sidescan and seistec sub-bottom profiler transect (from approx. 374000, 4861000 to 379000, 4837000 UTM, zone 20) indicates the following approximate proportions of seabed conditions:

29% bedrock
41% till
20% Emerald Silt (beneath thin sand or gravel)
10% LaHave Clay

Note that the measurement technique, with averaged geological annotations at regular spacings along the sidescan record represents a spatial averaging. This has the effect that, for example, scattered outcrops in an area measuring ca 150 x 150 m would be recorded as full bedrock exposure despite the presence of silt or till pockets between bedrock knobs or ridges. As such, bedrock exposure is over-reported at the “expense” of till and Emerald Silt.

In terms of sediment texture (sand, gravel, clay) at the seabed along this same transect:

28% gravel
12% sand
50% sand and gravel patches (alternating)
10% clay

Note that boulder densities (from sidescan) were not measured in the Liverpool offshore area. A similar transect seabed-type exercise is performed for the Shelburne skerry zone for comparative purposes.

The outermost (seaward) part of the nearshore map benefits from the offshore map control. It comprises a relatively low and broad moraine complex with intervening Emerald Silt and occasional LaHave Clay pockets. The offshore map indicates the Pennant Point and South Shore Moraines comprise much of a route alternative through LaHave Basin (See also Section 9.0).

10.9.2 Pipeline route Assessment – This Study

The Liverpool skerry zone, with its multiple bedrock ridges and superimposed moraines presents a zone about 20 km wide between the silts and clays of the LaHave Basin and the glacial and post-glacial sediment-filled bedrock channels and basins of the nearshore area (headlands to 10 or 12 km seaward). This presents a formidable challenge to pipe routing and no route alternate has been selected in this study. Furthermore, the moraine complex flanking the northern LaHave Basin is very broad. A straight-line traverse intersects the moraine complex from three to five times, totaling at least 5 km across difficult terrain with a likelihood of a multitude of boulders and iceberg scours. Figure 10.14 shows a bathymetric profile from the Liverpool area headlands to LaHave Basin. Relief in the skerry zone is much greater than, for example that off Shelburne (following section). The inner area, from ca 10 offshore the headlands presents much more benign conditions, especially if the sands in the basin in-fill areas can be followed. Sand waves (or megaripples) and the Parrott dredge-spoils study indicate some degree of periodic sediment mobility. The inner and outer Liverpool Harbour presents mainly muds but with considerable shallow gas. Firmer foundation conditions may be found in sands flanking the mud.

10.10 Shelburne region geological map

The same Arc View theme (Theme "Lpool_geol_ll.") presents the final geologic map for the area offshore Shelburne (including Port LaTour to Lockeport). Figure 10.13 shows the overview of the map, but with much of the information in the ArcView project not included (e.g. shaded relief images, some geologic boundaries, etc). This area contrasts with the Liverpool area in its more extensive and continuous unconsolidated sediment cover over bedrock. The geological reasons for this are unclear but pro-glacial deposition (with basinal infilling and blanket deposition) was greater than to the east, effectively smoothing out much of the bedrock and till relief. Furthermore, a readvance of the glacier to the headlands provided the opportunity for further proglacial sedimentation.

10.10.1 Morphological provinces

Figure 10.5 shows the shaded relief images for the area. (The ArcView project also has the Lockeport area image). The same general morphological provinces as offshore Liverpool are manifest, but not to the same degree of contrast. The muddy and sandy inner harbours give way to sand and gravel, commonly over a late-glacial till. Shelburne Harbour approaches is unique in its general paucity of bedrock outcrop. The Roseway to Port LaTour coastline is, however, bedrock-dominated to at least 10 km offshore. The bedrock is characterized by linear trends in a NNE-SSW orientation presenting small-scale ridge and trough topography. Off Shelburne there is considerable relatively flat-lying seabed which constitutes small basin infill of glacimarine sediment with sand and gravel cover. Till is present as ground moraine and mounds but seaward of this (22 km from Government Point) the till occurs mainly as bathymetric contour-parallel medium-scale moraines up to 15 m in height and variable length.

10.10.2 Geological conditions

Inner Shelburne Harbour, from McNutt's Island and landward is relatively well characterized geologically because of good geophysical and sample control. A sidescan mosaic was produced, a seistec and sidescan traverse going inward and out of the harbour was interpreted, and the CHS bottom type designations are dense. The inner harbour is mud-dominated though some outcrop is inferred, mainly along the coast. Locally mud-flanked till and bedrock outcrops express greater relief and higher topography and are exposed as "windows". It is up to several meters thick, contains pockmarks, and is raked by scallop drags (Fig. 10.15). A zone of particularly dense pockmarks to the north and east of McNutt's Island is mapped. Here individual but small pockmarks number upwards of 300 (small) features per km^2.

Shelburne Harbour and nearshore approaches is somewhat unique in its sub-bottom stratigraphy in that till is locally overlying a depositionally complex Emerald Silt unit. This till is built into a set of sub-linear moraines at the narrows west of "Government Point" at the head of the harbour (Fig 10.16). This till apparently extends east of the point and well into the outer mouth of Jordan Bay and Green Harbour approaches. Boulders are nearly ubiquitous on the till with the densest concentrations on the ridge-tops and scattered boulders in the intervening topographic lows. The sand and gravel-covered, low relief Emerald Silt appears to be continuous both seaward and landward of this till deposit, affording, with the exception of scattered boulders, a relatively amenable pipeline route at least out to the mid-sized moraines located about 20 km seaward of the headlands.

Beyond the headlands, the geological map shows a major east to west difference from dominance of bedrock outcrop (or bedrock with thin, patchy till) east of Shelburne Harbour approaches to dominant sand and gravel (generally over Emerald Silt) and ground moraine and end moraines (till) in a wide N-S oriented swath which extends east to Lockeport approaches and south to Roseway Basin (Fig 10.13). The bedrock outcrop dominance extends west to Port LaTour and the limit of data coverage. Here, only isolated small and shallow basins with relatively smooth seabed are interpreted to be sand and gravel over Emerald Silt but occasional till and bedrock outcrops are also likely. These basins are smaller, more isolated, and have a more irregular topography than the sand areas mapped south of Shelburne and the surficial geology is likely more variable than the map indicates. In the area south of Green Point and Port LaTour the seabed topography exhibits slightly lesser relief and thin, patchy till, generally with a thin sand and gravel cover. Figure 10.17 shows the shaded relief image. There is little geophysical control in this area. Much is mapped as bedrock outcrop but overlying patchy till and occasional mid-scale moraines are likely.

In the approaches to Jordan Bay and Green Harbour the seabed is mainly flat-lying or slightly inclined with the exception of the subtle topographic high interpreted to comprise till of the moraine system off Government Point. The headland between the two harbours extends seaward and is probably bedrock-dominated. Seistec (boomer) and sidescan along a traverse in central Jordan Bay show largely featureless seabed. The CHS bottom type designations indicate sand. This sand is locally thin, overlying Emerald Silt and till, only locally, where the seabed becomes gravelly. The upper bay is not surveyed but likely is mud-covered. Similar conditions are inferred for Green Harbour based on the seabed morphology. The Arc View Theme (Jordan_pipe_route_gsca) traces the optimum route for a possible pipeline (based solely on geologic conditions). Figure 10.14 shows a bathymetric profile from Green Harbour to Roseway Basin along a traverse shown in Arc View Theme "Pipe_route1". Topographic perturbations are mainly less than 1 m high with the exception of the two moraines in the skerry zone.

The approaches to Lockeport are largely bedrock-dominated as confirmed from the north-south linear bedrock trends extending from the land. However, the sands of Cresent Beach (immediately west of the town) apparently are continuous seaward in a narrow band, with little or no apparent pipeline routing impediments except for a few narrow (150 m wide) “pinch-points”. The harbour north of the town has a smooth seabed, likely sandy, which changes to mud in the innermost 3.5 km of the harbour. However, several bedrock-controlled “pinch-points” between this and the narrow sand belt probably pose routing impediments. Figure 10.14 shows shows a bathymetric profile from Lockeport Harbour to Roseway Basin along a traverse shown in Arc View Theme “Pipe_route1”.

Figure 10.14 also shows additional bathymetric profiles along selected routes to Roseway, and Port LaTour (again, traverse locations shown in Arc View Theme “Pipe_route1”) but these are not ideal routes based on geological conditions alone.

In the skerry zone offshore Shelburne a transect of sidescan and seistec sub-bottom profiler data along a ca. 25 km transect (from cruise 95-030, daytime 294/0100 to 294/0300, approx. 322500, 4824100 to 336900, 4819400 UTM, zone 20) indicates the following approximate proportions of seabed conditions:

1% bedrock
19% till
79% Emerald Silt (locally beneath thin sand or gravel)
0% LaHave Clay

In terms of sediment texture (sand, gravel, clay) at the seabed along this same transect:

27% gravel
7% sand
66% sand and gravel patches (alternating)
0% clay

The “densest boulders” classification covers about 5% of this transect. Note that this transect does not follow the optimum route based on geology/topography and as such the proportion of bedrock and till (with boulders) is over-represented mainly at the “expense” of Emerald Silt compared to a final lay-route. A similar transect seabed-type exercise is performed for the Liverpool skerry zone for comparative purposes.

Despite anecdotal reports of strong currents near headlands, the sidescan data show little evidence of bedforms. Some evidence for periodic sand transport (of unknown frequency or magnitude) is in the form of degraded (very low relief) transverse-flow bedforms of sandwave or megaripple size. These occur mainly in the relatively flat-lying sand and gravel area, typically near topographic highs. The ArcView Theme “Allcruise_interp_new” can be queried for their locations.

10.10.3 Pipeline route Assessment – This Study

The skerry zone seabed conditions transect offshore Shelburne indicates a much better suited pipeline route in terms of perceived hazards than the Liverpool transect. The route alternative extending from Roseway Basin and into Jordan Bay or Green Harbour presents the least bedrock outcrop possibility, greatest area of sand cover, least till and dense boulder terrain compared with all other route suggestions. Lockeport is an alternative but with several “pinch-points”. Many of the till morines of the skerry zone are short and numerous breaches (with the exception of the largest moraine) might allow a convoluted pipeline route. The till is boulder-strewn, especially on the crests of moraines. Even the more flat-lying sand-covered glacimarine deposits present scattered boulders. Sediment transport evidence is not common and if this is a routing factor, it commonly occurs in thin sands in the vicinity of topographic highs. Figure 10.18 provides and overview of possible pipeline routes and their bathymetric profiles.

10.11 Note on Blue Atlantic Survey techniques

Various geophysical survey instruments are particularly suited to penetrate, resolve and/or distinguish geologic features and sediment types in the nearshore areas. Of particular importance in the nearshore pipeline route alternative surveying will be differentiation of till and bedrock, especially where the till overlying bedrock is thin. In such cases it is typical that the lower resolution of a relatively low frequency reflection seismic source (eg. small air gun or sparker system) will not allow recognition of the till layer. Some instruments are clearly better suited than others and experience shows that such differences are not readily accounted for or explained by the typical instrument specifications alone. For example, two boomer systems often used by GSCA, the Huntec Deep-towed boomer/sparker combination, and the Seistec boomer with cone-in-line “focusing” both produce superior profiles for mapping purposes. The Seistec is particularly well suited to shallow water profiling and has similar acoustic penetration results of the deep-towed system but commonly will not register the bedrock surface through thin till. Sidescan is the best instrument for registration of boulders though in shallow water the nadir beams of (mid-resolution) multibeam have been demonstrated to register boulders. Sidescan data obtained under less than ideal conditions (unstable towfish, inappropriate tow depth) can successfully register gravel and sand textural differences wile failing to resolve boulders.

11.0 Saddle between LaHave, Baccaro and Roseway Banks

11.1 Location

The pipeline corridor crosses the outer Scotian Shelf as it swings in a northwesterly direction across an area know as the saddle between Emerald and LaHave Banks. This area does not have an official name on the hydrographic charts. For purposes of this study we also include the saddle area between LaHave, Baccaro and Roseway Banks.

11.2 Previous Surficial Geology

The previous published surficial geology of the region is covered by two maps, the Halifax to Sable Island map sheet and the Yarmouth to Browns Bank map sheet (Fig. 2.5 or ArcView theme “Corridor surficial geology.shp”). The dominant surficial material at the seabed across this region is the Sambro Sand unit, a muddy sand sometimes with gravel. It has been mapped in two facies on the basis of samples. Where it is dominantly a muddy sand it consists of dark greyish brown, medium to fine-grained well-sorted sand. In some areas it has a high proportion of gravel. Since the Sambro sand was formed as a sublittoral deposit in the near shore of the lowered sea level on the Scotian Shelf, it represents both a modified till (Scotian Shelf Drift) and Emerald Silt. Were the till has been modified the seabed has a high gravel content with boulders and where the Emerald Silt has been modified, the gravel content is low or absent.

The Sambro Sand is usually a veneer deposit, less than 1 m in thickness, but it attains thicknesses of up to 20 m in isolated depressions and other unique settings. There is no multibeam bathymetry across this area of corridor, with the exception of the shelf edge multibeam data set collected by the petroleum industry. Figures 8.2 and 8.3 provide some spot information on the seabed and shallow sub-bottom sediments.

11.3 Pipeline route Assessment – This Study

Since the production of the initial surficial geological map, some new information has been collected. This has been part of thesis work for students at Dalhousie University, assessment of cable corridors and on an ad hoc basis to apply Huntec DTS and sidescan sonar systems to this area of the shelf for a better understanding of the glacial stratigraphy. During the first mapping program no sidescan sonar or high-resolution seismic reflection data was collected.

More recent sidescan surveys indicate a number of features present across the Sambro Sand seabed (Fig. 11.1). Boulders are common. Surveys conducted between Emerald and Western Banks to the east, where conditions are interpreted to be similar to this saddle area, show a major unconformity beneath the Sambro Sand that has truncated seaward dipping strata of interbedded till and glaciomarine sediment. This was probably accomplished by advancing ice streams moving within the interbank channels. The distribution of boulders is likely controlled by the subsurface relative distribution of till versus glaciomarine Emerald Silt. Where the till forms the immediate subsurface, boulders occur at the seabed.

A few iceberg furrows are also interpreted to occur at the seabed between LaHave and Emerald Banks and the icebergs that made these marks could also be the source for some of the boulders through ice rafting. The iceberg furrows are interpreted as relict features as no modern icebergs impinge on this area of the Scotian Shelf. This lends support to the idea that much of the Sambro Sand seabed is also relict with minor modern modification.

Trawl marks are widespread across this region. In many places they are very dense and the seabed is covered with many generations of these linear parallel minor depressions. Their persistence suggests that sediment transport is not active in these areas or that trawling is repetitive. Evidence of the dragging of large boulders by fishing gear is seen in the distribution of a few linear boulder scours. Recent investigations of the Sambro Sand south of Baccaro Bank using towed video cameras show that there are large areas of 0.25 m diameter boulders scattered across the seabed. The presence of these boulders indicates that glaciers extended to at least the shelf edge during the maximum ice advance.

12.0 Roseway Basin, North

12.1 Location

Roseway Basin is the most westerly and smallest of the middle shelf basins on the Scotian Shelf. It is bounded by Roseway Bank in the east, the inner shelf in the north and a seaward extension of shallower bedrock dominated seabed in the west. The Basin is divided into two sections separated by the prominent Fundian Moraine, a large ridge of glacial till that forms Sewell ridge and the north flank of Browns Bank to the west, and extends north of Browns Bank across Roseway Basin and joins Roseway Bank. For purposes of this study we confine the discussion of Roseway Basin to the area north of the Fundian Moraine termed Roseway Basin North. It is the typical mid shelf basin of LaHave Clay and Emerald Silt deposition. The southern part of Roseway Basin will be dealt with in the following section because conditions of deposition are different in that area.

12.2 Surficial Geology

The published surficial geology map of Roseway Basin (Fig. 2.5 or ArcView theme "Corridor surficial geology.shp") shows that the deep water areas are overlain with a clayey silt facies of the LaHave Clay unit. This acoustically transparent Holocene mud reaches thicknesses of 20 m. The clay is a homogeneous dark greyish brown, loosely compacted, silty clay, grading to a clayey silt. Figure 12.1 shows a seabed photograph. It was eroded from till and Emerald Silt in the shallow areas of the shelf during post-glacial marine transgression, transported to the quiet basins of the shelf and deposited.

Underlying the LaHave Clay and rimming Roseway Basin is the Emerald Silt. It is a fine-grained clayey silt, but locally contains sand and gravel. The unit was deposited from indirect deposition by glaciers through sediment plume settlement and ice rafted deposition. The Emerald Silt in turn overlies the Scotian Shelf Drift (till) which is a cohesive poorly sorted mixture of mud, sand and gravel. The gravel consists of all grain sizes ranging from granules to boulders. Figures 8.2 and 8.3 provide some spot information on the seabed and shallow sub-bottom sediments. Till outcrops in a few isolated areas within Roseway Basin but dominates the seabed at the southern flank of Roseway Basin along the Fundian Moraine. Till surfaces are covered in relict iceberg furrows. These furrows can range up to hundreds of m in width and 10s of km in length and generally range to 8 m in depth. The berms of the iceberg furrows are dominated by boulders liberated from the till by the furrowing process and subsequent current erosion. Within some areas of Roseway Basin, till tongues are rises beneath the Emerald Silt and LaHave Clay and protrude through these sediments. They appear as hard bouldery seabeds in small areas sometimes associated with erosional moats.

Of particular importance to this study is the occurrence of pockmarks (gas escape craters) on the surface of the LaHave Clay. These were not mapped on the original surficial geological maps. The pockmarks in Roseway Basin are generally smaller than those in adjacent LaHave Basin and Emerald Basin, but they are the densest distribution of pockmarks on the entire Scotian Shelf. The concentration of pockmarks in Roseway Basin is 200 pockmarks per square km (Fig. 12.1). They range from 15 to 30 m in diameter and 3-6 m in depth.

Early ideas concerning the formation of pockmarks suggested either water of gas as the eroding agent. It is now believed that those on the Scotian Shelf were formed by venting gas and in the case of Roseway Basin, venting hydrocarbon gasses. The question remains as to the frequency of the venting, but recent studies suggest that it is a continual process. Sidescan sonograms from many pockmarks across the Scotian Shelf show highly variable pockmark floors with wide ranging reflectivity. This suggests that vent communities and the development of calcrete deposits is a strong possibility.

Repetitive studies have not been conducted on the rate of formation of pockmarks but in terms of pipelines a worse case scenario of present formation should be assumed. Pockmarks are not only confined to LaHave Clay and they do form in Emerald Silt. To avoid the pockmarks for the laying of a pipeline a circuitous route could be selected around the edge of Roseway Basin in an attempt to avoid LaHave Clay seabeds and lay over Emerald Silt. This would have to be surveyed in detail and would result in a longer traverse across the Basin.

The transition from the muddy sediment of Roseway Basin to the inner shelf in the north, based on interpretation of Huntec high resolution seismic reflection data, is as follows. Till and eroded Emerald Silt covered in a thin veneer of Sambro Sand and Sable Island Sand and Gravel dominate the seabed toward the shoreline. Bedrock crops out in a few areas but does not dominate the terrain. Closer to shore a transition to largely bedrock occurs. It appears to be overlain by small bouldery moraines.

It is important to note that on the early published map of surficial geology that the area to the north of Roseway Basin shows the seabed as dominantly sand. This is an anomaly along the entire Scotian Shelf inner shelf, as in other areas, gravel dominates. This suggests that suitable inner shelf transects may be more favourable in the Shelburne region.

13.0 Roseway Basin, South to Northern Browns Bank

13.1 Location

This area of the pipeline corridor covers the seabed extending from the southern part of Roseway Basin to the southwest, west of Baccaro Bank, and joins with the “Cove of Browns” eastern Browns Bank.

13.2 Previous Surficial Geology

The published surficial geology for this area of the western Scotian Shelf is contained in the map and report on the Yarmouth to Browns Bank map area (Fig. 2.5 or ArcView theme “Corridor surficial geology.shp”). Figures 8.2 and 8.3 provide some spot information on the seabed and shallow sub-bottom sediments. Three surficial units dominate the seabed across this area. The first is the very eastern end of the Fundian Moraine where it joins Roseway Bank. The moraine is till of the Scotian Shelf Drift. A large circular shaped body of Emerald Silt is mapped in the middle of the area. This is surrounded by Sambro Sand. A few small outcrops of till protrude through the Sambro Sand to the west and attest to the fact that the Sambro Sand is both a modified Emerald Silt and till.

The large circular deposit of Emerald Silt in southern Roseway Basin east of Baccaro Bank is an unusual large deposit of Emerald Silt and is not covered with LaHave Clay as is typical for most other areas of the Scotian Shelf. This suggests that Emerald Silt may we widespread in the subsurface beneath Sambro Sand. In contrast to areas to the north of the Fundian Moraine where the seabed is dominantly bedrock, the southern area of Roseway Basin is south of the moraine. This likely explains the dominance of Emerald Silt at the seabed. These materials were deposited in front of a grounded glacier. The gravel facies of the Sambro Sand, where samples contain more than 10% gravel, likely indicates that the subsurface is till and where there is less than 10% gravel indicates the subsurface is Emerald Silt. This is a good situation for the selection of a pipeline corridor through southern Roseway Basin.

13.3 Sample Control

Sample control is sparse across this part of the corridor. They are spaced on average every 5 nautical miles north of Browns Bank. Echogram control in this area is also sparse.

13.4 Pipeline route Assessment – This Study

This area of the pipeline corridor has no additional coverage with sidescan sonar or high-resolution seismic reflection data. Some speculation on conditions can be inferred from other regional data. North of the Fundian Moraine the seabed is largely exposed bedrock with minor gravelly moraines. Although mapped as Sambro Sand, the sand in that area likely formed as a result of very strong currents which have winnowed the till and glaciomarine sediments and is not altogether associated with the low sea level stand in early post glacial time. This is a similar situation to the Sambro Sand in the Bay of Fundy. The development of this Sambro Sand is a more recent process change related to the tidal dynamics of the Bay of Fundy.

The pipeline corridor east of Baccaro Bank and south of Roseway Basin is an area south of the Fundian Moraine. The large deposit of Emerald Silt is also south of the Fundian Moraine and indicates that conditions are much different south and north of the Fundian Moraine. The modification of the Emerald Silt circular deposit and deposition of Sambro Sand could be also the result of very strong recent currents and sediment transport. However, without high-resolution seismic reflection information it is difficult to know if the Sambro sand is modified till with boulders or a thin veneer deposit over bedrock.

This is an important area for additional study using multibeam bathymetry, sidescan sonar and high-resolution seismic reflection data. Most of the corridor in this region appears to be Emerald Silt but the closer the approach to Browns Bank it cannot be determined if there is modified bouldery till or exposed bedrock.

14.0 Browns Bank

14.1 Location

The Browns Bank portion of the pipeline corridor crosses the bank in a southwest trending orientation connecting Roseway Basin in the northeast to Northeast Channel in the southwest. This portion of the corridor crosses the northern edge of Browns Bank in an area locally known as the “Cove of Browns”. This is an unofficial term not recognized by the Canadian Hydrographic Service and the Geological Survey of Canada. The corridor is approximately 30 km in width. A later revision broadened the corridor in the southwest area of Browns Bank to include shallower depth areas.

14.2 Previous Surficial Geology

As depicted on the surficial geology map of Drapeau and King, 1972 (Fig. 2.5 or ArcView theme “Corridor surficial geology.shp”), the seabed of most of this segment of the corridor consists of Sable Island Gravel. The southwestern 20% of the bank is presented as dominantly Sable Island Sand. Sample control for this compilation is sparse, with samples located approximately 10 nautical miles apart. Additionally, the echogram control is also sparse. The Sable Island Sand and Gravel formation is described as a clean, buff to greyish brown, medium to coarse-grained, very well-sorted sand, grading laterally to very coarse gravel with boulders. Of particular note in that study was a recognition that the proportion of gravel increases westerly in the Halifax to Yarmouth study area. Most of adjacent LaHave and Baccaro Banks are gravel covered and Browns Bank was estimated to have a 50/50 split of sand and gravel. They also noted that sand distribution was favoured to shallower areas of the bank and that the sand was in active transport in small and large bedforms in the shallow areas.

14.3 Multibeam Bathymetry

The most recent assessment of the surficial geology of Browns Bank contained in this report is based on multibeam bathymetry collected by the Canadian Hydrographic service in 1996 and 1997 using the Frederick G. Creed with a Simrad EM 1000 multibeam bathymetric system (Fig. 14.1). The system has 60 beams and line spacing was 3 – 4 times water depth for outer beam overlap. In addition to the multibeam bathymetry, the data were processed for backscatter strength to use as a proxy for sediment grain size. The backscatter shows geological materials not apparent in the multibeam bathymetric image. Based solely on multibeam bathymetry, for example, areas of sand can only be differentiated from gravel based on the presence of sand bedforms (megaripples and sandwaves) which present a distinctive pattern on the morphology, or where sand occurs in flat areas such as sand sheets.

The multibeam data from Browns Bank was specifically groundtruthed during a subsequent survey in 1998 from the CCGS Hudson using Huntec DTS, airgun seismic reflection systems, sidescan sonars, bottom samples and photographs. Based on the correlation of the sidescan information and the bottom sample and video analysis with the multibeam bathymetry and backscatter information, a geological map of the seabed was interpreted. This identified sediment texture at the seabed, built in a component of thickness of surficial sands and assessed areas of dynamic bedforms at the seabed (Fig. 14.2 and ArcView themes “Browns morphodynamic interp”, “Browns morphodynamic lables” and “Browns linear features”).

In the corridor crossing Browns Bank, approximately 30 bottom camera and 10 large bottom grab stations were occupied for groundtruth. The stations were chosen to assist in the interpretation of the multibeam data and the geophysical data to sample both regional terrains and site-specific features of uniqueness. Additional bottom photographs collected by DFO in 1984 and 85 were utilized in the interpretation.

It is important to note that the multibeam imagery off southwest Nova Scotia covers a large area of the pipeline corridor. However, a gap exists between south central Browns Bank and the middle Northeast Channel multibeam data set. Additionally, the inner Northeast Channel/Georges Basin multibeam does not cover all of Georges Basin. It is mainly confined to southeastern Georges Basin. We must rely on previous surficial geological mapping and assessments in this study for understanding of these non-multibeamed areas.

14.4 Multibeam Morphological Interpretation

The interpretation of the morphology and seabed features from the multibeam data on Browns Bank has been undertaken for this study and shows a variety of terrains and geological attributes. These characteristics have been grouped into specific zones and are presented in Figs 14.3 through 14.9 . Figure 14.9 (also Enclosure 7) provides a number of multibeam-generated profiles across the bank and features of interest. Their locations are in the ArcView project, theme "elpaso3_figs.apr in folder "figure&profile location". The features have resulted from a complex history of glacial ice advance and retreat, a lowered sea level and subsequent marine transgression. A few areas exhibit dynamic sand bedforms but most of the area presents a hard bouldery gravel surface. Many prominent boulder ridges occur across the area and are several metres in height.

A criss-crossing pattern of overlapping ridges up to 2 m in height occurs in the central portion of the Browns Bank corridor (Fig. 14.3). These are unusual features not seen before on multibeam data off eastern Canada. Profiles "Browns Bank, center traverse" and "Browns Bank, eastern traverse" in Fig. 14.9 (and Enclosure 7) provide the multibeam-generated bathymetric profile across this area. We interpret these features to be ancient eskers formed directly under glaciers or some form of moraine developed beneath grounded glaciers (perhaps through squeezing into basal ice crevasses). We have observed a few paired berms in the same area suggesting the presence of iceberg furrows, but the majority of the features are singular ridges. They occur in water depths of between 91 and 98 metres. The seismic reflection data suggests that the material they are composed of is glaciomarine Emerald Silt, not till, as is the common case regarding linear ridges. They also may have formed as features squeezed into the bottom of ice sheets that occupied this area. What is unusual is their preservation on the bank in depths that would have been subjected to wave erosion during times of lowered sea level. Features such as these were thought to be eroded by such high energy conditions, but their preservation suggests: 1) less high energy, 2) that sea level was not as low as previously thought, or 3) that they were formed at a later time when sea level was higher. Samples indicate that the seabed is dominantly a gravel bottom and is interpreted as a lag sediment. Pipeline trenching should not be a problem across this zone if the material is Emerald Silt. It does, however contain many large boulders and some of these boulders are scattered across the seabed. The largest of the boulders as interpreted from sidescan sonograms are 2 m in diameter.

A very prominent ridge (Fig. 14.4) trends from northwest to southeast across the study area on the Bank and is over 40 km in length. Profile "Browns Bank, center traverse" (Fig. 14.9 (and Enclosure 7), labled "lateral moraine) provides a bathymetric profile generated from the multibeam data across this feature. Multibeam bathymetry accentuates relief and this feature is actually only a few metres in height and several hundred across, but it demarcates two major terrains of the region. To the southwest the terrain is a hummocky seabed with ridges. This is interpreted as glacial till with a gravel lag surface with boulders, deposited and perhaps overconsolidated beneath the sole of an ice stream that occupied all of Northeast Channel and spilled over on Browns Bank. The moraine is interpreted as a lateral moraine deposited along the northeast flank of the ice stream and the seabed to the north is flatter and smoother with deposition of sandier sediment, possibly as glacial outwash. Sand bedforms occur on this surface. An interpretation of the seismic reflection profiles of this area shows that the seabed is dominantly a gravel lag surface developed over glacial till.

In the northwest area of the long linear ridge is a small curvilinear feature on the south side, up to 5 m in height with a distinct crest line (Fig. 14.5). The seabed is gravely. The small ridge is normal to the linear moraine and joins it with a narrow breach in the moraine and a deposit of sediment on the north side which is interpreted as a small delta. This feature is very similar to eskers on land and we interpret this to be the same. Its character and intimate relationship with the long linear moraine add support for interpretation of the long feature as a moraine. The esker formed at the northeast margin of a ice stream and deposited sediment beneath the ice in a discharge tunnel and at the floating or subaerial margin of the moraine. A few other linear eskers occur along the south edge of the moraine.

Both northwestern and southern edges and flanks of Browns Bank consist of bodies of sediment with a progradational structure. These sediments are likely sands and gravels that spilled over the bank during periods of lowered sea-level and were also transported along the bank edges by strong longshore contour following currents. Similar processes may be operating today. An area on the north edge of Browns Bank displayed the highest values for backscatter in the entire region within a similar progradational sequence. Samples were very well rounded gravel clasts in the cobble range in that area. The clinoform reflections likely represent well sorted sand and gravel sediments. On the southern edge of Browns bank there are several generations of bodies of sediment with clinoform reflections separated by a broad regional unconformity. These were likely formed at times of lowered sea level. Often such bank edge deposits represent slight mounds at the bank edge suggesting that in addition to progradation of the bank edge during development, they built upwards.

At the southern edge of Browns Bank in the western part of the pipeline corridor the sidescan imagery shows the presence of comet marks. These are erosional and depositional scours around boulders and attest to periodic strong currents in the area. The orientation of the comet marks indicates that the currents are dominantly westerly running along the bank flank and edge. Inferred transport directions are suggested and shown in the ArcView theme “Browns transport direction”. The slope of the Browns Bank/Northeast Channel flank varies considerably in this area of the corridor. The steepest flanks are on the southeast area of Browns Bank and may not be suitable as a pipeline route (Fig. 14.6 and Fig. 14.9, profile “Browns Bank, western traverse”).

14.5 Seabed Samples

Seabed samples were collected on Browns Bank with the large IKU grab sampler which can obtain samples are large as 0.75 m^3 when full. The sampler obtained samples in very coarse bouldery sediment, including subsurface fine-grained matrix that could not be sampled with smaller, more conventional samplers. The IKU sampler collected large volume samples in the sandy sediments. Where a varying stratigraphy was observed in the large samples, subsamples were also collected. In many of the gravel samples, a lag occurred at the seabed. Growth on the clasts indicates that the lag is not an artifact of surface washing during sample retrieval.

An IKU sample was collected at the northern side of Browns Bank in 70 m water depth over the deltaic unit of clinoform reflections. This feature likely represents a former low sea level stand. The clasts were very well-rounded and a large number of bivalves were found within the sediment. Some of the shells were hinged pairs suggesting little transport before burial.

An IKU sample collected from the eastern area of the bank contained approximately 20 unusual concretions, 10 to 15 cm in diameter. They consisted of calcareous nodular deposition surrounding well-rounded pebble clasts. Small bivalves have either burrowed into, or occupied cavities in, the calcareous coating which is up to several centimetres in thickness. The nodules resemble calcrete masses found at the base of pockmarks suspected to form as a result of chemosynthetic bacterial deposition resulting from the venting of subsurface hydrocarbons.

Samples collected in an area of clinoforms at 90 m water depth in the southeastern area of Browns Bank consisted of very well-rounded clasts in a coarse sand-granule matrix. The majority of the gravel clasts from the bank consist of granitic, metasedimentary and volcanic clasts. Only one sample collected in the northeast of the bank showed positive evidence of glacial transport. It consisted of striated and faceted bullet-shaped clasts that were generally angular in shape.

14.6 Geological History

The multibeam image on Browns Bank displays a variety of terrains as well as features that resemble glacial features on land. These include linear moraines (Fig. 14.4), fluted terrain (Fig. 14.7) and rough hummocky ground moraine (Profile “Browns Bank, center traverse”, Fig. 14.9 (and Enclosure 7), labled “hummocky relict sub-glacial terraine”. It also shows transgressive and modern features of sediment transport such as sand waves, megaripples(Fig. 14.8), barchan-like dunes, shelf-edge deltas, long-shore transport deposits, and transport directional indicators. Some of the terrains are separated by low-relief linear features.

A preliminary interpretation indicates that the eastern area of Browns Bank is underlain by a series of thin multiple tills, approximately 10 m or less in thickness. They are separated by thin layers of eroded and discontinuous glacial marine sediment. The extent of till deposition (glacier extent) to the shelf edge was not determined. However, seismic profiles allow identification of a series of stacked moraines (Fig. 14.10) on the southern flank (into Northeast Channel) Browns Bank., These glaciogenic sediments indicate that it was completely covered by glaciers during the Wisconsinan, the last major glaciation in Atlantic Canada.

To the east of the corridor area, a series of overlapping flutes (Fig. 14.7) likely represents ice-formed scours by the last glaciers present on the bank. The flutes are flanked by bouldery ridges and formed by local surging ice tongues at times of minor advance during an overall regional retreat. The conspicuous ridge (Figs. 14.4 and 14.5), extending from the northern area of west Browns Bank to the southeast, is composed of till. It is not very pronounced on the Huntec DTS data only rising a few metres above the surrounding till seabed. Multiple tills in the immediate subsurface of the feature show no offset ascribable to faulting, suggesting that the feature represents a moraine formed by a large ice tongue in Northeast Channel that spilled over on Browns Bank. The moraine curves off the bank in the south suggesting that it may continue across Northeast Channel. A consistent terrain to the southwest of this ridge is a hummocky surface on till with many large boulders.

A small basin in the centre of eastern Browns Bank consists of well-defined crossing ridges (Fig. 14.3). Data collected during this cruise confirm the existence of a mixture of two features: relict iceberg furrows and eskers up to 5 m in height. The relict iceberg furrows are very degraded.

The sea level history of Browns Bank must await processing of samples for grain shape and dating of shells. The sea level history is very important as it exerts a major control on the texture of sediments at the seabed. Areas of transgression usually consist of well sorted sediments and lag gravels. A delta on the north of the bank, west of the study area, is clearly a low stand feature at 70 m water depth.

However, clinoforms occur in 90 m water depth on the southern edge of the bank with well-rounded clasts, suggesting that sea level may have been at or below this level. Several bodies of clinoform reflections occur on the bank edge, each indicating a low sea level position for extended periods of time. The presence of iceberg furrows and delicate esker–like features that could not have survived a marine transgression provide evidence for a lower limit for the post glacial low sea level stand. It is possible that some of these features may have formed beneath thin, partially floating ice, with sea level at a higher level without the development of beach features. Clearly the timing of ice retreat and its relationship to the low stand is critical to such an understanding.

14.7 Pipeline route Assessment – This Study

In summary, eastern Browns Bank is a glacial surface, modified as a result of close proximity to a former low sea level stand. It is dominantly a hard seabed of sandy gravel with many boulders overlying till and glaciomarine sediments. In some areas bedforms (sand waves and megaripples) occur on the surface. We interpret that the sand bedforms are in active transport, especially in shallow water of this region. Inferred transport directions are suggested. Some sand wave features may be relict in deeper water. The morphology and roughness of the seabed on the multibeam bathymetry can be separated into several terrains. The terrains and their superimposed features (ridges, mounds and depressions) are very subtle on the conventional seismic and sidescan data and in most cases would not be easily identified on this basis alone. Strong current conditions exist on the Browns Bank southwestern flank and edge. On the southeaster edge the seabed is very steep. Boulders are widespread across the seabed over much of the Bank.

15.0 Northeast Channel

15.1 Location

Northeast Channel is a shelf crossing channel that joins Georges Basin in the northwest with the continental slope between Browns and Georges Banks. It is a deep glacially eroded pre-existing fluvial channel. The currents are very strong and tidally driven from the Fundy system (Fig. 15.1).

15.2 Previous Surficial Geology

The previous surficial geology of the Northeast Channel indicates that most of the seabed is glacial till (Scotian Shelf Drift) covered in a veneer of Sambro Sand. Recent observations in the outer area of Northeast Channel show a seabed of iceberg pits and furrows imprinted on till. The till is thick and three generations are evident (Fig 15.2). Boulders are common and range up to several metres in diameter. Several areas display thin sand ribbons in transport. Currents are very strong at the seabed. Deep-water cold coral is common attached to boulders. The limit for most of the coral occurrences is depths greater that 300m. In inner Northeast Channel a transition to Emerald Silt occurs and it appears that it is also overlain by Sambro Sand. Moving to the west the Sambro Sand is not evident and the seabed is till and Emerald Silt. This is likely a function of strong currents and modern sediment transport. Thus the Sambro Sand in Northeast Channel is not related to the low sea level stand in post-glacial time but to modern processes. This is similar to the situation in the Bay of Fundy and is controlled by tidal circulation.

15.3 Multibeam Bathymetry

Multibeam bathymetry has been collected in Northeast Channel and its extension to the northwest in Georges Basin in 3 broad areas referred to here as the mouth of Northeast Channel, Middle Northeast Channel and inner Northeast Channel/Georges Basin. The multibeam data does not cover all of Northeast Channel nor does it extend fully across the entire channel in the middle and inner areas. Of relevance to this study are the middle and inner images, as the mouth area is planned to be declared a limited activity area by Fisheries and Oceans Canada in order to protect species of deep water cold coral and it is likely that pipeline transects will not be permitted. The multibeam data has provided additional information to the previous surficial geology assessments and complements this information. Perhaps the most significant aspects are the 100% coverage, ability to accurately connect features and attributes from widely spaced survey lines of sidescan sonar and seismic reflection data, the portrayal of subtle aspects of relief, i.e. several sills, and an ability to map and assess dynamic sediment transport features.

15.4 Middle Northeast Channel Multibeam Bathymetry

The middle Northeast Channel multibeam bathymetric image covers an area extending from 42 degrees 25 ‘ in the north to 42 degrees in the south and extends from 65 degrees 40’ west to 66 degrees 10’ west. The seabed of this region has been interpreted from the multibeam data (Fig 15.3 , Enclosure 8, and ArcView theme “NEC Morophodynamic interp”). Two large regions of sand bedforms occur at the seabed. The zone designated “*Large sand bedforms, showing crest orientation, Sambro Sand*” is an area of large sandwaves up to 8 m in height and with a wavelength of over 50 m. Profiles “NEC mid 1” and Profiles “NEC mid 3” on Figure 15.4 (Enclosure 14) show multibeam generated profiles. This sand wave field occurs in a gentle depression at the seabed and almost extends across the entire Northeast Channel. It shows their slight assymetry suggesting some migration towards the basin. To the southeast, the zone is adjoined to a smaller region defined as “*Mixed bedforms, (2a) short length* *crested bedforms, (2b) linguoidal sand bedforms, Sambro Sand*". The water depth shallows slightly in the zone to the southeast and the bedforms are linguiodal and appear as degraded sand waves. The crests of all the sandwaves are oriented normal to the axis of the Northeast Channel indicating formation from strong currents, likely tidally driven. On the flanks of both Georges and Browns Banks are linear zones of smaller sand bedforms, likely large megaripples, designated "*Small sand bedforms, channel flanks, short wavelength linear patches, Sambro Sand*". They extend in linear fields for distances of over 10 km.

Figure 15.5 shows two seabed photographs of the Sambo Sand in Northeast Channel.

Toward the southeast of the centrally located bedforms, the seabed is an iceberg pitted and furrowed glacial till bottom. This is similar to the seabed that continues further to the southeast toward the mouth of Northeast Channel. This seabed can be further subdivided into a southwestern area of predominantly linear iceberg furrows and to the northeast into a zone of predominantly isolated iceberg pits. Observations from other similar areas on the Scotian Shelf and the Grand Banks of Newfoundland suggest that where iceberg pits are the dominant iceberg formed feature, this results from a harder seabed of more compact or bouldery till or the presence of bedrock in the subsurface closer to the seabed. Other factors such as winds and currents can also affect this relative distribution. Iceberg pits and furrows that form in till usually consist of linear and circular berms along the flanks of the features. The floor of the pits and furrows is often flat covered in cobbles with an occasional ice rafted large boulder. Slopes can be steep on the furrow and pit flanks and sand and mud can sometimes accumulate in the troughs. This is not the case in Northeast Channel where the currents are very strong and little fine-grained muddy sediment is found on the seabed. Figure 15.4 (Enclosure 14), profile entitled "NEC mid 4" shows multibeam-generated bathymetric profiles whereby the selected traverse intersected several pits. Note the considerable relief; nearly 10 m.

An important point to note here is that the seabeds of iceberg furrows and pits do not suggest that currents are not strong and that sediment is not in transport. This area is in contrast to the adjacent area of sand waves to the northwest. A natural interpretation is to suggest that the areas of sand waves have stronger currents. It is more likely that the currents are lower in the large depression area of sand waves than the till sill areas where sand is in active transport in a higher current regime and only shows on sidescan sonar data as thin sand ribbons actively moving across the seabed.

The middle multibeam image also covers part of southwest Browns Bank and shows areas of varying slope from the bank to the Northeast Channel. The northwestern slope is more gentle in contrast to the southeastern flank which presents a linear and uniform scarp from the bank to the Channel floor. Near the edge of Browns Bank on the northeastern part of the image, is a large linear depression. Its origin in not understood at this time. It could represent a relict, buried, partially infilled subglacial channel or it could be a modern feature similar to a sedimentary furrow. The former interpretation is preferred. On the northeastern part of the image on Browns Bank is an area of east-east trending linear ridges. These are interpreted as linear boulder ridges and could represent moraines or former beach ridges.

A few isolated linear features occur on the multibeam image that could be shipwrecks or processing errors and cannot be assessed at this time. In the field of iceberg pits is a large unusual-shaped depression that appears as a collection of superimposed iceberg pits. It is noted here because of its unusual composite shape and large area coverage.

15.5 Inner Northeast Channel Multibeam Bathymetry

The multibeam bathymetric image from the inner area of Northeast Channel/Georges Basin extends from 66 degrees 10’ w to 66 degrees 57’ west and from 42 degrees 25’ north to 42 degrees 10’ north. The southern part of the image extends down the north slope of Georges Bank into Georges Basin. The image does not cover all of Georges Basin, particularly the northern half and flank extending toward Sewell Ridge.

In a cursory examination of the multibeam image the seabed appears uniform, covered in iceberg furrows with little variation. However, a detailed assessment shows that the seabed is very complex with a variety of iceberg furrow provinces, a field of sand bedforms and some areas entirely devoid of iceberg furrows likely resulting from burial by more recent sand sediment transport or deposition of LaHave Clay.

Most of the seabed in this region is covered with iceberg furrows. They are long and linear, subparallel, and tend to follow the contours. They trend more or less east-west on the inner and southern part of the area and swing to the southeast in the eastern part. The iceberg furrows in deeper water tend to be wider than those in shallower water and those in shallower water tend to be more densely distributed. Figure 15.4 (Enclosure 14) profile entitled “NEC in 1” shows the magnitude of scours in the Emerald Silt. Profile entitled “NEC in 3” shows an area of “featureless seabed” where only small perturbations of the seabed occur (possibly mainly multibeam “noise”). Some of the variation as portrayed on the multibeam data may result from artifacts of deeper water multibeam bathymetric data collection. Iceberg pits are rare in this area but a grouping occurs on the southeasternmost area of the image where Northeast Channel curves around the northeastern flank of Georges Bank.

There are several areas where the iceberg furrows are not evident on the multibeam imagery. The furrows appear to be buried in these areas. They occur in the deeper water to the northwest, in an area of the central western part of the image and along the flank of Georges Basin. In several areas the zone of no furrows projects into Georges Basin from the flank of the Bank and may have resulted from sand transport off the Bank.

In the central part of the image is a unique zone of parallel linear short-segmented morphologic features. They trend northeast – southwest and are interpreted as a field of sand bedforms. They are located on the upslope of a sill separating Georges Basin from Northeast Channel. The sill (shallower area) is covered with the southeast trending iceberg furrows.

From an interpretation of the multibeam data it appears that bottom currents become progressively stronger from west to east in Georges Basin and Northeast Channel. This has affected the deposition and transport of sandy sediments overlying both Emerald Silt and till (Scotian Shelf Drift).

16.0 Georges Basin

Georges Basin is an elliptical, east-west trending feature with a maximum depth of 377 m. Its bottom is generally smooth and featureless except for a local high near the centre created by a bedrock protrusion. The bedrock is varied, including hard and undulating, mainly Paleozoic rocks in the north flanked by younger bedrock and less consolidated strata in the south and underlying Georges Bank (Fig. 16.1). The main paleo-drainage system lay to the north through the Bay of Fundy and northern Gulf of Maine, through Georges Basin and Northeast Channel, linking this system to the continental slope. This drainage system carved out the now drowned cuestas which are Georges and Browns Banks during at least two periods of emergence in Cretaceous and Tertiary time. Multiple glaciations overdeepened Georges Basin and smaller depressions such as Crowell Basin, deepened, widened and smoothed out Northeast Channel and deposited the Fundian, Browns, and Northeast Channel tills and moraine systems. During late glacial and post-glacial periods Georges Basin acted as a sediment trap for fine-grained sediments. Figure 16.2 shows total Quaternary sediment thickness. The banks experienced transgression and high energy levels, leaving the surficial sand and gravel sheet.

16.1 Surficial Geology

Georges Basin has no multibeam coverage so the present compilation is derived largely from various existing sources, tailored in this presentation to factors relevant to pipeline routing. The surficial geology map presented (Fig.2.5, Enclosure 4, and ArcView theme "Corridorsg_apr15") was derived largely from the Geonautics study (Fader, 1984) in this area, modified to be compatible with the Gulf of Maine Marine Sciences series to the north. A further map was compiled (Fig. 16.3, Enclosure 9, and ArcView theme "Gb_geol_ll." and accompanying linework, "Gb_contour_ll") for this study (Georges Basin and Georges Bank corridor area) including thickness information of all but the Scotian Shelf Drift (till) as well as iceberg pit and furrow distribution. Accompanying geologic sections (Fig. 16.4, Enclosure 12) depicts the geometry, surface and subsurface sediments and features across the basin and along the northern Georges Bank flank.

Grab sample and upper core sediment sample grainsize analyses for Georges Bank and Basin are presented in ArcView theme "Georges_samples_clipped"). This supplements missing sample stations in the ArcView theme "Gsca_stations-clipped" which covers most of the remainder of the ElPaso corridor. Figure 16.5 shows grainsize curves for representative samples in the Georges Basin and Bank areas. These are organized according to the stratigraphic map units. Figure 16.6 presents the same samples in a ternary diagram. The following surficial geology description includes factors and features specific to the area including further grainsize descriptions.

Figure 16.7 shows spot information on surficial and sub-bottom sediment types across Georges Basin. The Scotian Shelf Drift (mainly till) is present as a blanket deposit overlying bedrock over most of the basin and north to Sewell Ridge but it is rarely exposed at the seabed. However, thick accumulations occur on the northern and western flanks of Georges Basin (40-140 m thick), on the southern flank of Browns Bank (40-100 m thick) and along Northeast Channel (20-120 m thick). This is best shown in the Figure 16.4 profiles, also Enclosure 12). Those accumulations associated with the north and west flanks of Georges Basin and underlying Sewell Ridge are part of the Fundian Moraine and the thick deposit on the northern flank of Northeast Channel is called Browns Moraine (Figs. 15.1). Both moraines have associated, till tongues (Figs. 16.8 and 16.9) which probably have lesser soil strength than the moraine tops owing to their interpreted debris flow nature (King, 1993) but they are largely buried beneath glacimarine muds.

King (1970) described the till as “a cohesive, poorly sorted sediment generally containing angular fragments in the pebble, cobble and boulder range. It is dominantly sandy but everywhere contains abundant silt and clay". To date, no cores have been taken from this formation within the study area so descriptions are based on grab samples and photographs. Fader, et al (1977) describe component grains from till samples collected within the study area. Fragments within these samples are angular to subangular, often with percussion marks, irregular conchoidal fractures and striations on some of the larger clasts. Sand grains within the till are iron stained, indicating probable derivation from Triassic sandstones in the Bay of Fundy area. It is important to note that much of the till at the seabed has undergone modification by ice scouring and currents. Both processes result in winnowing of the till surface removing the fine (silt and clay) component. As a result, grab samples of indicate a mixture of sand and gravel with a range in median diameter of 2.97 to -3.92 phi. A seabed photograph of Scotian Shelf Drift is shown in Fig 16.10.

Emerald Silt generally overlies and in part interbeds with the till. It is a rhythmically laminated blanket deposit deposited pro-glacially from suspension through the water column (Fig. 16.11). In core samples from the stratigraphically lower part of the section (Facies A), gravel content averages 3%, which is significantly higher than that found in the type area further east. Clast diameters range from 0.1 to 2.0 cm and appear to be uniformly dispersed. In addition to the gravel component, grainsize analysis indicates an average composition of 10% sand, 409 silt and 47% clay, with a slight coarsening upward in the section. Figure 16.5 shows grainsize curves. Grab samples of the stratigraphically upper Emerald Silt, (Facies B) in the study area are composed of gravelly sand with minor silt and clay. A wide range in gravel to sand ratios is evident with gravel content ranging from 0-64% and sand from 33-96%. Mud content increases from east to west across Georges Basin to a maximum of 14%. The absence of mud at the surface across the eastern part of the basin is believed to be due to post-depositional winnowing. A seabed photograph taken over Emerald Silt, (Facies B) is shown in Fig.16.12.

Sambro Sand occurs adjacent to Browns and Georges Banks, most commonly overlying the till over much of the bottom of Northeast Channel and along the margins of Browns and Georges Bank (Fig. 16.3 and Enclosure 9 and ArcView theme “Gb_geol_ll.”). It is referred to only as “surficial” sand in this figure and not distinguished from the bank sands. It is thickest just below the bank edges, sometimes with internal, progradational stratification, up to 10m thick (Fig. 16.4, profiles 3 and 7, 6 and 8). In deeper parts of Georges Basin and over most of the Northeast Channel, Sambro Sand represents a thin deposit generally not more than l m thick (light yellow “thin surficial sand” in Fig. 16.3 and Enclosure 9 and ArcView theme “Gb_geol_ll.”). Where worked into bedforms in narrow but continuous fields on both north and south flanks of NE Channel and southern Georges Basin it is typically several m thick, over 5 m locally. It thins to only partially infill the undulating till surface in a basinward direction in both these areas, affording possibly the optimum pipeline routing (as discussed below).

A unique stratigraphic situation exists in the northeastern part of Georges Basin where a thin surficial cover of Sambro Sand overlies LaHave Clay (orange, SW-extending tongue in Fig. 16.3, Enclosure 9 and ArcView theme “Gb_geol_ll.”). The 2 m isopach contours of underlying LaHave Clay and Emerald Silt pass through this region. This might reflect a rejuvenation of strong currents associated with the late Holocene enhanced tidal range development in the Bay of Fundy, This presents the unusual situation whereby a relatively competent sediment (sand) overlies thick soft clays; this might be a pipeline foundation issue where the sand is thin.

Grab samples of Sambro Sand within the study area are an olive green, poorly sorted sand, with some gravel and a small component of silt. This silt component is fundamental in distinguishing between this formation and Sable Island Sand and Gravel in the type area (King, 1970) but here this criterion is less reliable. Gravel content in Sambro Sand can be high, especially where this unit is developed as a lag on Scotian Shelf Drift. Figure 16.5 shows grainsize curves.

LaHave Clay occurs in the northwest part of Georges Basin, in Crowell Basin and in other small depressions on the surface of the Fundian Moraine. Thicknesses in the area range up to a maximum of 16m in the north-central part of Georges Basin. The LaHave Clay depocentre lies north of the deepest part of the Basin, possibly due to the slightly stronger currents which might have prevented deposition along the northern flank of Georges Bank. The two metre LaHave Clay thickness contour (isopach) is shown for much of Georges Basin (Fig. 16.3, Enclosure 9 and ArcView theme “Gb_contour_ll”). Lack of sufficient seismic control precludes extending these contours to the westernmost part of the Basin.

Cores from LaHave Clay within the study area (King and Fader, 1985) indicate a wispy-laminated, sandy silt. The average textural composition of core subsamples is 1% gravel, 27% sand, 55% silt and 17% clay. Woody, organic fragments are often present. Grab samples indicate a clayey silt with a trace of sand, becoming sandier near the edges of the deposit. The average median diameter of the grab samples is 0.003-0.06mm. Figure 16.5 shows grainsize curves from grab samples and Figure 16.13 shows a seabed photograph.

16.2 Sediment mobility

The flanks of Georges and Browns Banks and Northeast channel experience strong oceanographic circulation that influences past and present sediment distribution and processes. A brief overview of the oceanography of Georges Basin, Browns and Georges Banks region follows.

The most energetic currents are the oscillatory semidiurnal tidal currents associated with the ebb and flood of water into the Bay of Fundy - Gulf of Maine tidal system. The amplitude of the dominant M2 tidal current (period 12.42 hour) is generally larger in the region's shallower water (Fig. 16.14). This component swings in a clockwise sense through an ellipse whose major axis lies in a general northwestward - southeastward direction, resulting in periodic reversals of the flow. Individual water parcels undergo elliptical horizontal excursions. The background residual currents (Fig. 16.14 are primarily parallel to bathymetric contours, in a clockwise sense around Browns and Georges Bank with inflow to the Gulf of Maine on the northeastern side of Northeast Channel and outflow on the southwestern side. These currents are strongest over the sides of the Banks and sediment movement is evident. Sediment movement in the region is also influenced by shoaling surface gravity generated during storms and internal gravity generated over steeply-sloping bottom topography. Surface-wave-induced bottom currents are most significant in depths shallower than 100 m during the winter season, while internal-wave-induced bottom currents are most frequent in the vicinity of the shelf-break in summer.

In summary, the most energetic bottom currents (contributing to sediment suspension) in the region are the oscillatory tidal currents reinforced intermittently by wind- and wave-induced currents, while the large-scale horizontal movement of sediment is dependent on the weaker background residual currents which vary seasonally and on the time scale of storms and Gulf Stream eddy intrusions.

The sections concerning Northeast Channel and Browns Bank already addressed the presence of bedforms and sediment mobility. The narrow band with sediment mobility, as indicated by bedforms presence on multibeam coverage along the southern Browns Bank flank, continues westward towards Georges Basin. The surficial sediment thickness map (Fig. 16.3, Enclosure 9, and ArcView theme “Gb_geol_ll” shows a narrow band of dark yellow here, labeled “Surficial sand, 1 to 5m thick, highly variable". The thickness variability is mainly a function of the presence of sandwaves and megaripples in this zone. Net transport is in a westerly direction.

16.3 Pipeline route Assessment – This Study

This part of Georges Basin was included in the study to provide information on a route if the Georges Bank drilling moratorium cannot be entered. A route in NE Channel, SE of Browns Bank has two broad areas of till. The till outcrops here provide a stable foundation for a pipeline. However, the rough surficial topography from iceberg furrows and pits and the concentration of gravel may prove difficult conditions. Very little sidescan data is available, due to the deep water depths. Thus, little information is available on boulder presence or concentrations. A suitable pipeline corridor should minimize traverses across the till for this reason. The rough topography of the till is locally partially infilled of the Sambro Sand, mitigating these concerns. This occurs in narrow but thin surficial sand deposits on the flanks of the protruding till outcrops. The zone of high sediment mobility on the southern Browns Bank is best avoided where possible (must be crossed at some point).

East of this, as noted above, there is an unusual situation whereby sand varying in thickness from 0 m to (possibly) 5 m thick, overlies thick, soft clays in Georges Basin. This is in an area which would be traversed by a pipeline route skirting the northern limit of the drilling moratorium zone; it might present a pipeline foundation issue where the sand is thin.

In the central to western Georges Basin area, a pipeline route would remain on the northern flank of the Basin, due to water depth constraints. It would be prudent, if possible, to avoid the rough, presumably bouldery, Fundian Moraine and the Sewell Ridge. Relatively planar and much less gravelly/bouldery conditions are afforded by the outcropping band of Emerald Silt flanking the southern side of the moraine. It extends to the westernmost basin. If the soft clay is a preferable lay-medium (it would not contain gravel) this also presents a continuous outcropping to the westernmost basin.

17.0 Sewell Ridge

Sewell Ridge is a large east-west trending morphological feature at the north flank of Georges Basin, Gulf of Maine. It is depicted and mapped on the surficial map and report of Fader et al, 1977 (Fig.2.5, Enclosure 3). Sewell Ridge is composed of the Fundian Moraine, an ice shelf grounded moraine formed approximately 20, 000 years ago. This moraine continues to extend to the east forming the prominent boulder ridge on the north side of Browns Bank and continuing into Roseway Basin south, where it terminates against Roseway Bank. It is composed of till and is covered with many generations of criss crossing iceberg furrows up to 10 m in depth. Boulders are strewn across the till surface. Depressions on the moraine surface are local basins of Emerald Silt deposition. To the south of Sewell Ridge, the moraine is interbedded and lapped by the Emerald Silt. Further to the south the LaHave Clay overlies the Emerald Silt. Figure 17.1 shows spot information on the surficial and sub-bottom sediments and features across the northern Gulf of Maine.

This is the area where a pipeline corridor will trend east-west and head across the Gulf of Maine. Sewell Ridge itself, where the till outcrops, is too rough and irregular a surface for a pipeline route. A preferred route is on the southern flank of Sewell Ridge, parallel to the front of the moraine, but in Emerald Silt or LaHave Clay. The Emerald Silt has a few iceberg furrows developed on its surface and boulders could be scattered across its surface in places.

18.0 Crowell Basin

The surficial geology of Crowell Basin is mapped and described in Fader et al., 1977. Crowell Basin is a depression between the ridges of Sewell Ridge and Truxton Swell. Both of these ridges are regional ice shelf recessional moraines that trend east-west in the eastern Gulf of Maine.

Within Crowell Basin the seabed is dominated by LaHave Clay. Samples indicated that the LaHave Clay is coarser with a sand component. It overlies Emerald Silt which is the remaining sediment exposed at the seabed of Crowell Basin. Till outcrops in a few areas in the eastern part of the basin and in isolated areas of the deeper part. The seismic control for mapping the distribution of sediments in Crowell Basin is limited, therefore the distribution could be different and more complex than indicated on the map. The sediment boundaries are coded as approximate. Figure 18.1 shows spot information on the surficial and sub-bottom sediments and features across the northern Gulf of Maine.

Suitable pipelines routes could easily be located in Crowell Basin, but to get into the basin from the southeast, large moraines would have to be crossed.

19.0 Northern and NE Georges Bank

19.1 Data coverage

The corridor along the northern edge of Georges Bank follows approximately along the shelf- in slope break (ca. 100 m) and to over 200 m depth. Numerous high and medium resolution sub-bottom profiler data area available here (Fig. 2.6, Enclosure 4). Multibeam coverage (25m resolution) extends along the shallower areas of this corridor from the bank down to about 200 m water depth. It covers only the Canadian jurisdictional waters. Sidescan coverage is variable in quality due to operational restrictions from the steep slope and the great water depths. Samples are sparse. Figure 19.1 (Enclosure 10) provides an overview of the morphodynamic map, derived from the multibeam and geophysics data.

19.2 Geomorphological description

Sand dominates to a certain water depth below the shelf break and is commonly worked into bedforms. Gravel is dominant deeper than this and on the top of the bank. The seabed is largely smooth with the exception of broad zones of relatively high relief.

The seabed slope is steepest just north of the shelf-break as shown on profile “Georges west 2” on Enclosure 14, and all geologic profiles on Enclosure 12. This is largely due to glacial erosion from SE flowing ice but it is accentuated by post-glacial transport of sand from the bank, locally exhibiting north-prograding beds. About mid-way down the slope a series of very prominent and continuous troughs and associated ridges are perched along this steep slope. These are interpreted as mega-scale current scour features and described below. In the deeper parts of the corridor, below the shelf break in about 200 m water depth, the features and morphology are dominated by exposed till with iceberg scours and less commonly pits. Shallower than this the till becomes covered with a thin sand or sand with trace of silt (Sambro Sand Fm.) (geologic profiles on Enclosure 12). Thickness varies considerably, largely as a function of sandwave presence, reflecting the dynamic currents along this edge. Samples are generally sand with a lesser gravel component.

Long, linear current scour features are perched midway and near the base of northern Browns Bank flank. Figure 19.1, Enclosure 10, and ArcView theme “GBank Current furrows” show the traces of crests and major troughs. The most prominent of these expresses several metres relief (locally 10 m), is about 300 to 400 m wide, and continuous for over 55 km. Profile “Georges west 2” of Enclosure 14 shows a multibeam generated transect across the mega-furrow. Sub-bottom profiler records indicate it is largely erosive in nature (unconformity in Fig. 19.2). Locally, megaripples are perched on the berm. Multibeam backscatter is very high in the trough, indicating gravel. This gravel is locally very thin (0.5 m), and apparently developed as a winnowed lag over sands and locally probably stratified muds. Another very continuous (39 km) but smaller feature near the base of the slope possess low berms on either side, is typically only 100 m across (berm to berm), and has a total relief of under a metre. The mega-furrows have the appearance on multibeam data of a contour-parallel current scour. They appear to be carved into the post-glacial sands, which would preclude a fluvial-glacial-related origin. It remains unclear if currents are still eroding or just maintaining their form. The trough parallels the potential pipeline route, there are no apparent transverse bedforms, the overall morphology is probably quite stable. However sediment dynamics may be great, with significant along-trough flux of sands. As such the current mega-furrows represent a potential hazard to a pipeline.

19.3 Relict glacial topography

Large areas of the northern and northeastern parts of the bank are characterized by uneven topography which is not bedform related (Relict glacial topography, on Fig. 19.1, Enclosure 10, and ArcView theme “GBank Morophodynamic interp”). Multibeam profiles Georges west 2 and Georges west 7 (SE end) on Enclosure 14 show representative relief, typically 5 to 10 metres. The topography exhibits a “sculpted” appearance. Its upper surface is primarily glacigenic sediments, probably a chaotic mix of till and stratified channel cut and fill material. Thus it appears to be deposited and/or modified by paleo-fluvial and/or sub-glacial erosion. The are no recognized iceberg scours. The Valentine et al. (1991) map shows broad areas designated “areas of rough bouldery seabed”, which, given the scarcity of his data coverage, apparently correspond to these zones of exposed glacial sediments. They are gravel areas and, though not all sidescan images resolve boulders, they are inferred, by the setting, to be ubiquitous. Locally thin sand covers the gravel lag.

19.4 Surficial sediments

Seabed sediment along the north flank of Georges Bank is largely governed by relict glacial topography and sand dynamics. The multibeam backscatter, together with sparse sample coverage formed the basis for a sediment texture map (Fig. 19.3 and Enclosure 11). Backscatter relationship to sediment texture is not always straightforward because factors other than grainsize-induced roughness can be influential. This uncertainty must be considered in using this map.

In water depths shallower than about 100 m the multibeam backscatter allows a differentiation of large zones of a smooth, relatively uniform gravel (gravel, trace of sand) seabed from broad zones of lesser backscatter (visible on sidescan sonograms also) comprising a higher sand component. Figure 16.5 shows typical grainsize curves. Samples are generally gravel but with a variable sand component (Figs. 19.4 and 19.5).

The lesser backscatter (sandier) zones are generally associated with a rougher topography that is the sculpted/eroded upper surface of primarily glacigenic sediments (a chaotic mix of till and stratified channel cut and fill material).

Five sub-divisions of the seabed area, based on this backscatter have been mapped.

- Gravel
- Gravel and scattered boulders, some sand, epifaunal community (filograna sp.)
- Gravel, trace of sand
- dominantly Sand in sandwave and sand ridge fields
- gravelly Sand: sandy on sandwaves, more gravelly otherwise

The “gravel” zone represents the strongest backscattering and is largely confined to the mega-furrow trough and the outer southern part of Georges Bank, at the shelf-break. Presence of boulders in unconfirmed but occasional boulders can be inferred.

The “Gravel and scattered boulders, some sand, epifaunal community (filograna sp.)” zone presents a slightly lesser backscattering strength. This may be due to a greater aerial coverage of thin sand over the gravel. However, the GSCA-DFO habitat mapping data indicate some degree of correlation between this zone and the presence of an infauna which has a brittle projection above the seabed (filograna sp.) and also to massive and extensive horse mussel beds (Vladimir Kostylev, pers. comm.).

This correlation probably does not apply to the most eastern and southern areas of the zonation (southern pipeline route) so the patchy sand dusting is inferred.

The “gravel, trace of sand” zone occurs generally in slightly shallower areas. It comprises a uniform, smooth, nearly flat-lying surface that lies atop largely stratified deposits which in turn overly the deposits of the relict glacial topography. It is probably a thin (10 to 50 cm) lag deposit. The nature of the underlying sediments is largely unknown but it is not likely clean sand but rather a glacial deposit. A northern pipeline route would not likely intersect this zone, however, a southern route might. It is further considered in that section.

The “dominantly Sand in sandwave and sand ridge fields” zone extends along most of the length of the bank flank, including the area where conditions are best suited for a pipe route. It includes bedforms of various types (discussed below). It comprises sorted sand and any significant gravel component is not likely. This is the Sambro Sand which has spilled over the bank edge and fully to partially infilled iceberg scours on the till. Figures 19.6 and 19.7 show Huntec boomer profiles across the area and the geologic profiles on Enclosure 12 depict this zone. The sediment thickness map shows generally greater than 1 m (variable due to the sandwaves) and over 5 m in a narrow flanking zone.

The zone entitled “gravelly Sand: sandy on sandwaves, more gravelly otherwise” occurs only on the southern Bank route and is considered in that section.

Grab samples from the sand facies of the Sable Island Sand and Gravel Formation consist of well sorted, reddish brown to buff, fine to coarse grained sand (Fader, 1984). It is texturally similar to reworked Sambro Sand deposits making the differentiation between the two difficult. On the sediment thickness/variability map the sand formations are not differentiated. Recent BIO Department of Fisheries and Oceans cruises (Cruise Chief Scientist Donald Gordon) in the area collected continuous videography, photographs, and grab samples, primarily for benthic habitat assessment. Also, a GSCA cruise using similar equipment has just been completed in this area (B. Todd and V. Kostelev). These data have not been accessed for this report.

19.5 Bedforms

See the discussion regarding oceanographic conditions and sediment mobility in Section 16.2. ArcView theme “GBank Morophodynamic interp” shows the distribution of bedforms while the “Bedform crestline examples” theme presents tracings of their crestlines.

Bedforms are prominent features along the shallow flank of northern Georges Bank. The most prominent of these are sandwaves with crestline orientations normal to the contours (i.e. transport along the bank flank) and wavelengths of about 80m. Examples of the crestline pattern are shown in Fig. 19.7. Multibeam-generated profiles “Georges west 3” and “Georges west 4” on Figure 19.8 (and Enclosure 14) show a traverse through two sets of such sandwaves. The asymmetry on the latter show a general eastward transport direction, consistent with the oceanographic observations.

Smaller sandwaves (or megaripples) with ca. 5 m spaced crestlines oriented parallel to the contours are present in large zones along much of the flank, west of the contour normal features. Figure 19.9 shows their crestline pattern and the multibeam-generated profile “Georges west 1”, (Fig. 19.8 and Enclosure 14) shows these small sandwaves in profile. These bedforms suggest a downslope transport of sand. They are positioned between the current mega-furrows but their process relationship with these is unknown.

In the vicinity of 4946300N, 3455500E, two sets of current-transverse bedforms with wavelengths of 50 and 80 m are superimposed at right angles (ArcView theme “GBank Bedform ID, entry “small_SW_ortho_interference”. This results in some areas of rough, irregular topography where the waveforms interfere constructively and destructively. Total relief is about 5 m.

19.6 Pipeline route Assessment – This Study

The current mega-furrows represent a potential hazard in terms of strong currents. The relict glacial topography, apart from rough ground, includes boulders. This occurs on the bank top and at the southern extremity of the corridor. In the event of pipeline placement along the shallow northern flank of Georges Bank, seabed conditions are most benign in a relatively narrow zone constrained in greater water depths by the outcropping till and rough, iceberg scoured surface, and in shallower water depths by the prominent ridge/trough (current scour?) feature and the dominant small-scale sandwaves and megaripples. Here the sand is relatively flat-surfaced and free of indications of major sediment mobility. The fact that the iceberg scours remain exposed below this indicates very low rates of sedimentation, despite apparent active movement in immediately shallower water depths. One drawback is the relatively great water depth of this zone. Along much of the corridor it exists between 150 and 200 m (500 to 660 ft) water depth. The bedforms are active, based on the knowledge of currents, the clear asymmetry and the relatively high height to width ratios. A pipe along this flank may have to pass through a zone of sandwaves but placement at the edge of the zone, where crest heights are much lesser, would minimize any scour or freespan concern. The base of the sandwaves comprises stable till and is 5 m or less below their crests, so any current-induced scour around the pipeline would be minimal. Repetitive multibeam and sidescan over existing GSCA coverage would be an initial method of attempting to establish mobility rates.

20.0 South Georges Bank

20.1 Data coverage

The corridor along the NE and southern edge of Georges Bank follows approximately along the shelf-in slope break (ca. 100 m) and shallower. Numerous high and medium resolution sub-bottom profiler data area available here in a ca. ten km grid (Fig. 2.6, Enclosure 4). Multibeam coverage (25m resolution) extends along the entire corridor here, to the international border. Samples are sparse.

20.2 Geomorphological description

Fig. 20.1 (and Enclosure 10, and ArcView theme "GBank Morphodynamic interp") shows the subdivision of the area into several geo-morphodynamic zones. The same classification scheme described in the northern Georges Bank section applies to the southern route and these are adequately described there. The NE bank is relatively complex geologically but the southeast margin is relatively uniform.

One additional morphologic zone not present on the northern flank is the "mini-canyons" ("mass wasting (relict?)" in the ArcView project). These are a series of short (max. 1 km along axis) mass-wasting features arranged along the distal (NE) edge of a thick blanket-like deposit of supposed glacigenic sediments. The ArcView theme shows the canyon axes (along thalwegs). Multibeam-generated profiles across these ("Georges West 5" and "Georges West 6", Enclosure 14) show cross and longitudinal sections respectively. Relief is commonly 5 m and the canyons are about 300 m across. These are thought to be relict features, possibly from the lateral margin of an ice stream that filled NE Channel and "spilled" over the edge. This could have allowed build-up of a large kame terrace-like feature that failed when the supporting ice retreated. The pipeline route can avoid this zone.

The zone of iceberg pits and furrows is extensive on NE Georges Bank; a few are rather extreme in size (profile "Georges West 7" on Enclosure 14), exceeding 10 m depth.

The SE bank is characterized by sand with little gravel and a multitude of active bedforms of various scales. All the geologic profiles (Enclosure 13) indicate at least several metres of sand thickness in the uppermost stratigraphic unit and underlying units are likely sands also. The sand thickens where worked into large, broad NW-SE oriented sand ridges (see below).

The areas surrounding the heads of the canyons on the SE bank have a more rugged topography than the surrounding areas. This is probably a function of erosion and sediment transport from accelerated currents. The areas can be readily avoided on a southern pipeline route.

20.3 Surficial sediments

The same classification scheme described in the northern Georges Bank section applies to the southern route. Figure 20.2 and Enclosure 11, (ArcView theme "GBank Seabed sediment texture") shows the zones. Description of these zones is presented in the previous section (Northern and NE Georges Bank).

The “gravel, trace of sand” zone comprises a thin (10 to 50 cm) lag deposit, with a uniform, smooth surface. The type of sediment underlying the lag is unknown (this is the unit with the mini-canyons) but, as noted earlier, it is not likely clean sand but rather a more poorly sorted glacigenic sediment. It stratigraphically overlies the relict glacial topography surface. Only a small area of this is exposed in the corridor.

The most expansive sediment type zone is that described as “gravel and scattered boulders, some sand, epifaunal community (filograna sp.)”. As noted earlier, the epifaunal correlation with this characteristic of multibeam scatter probably does not apply to the southern parts of the northeast bank. This zone is nearly continuous along the outermost bank, where the surficial sand thins, generally below about 150 m water depth. Beyond this, over the shelf-break, the gravel is ubiquitous in the “gravel” zone.

The “dominantly Sand in sandwave and sand ridge fields” represents only a small portion of the southern route, just east of the “mini-canyons”. Where the sand associated with large bedforms is more expansive, especially on the southernmost areas of multibeam coverage, it is mapped in long, narrow bands. Here, contrary to normal relationships, the surficial sandy areas are not associated with the crests of the low, broad, NW-SE oriented sand ridges (sand_ridge-low&broad) despite that the build-ups comprise mainly sand. Rather, the ridges are more gravelly. Apparently they have experienced erosional winnowing, with more sandy deposition in the trough areas. This is interpreted as evidence that the ridges are relict, stemming from a period of lower sea–level and higher energy.

The zone entitled “gravelly Sand: sandy on sandwaves, more gravelly otherwise” covers most of the southern corridor. The very common bedforms are sand but the troughs between crests are gravelly, on both a regional and local scale. Where these gravelly expanses are large it has been mapped as the “gravel and scattered boulders” zone. A thin gravel lag is inferred but not confirmed. The boulder component here is not confirmed but largely assumed as an erosional remnant of glacigenic deposits following transgression.

20.4 Sediment mobility

Some of the largest and most diverse bedforms of the entire eastern Canadian Continental shelf are found within the study area on Georges Bank and Browns Bank, formed mainly in response to the extremely dynamic Bay of Fundy - Gulf of Maine oceanographic current system. The bedforms include various types and sizes of ripples, megaripples, sand waves and sand ridges. The reader is referred to the bedform classification (metric and generic) of Amos and King (1984), which is adopted in this study.

On Georges Bank the largest bedforms are long and wide sand ridges which are most prominent in the Georges Shoal and surrounding area. They do not occur in the corridor but are noted here for purposes of comparison with the less spectacular (though also active) bedforms of the southern Georges Bank corridor. The shoals of Georges Bank have a system of wide, long sand ridges with a spacing of 10 to 15 kilometres and heights of up to 20 metres and heights up to 15m are common. In general, those sand ridges which occur in water depths of less than 70m have average heights of 3 to 10m with superimposed megaripples and sand waves of various heights. These ridges are considered more active in terms of sediment movement than those that occur in water depths of approximately 70 to 100 m (southern corridor). The ridges in deeper water are low and broad (average about 4 m) with a dominant NW-SE crestline orientation and spacing of 1.5 to 2 km (Fig 20.1, Enclosure 10, and ArcView theme “Bedform crestline examples”). Profile “Georges west 9” on Fig. 20.3 (Enclosure 14) shows a multibeam profile across the ridges and Profiles 11 to 14, Enclosure 13 show boomer profile interpretations. They might be remnants of once more active features generated during times of lower sea level (as noted above).

Perhaps the most spectacular bedforms are the many and varied sandwaves in the Georges Shoal area. Most appear on the Huntec DTS profiles as composite forms (developed as a result of the merging of bundles of megaripples and/or other sand waves); usually with superimposed megaripples; a marked asymmetry with no pronounced slip face; and a weak coherence in spacing between crests of adjacent sand waves (Amos and King, 1984). They may also occur as symmetrical, sharp crested trochoidal forms. All of these types are illustrated in Fig. 20.4. They occur primarily in association with the sand ridges with their crestlines oriented a general E/W to NE/SW direction, transverse to the ridge axes. Many of the sandwave crestlines have a broad arcuate shape and stretch for several kilometres. There is often a fairly regular spacing of the sand waves, especially along the sand ridge crests where they are best developed. Wavelengths range from 170 to 820m. They do not occur in the troughs between sand ridges, possibly as a result of the sediment paucity. On Georges Bank most sand waves are greater than 3 m height and average 5.7m height, while maximum recorded height is 17m (Amos and King, 1983).

By contrast, sandwaves in the deeper water of the southern corridor are much more continuous laterally but not as high. The sandwaves in the southern corridor are quite unique morphologically given their extreme lateral continuity. They present a branching pattern reminiscent of feathers and are here termed “plumose sandwaves. Superimposed megaripples are not visible from the multibeam images but Huntec profiles show they are nearly always on the sandwave crests (Fig. 20.5). Profile “Georges west 8” on Fig. 20.3 (Enclosure 14) shows a multibeam profile across the plumose sandwaves. These megaripples have a high height to wavelength ratio (unlike many in the nearshore or on Sable Island Bank). This indicates they are periodically active. Their orientation is in general agreement with present oceanographic conditions (Fig. 16.14).

The megaripples on Georges Bank are almost ubiquitous, occurring in large continuous fields over most of the area in less than 80 m but also locally in the southern bank area. They are mainly 2-D megaripples (straight or bifurcated crestlines) occurring in the Sable Island Sand and have an average height of 0.5 to 1.0m with wavelengths between 5.5 and 6.5m. As for the sandwaves, megaripples on the bank show a southerly to southeasterly direction of migration.

20.5 Pipeline route Assessment – This Study

Pipeline routing can avoid the most intensive rough ground associated with iceberg scours in the till, mainly by keeping to shallower water depths. They are not an issue on the SE bank. Likewise the area of rough topography in the mini-canyons can be avoided, as can the rougher areas surrounding the SE bank canyon heads. The relict glacial terrain must be crossed but is apparently relatively benign in comparison to the scoured till surface yet bouldery terrain is anticipated.

If the pipe is to cross the areas of smooth surficial gravel (Gravel, trace of sand, Fig. 20.2, Enclosure 11) and be buried beneath the lag, (presumably for protection from fishing activity) the uncertainty of underlying sediment type might be an issue. Inference based on the seismic character and the presence of the mini-canyons which developed in this stratigraphic unit suggests it may not be clean sand. A cohesive, likely gravelly might be present. Boulders are, however, inferred to be unlikely in this presumably pro-glacial sediment.

Perhaps the issue of greatest concern is seabed sediment mobility on the SE bank. The plumose sandwaves are recently discovered and change the previous thoughts of a relatively inactive southern bank area. Clearly they are not as active as in the Georges Shoals area. The sediment mobility issue is entirely negated if the pipe is to be buried (for other concerns, e.g. fisheries). As the bedforms sit upon an otherwise featureless, fairly gravelly seabed, natural disturbance below this gravel is unlikely. It may even provide a protective substrate for potential current scour around an unburied pipe. If the mobility of the up to 5 m high sandwaves remains unknown at time of laying it would be prudent to bury to the base of the sandwaves (to avoid potential spanning) even if there is no pipe burial into the gravelly substrate. Repetitive multibeam and sidescan over existing GSCA coverage would be an initial method of attempting to establish mobility rates.

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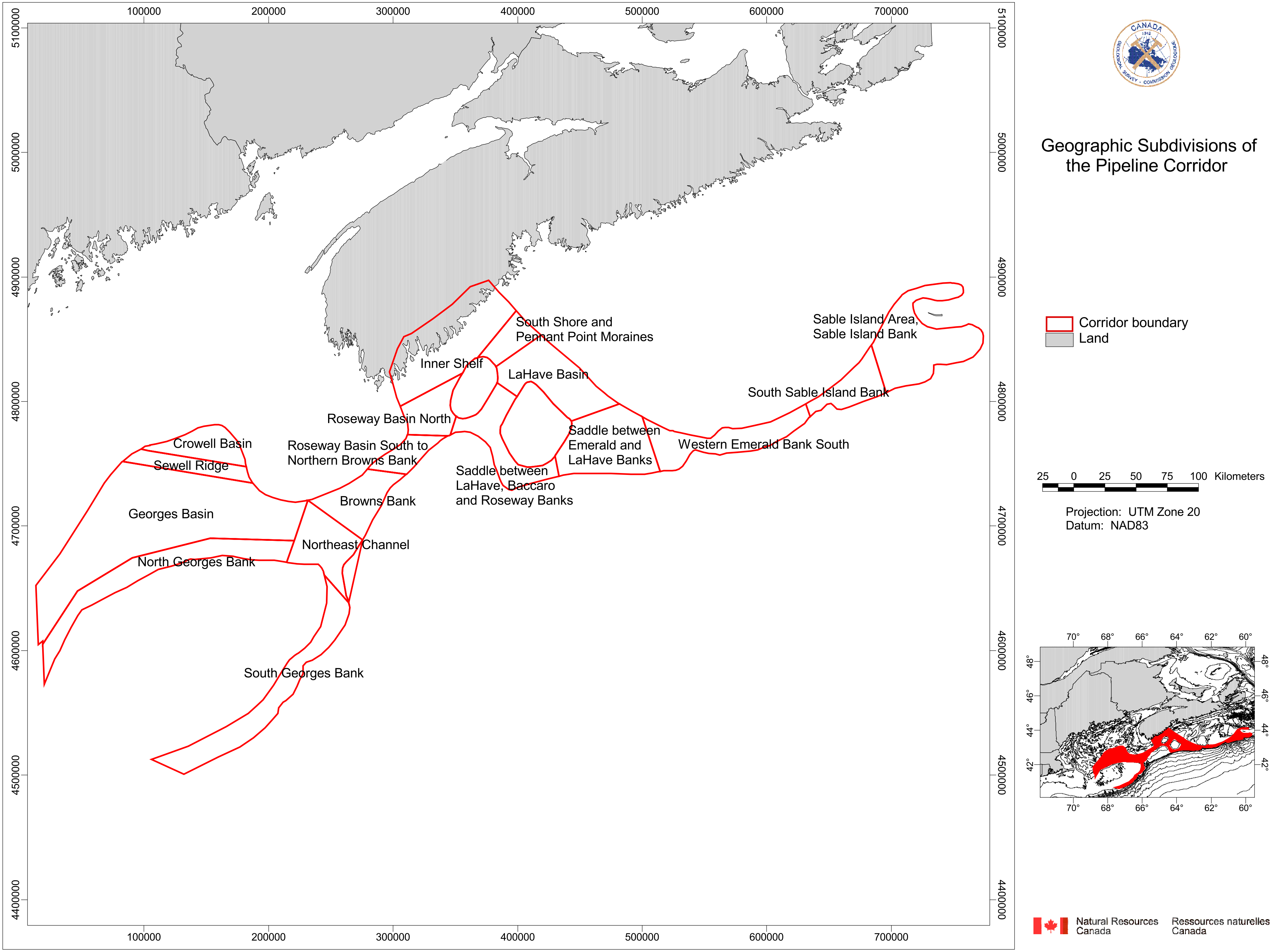

Geographic Subdivisions of the Pipeline Corridor
Corridor boundary
Land
25 0 25 50 75 100 Kilometers
Projection: UTM Zone 20
Datum: NAD83
South Shore and Pennant Point Moraines
Sable Island Area, Sable Island Bank
Inner Shelf
LaHave Basin
South Sable Island Bank
Roseway Basin North
Saddle between Emerald and LaHave Banks
Western Emerald Bank South
Crowell Basin
Roseway Basin South to Northern Browns Bank
Sewell Ridge
Saddle between LaHave, Baccaro and Roseway Banks
Browns Bank
Georges Basin
Northeast Channel
North Georges Bank
South Georges Bank
Natural Resources Canada
Ressources naturelles Canada

Figure 1.1

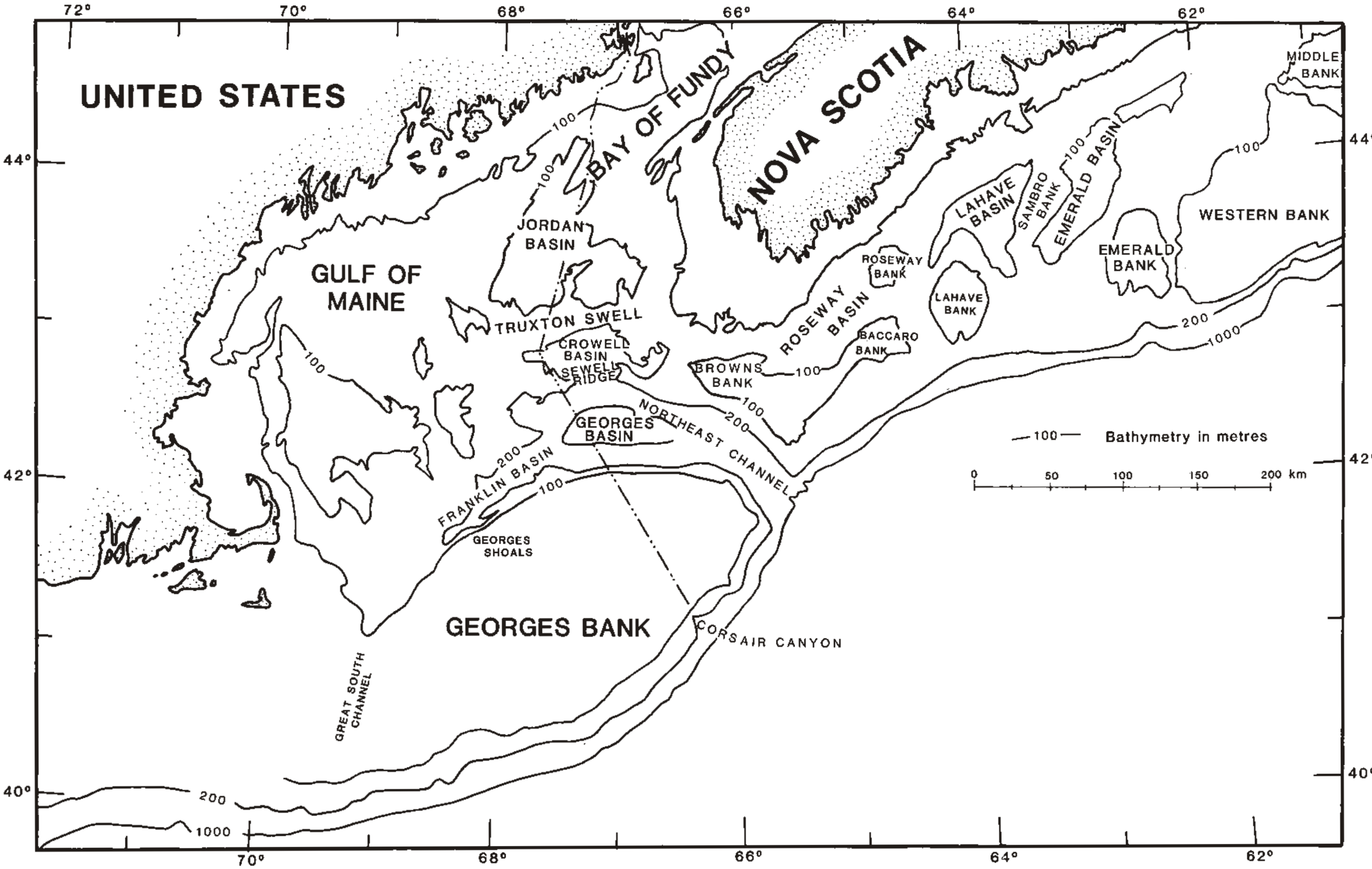
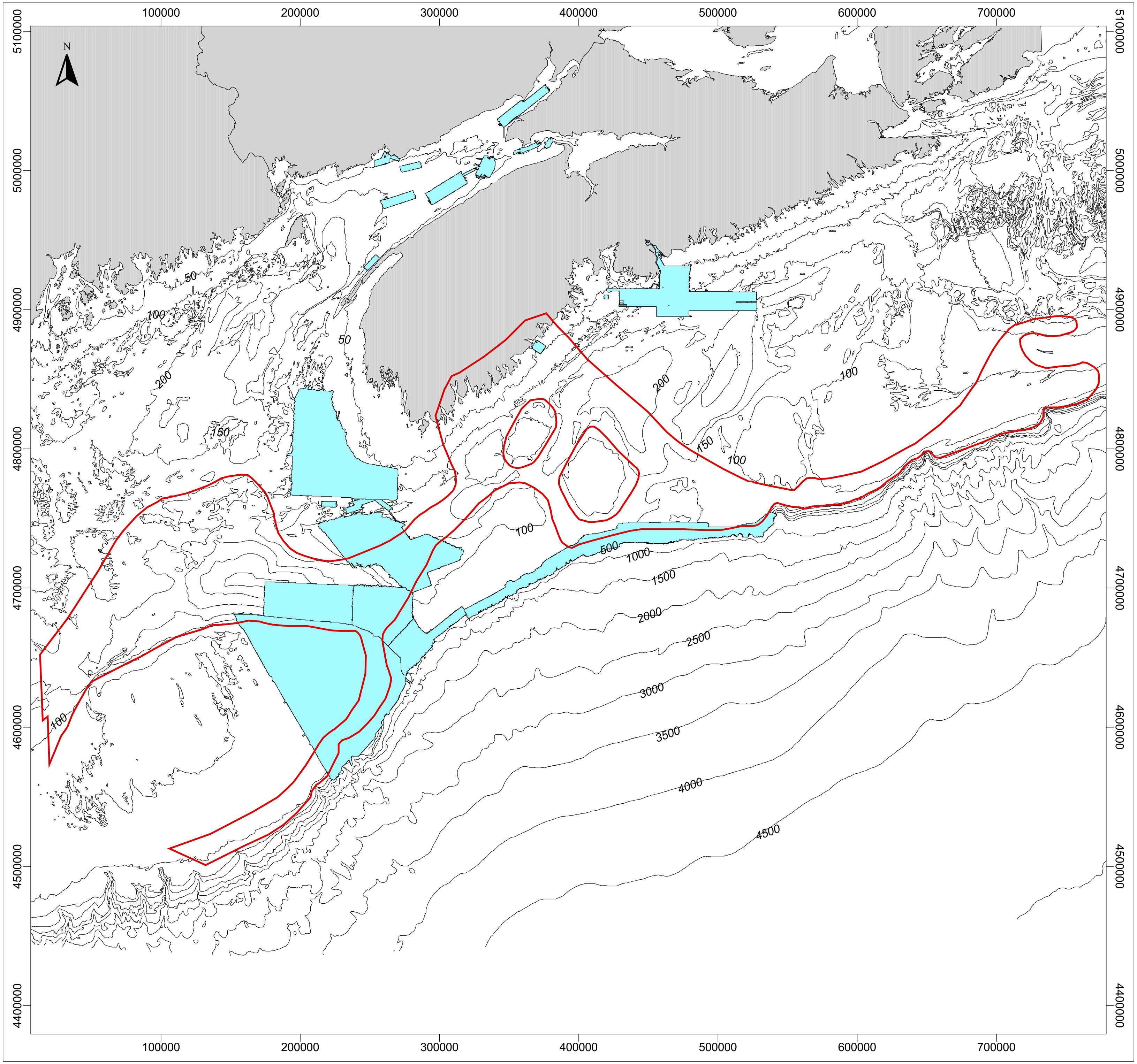


Figure 2.1. Geographic location names on the western Scotian Shelf.

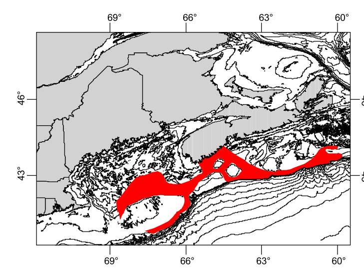


Pipeline Corridor and Areas of Multibeam Coverage

Multibeam coverage
Bathymetric contour
Land
Corridor boundary

25 0 25 50 75 100 Kilometers

Projection: UTM Zone 20
Datum: NAD83



Natural Resources Canada
Ressources naturelles Canada

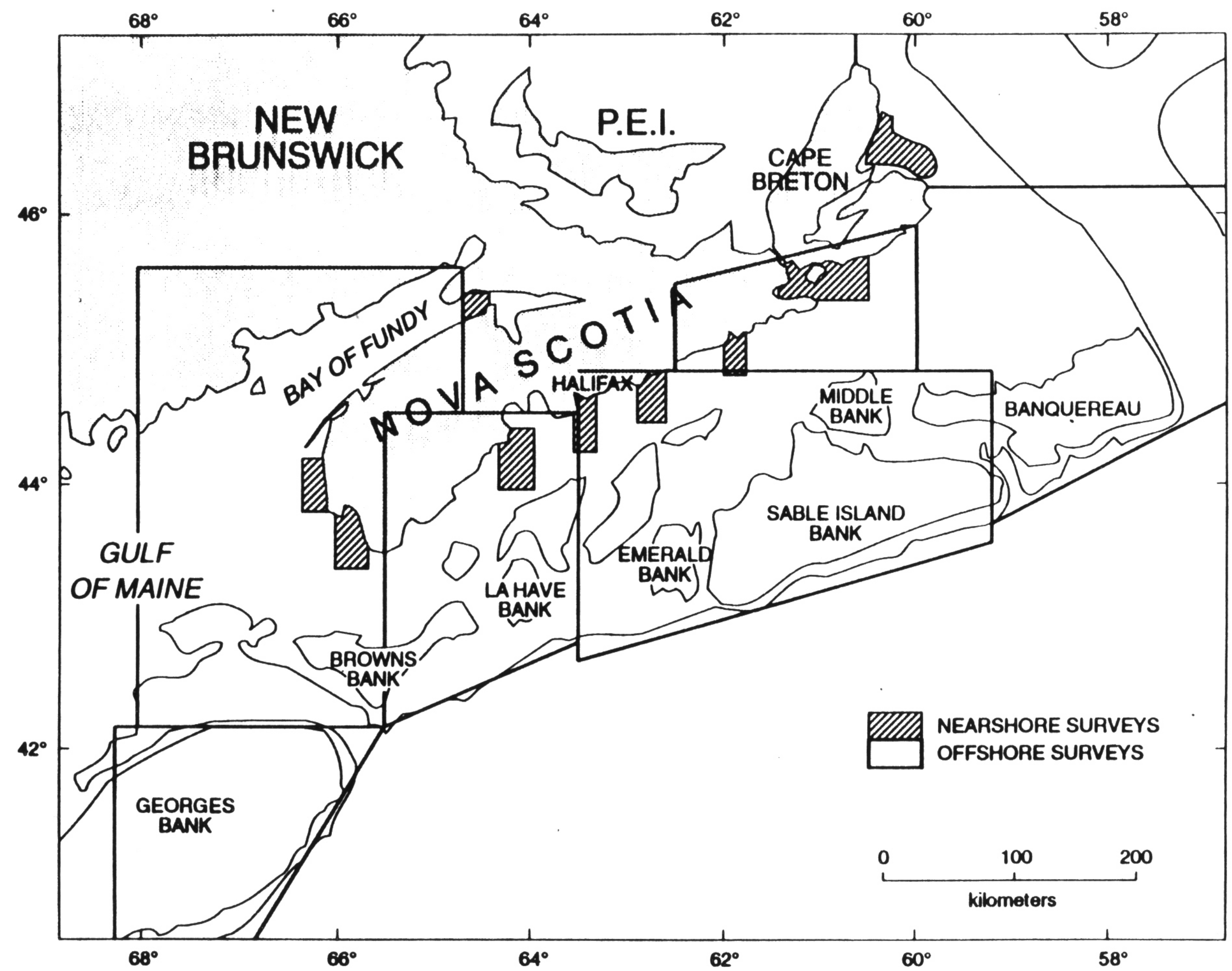


FIGURE 1. Index for the Scotian Shelf and adjacent areas showing the presently mapped areas in both the offshore and nearshore.

Figure 2.3. Index of map coverage for the Scotian Shelf, 70's era Marine Sciences series offshore maps.

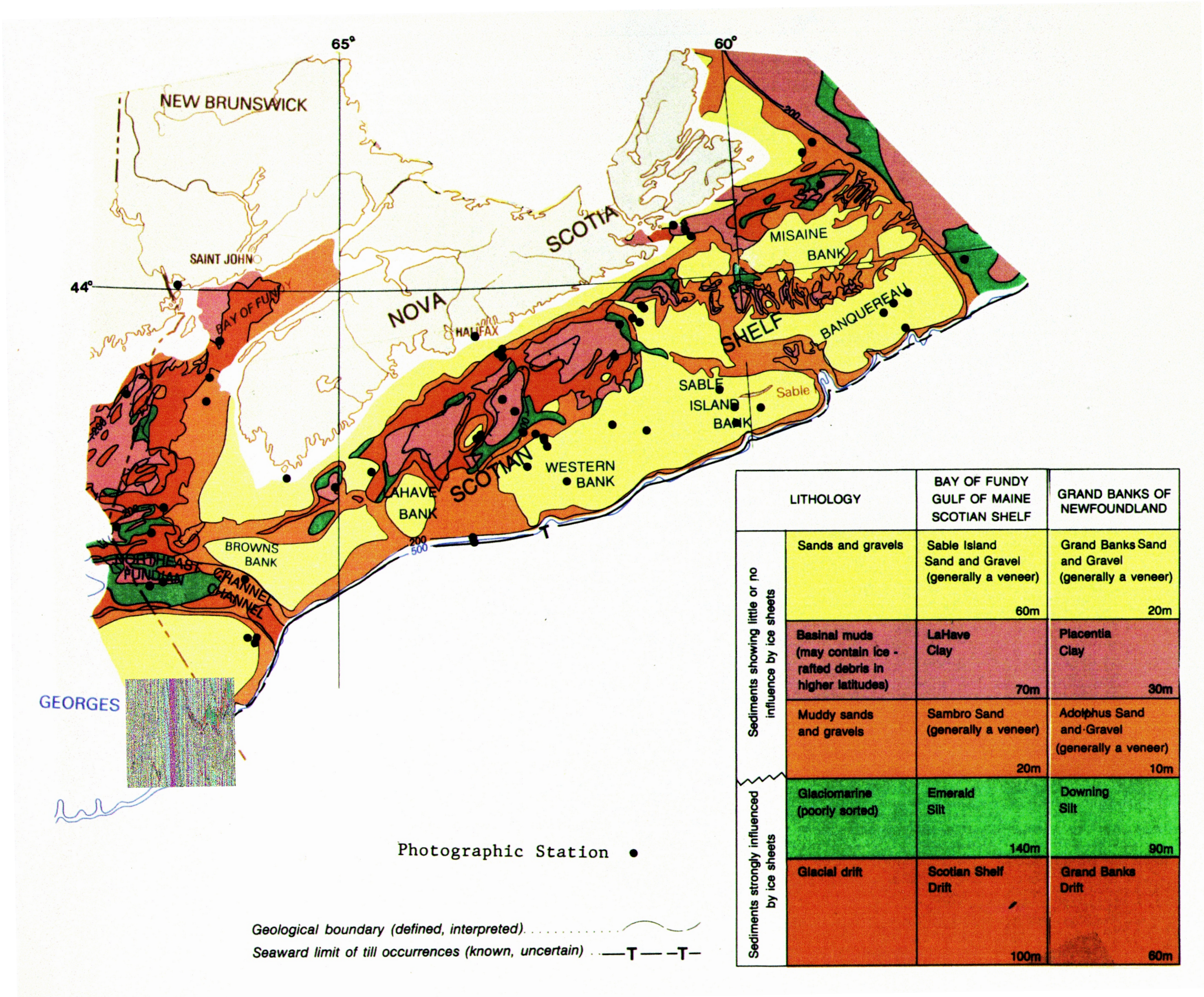
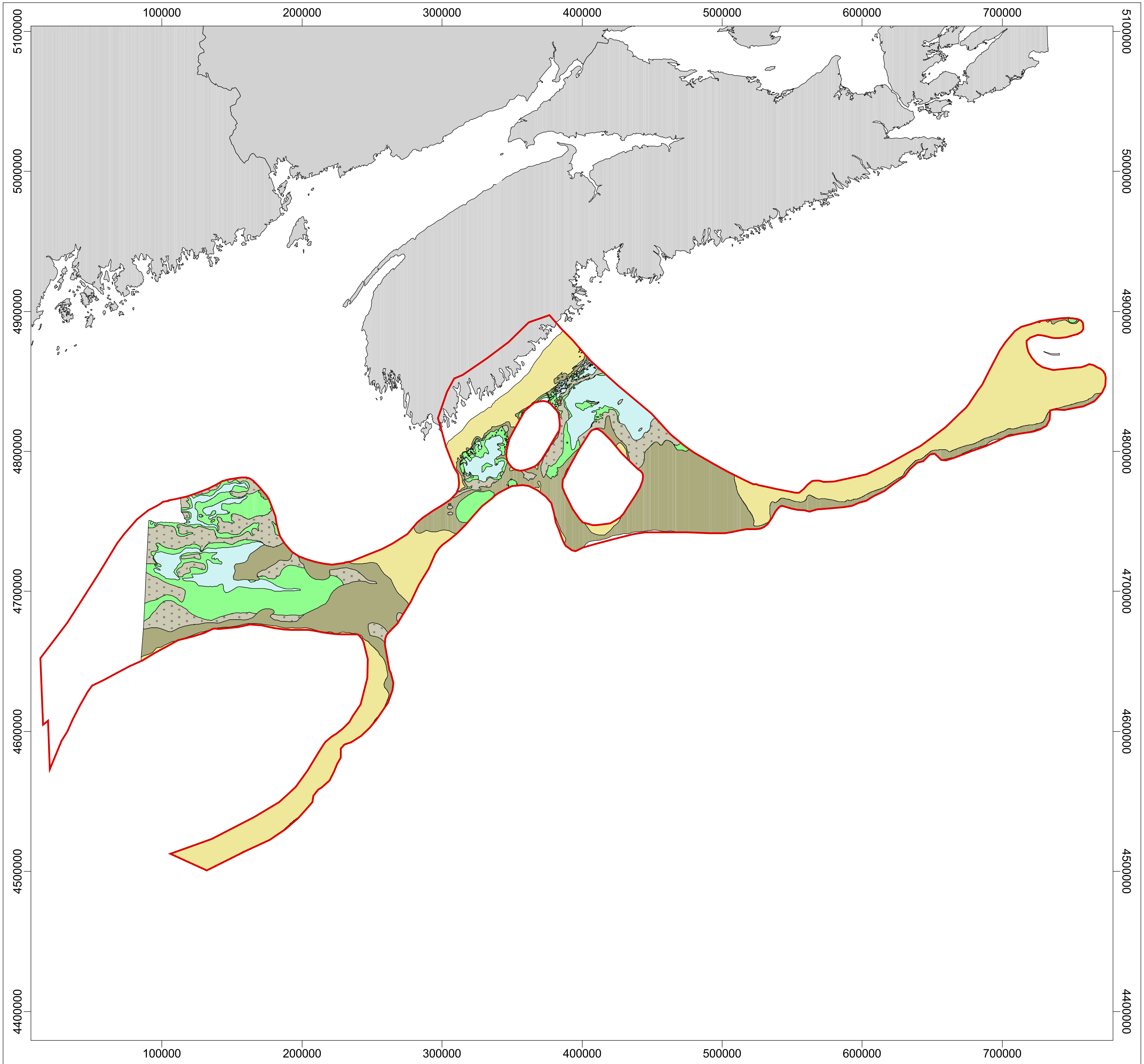
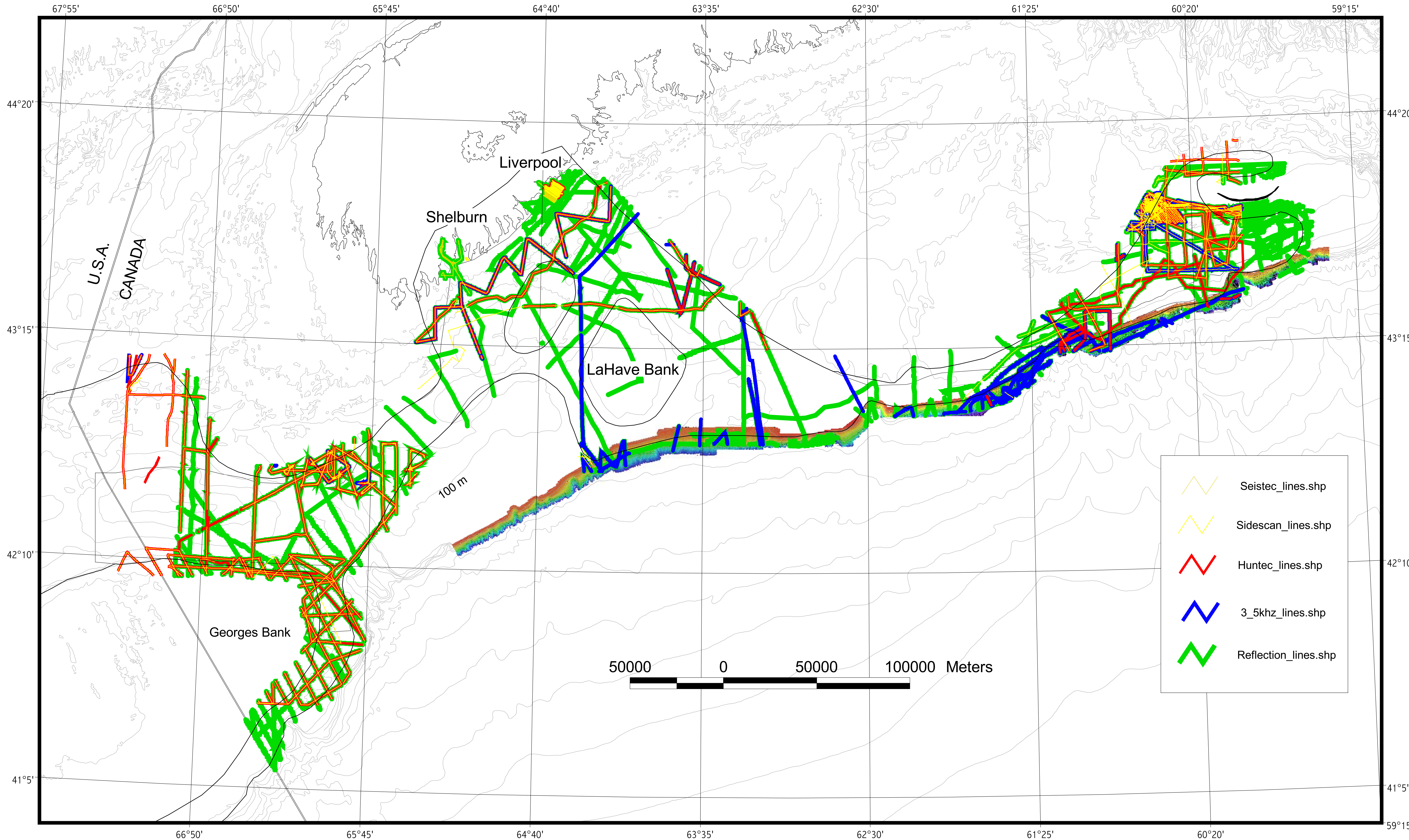
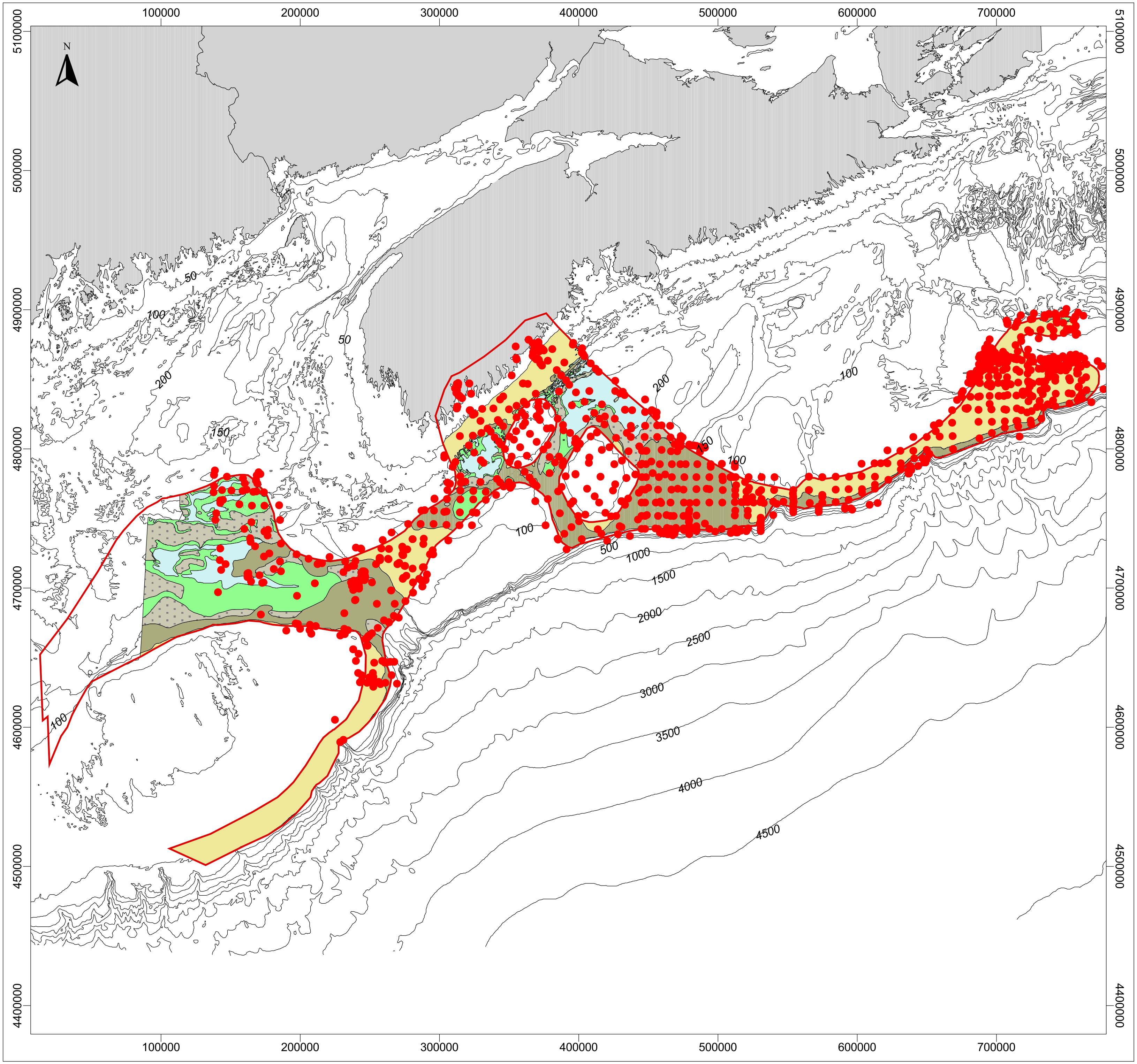


Figure 2.4. Overview of the surficial geology on Scotian Shelf.


Surficial Geology of the Pipeline Corridor
Surficial Geology
Emerald Silt
LaHave Clay
Sable Island Sand and Gravel
Sambro Sand
Scotian Shelf Drift
Corridor boundary
Land
25 0 25 50 75 100 Kilometers
Projection: UTM Zone 20
Datum: NAD83
100000 200000 300000 400000 500000 600000 700000
5100000 5000000 4900000 4800000 4700000 4600000 4500000 4400000
70° 68° 66° 64° 62° 60°
48° 46° 44° 42°
CANADA
Natural Resources Canada
Ressources naturelles Canada



67°55'
66°50'
65°45'
64°40'
63°35'
62°30'
61°25'
60°20'
59°15'
44°20'
43°15'
42°10'
41°5'
U.S.A.
CANADA
Liverpool
Shelburn
LaHave Bank
Georges Bank
100 m
50000
0
50000
100000 Meters
Seistec_lines.shp
Sidescan_lines.shp
Huntec_lines.shp
3_5khz_lines.shp
Reflection_lines.shp



Surficial Geology of the Pipeline Corridor with Sample Locations

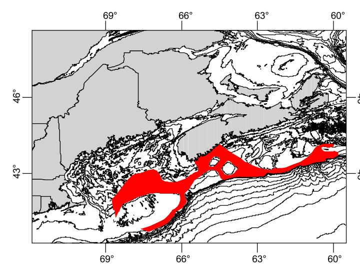
Surficial Geology

- Emerald Silt
- LaHave Clay
- Sable Island Sand and Gravel
- Sambro Sand
- Scotian Shelf Drift

- Corridor boundary
- Sample location
- Bathymetric contour
- Land

25 0 25 50 75 100 Kilometers

Projection: UTM Zone 20
Datum: NAD83



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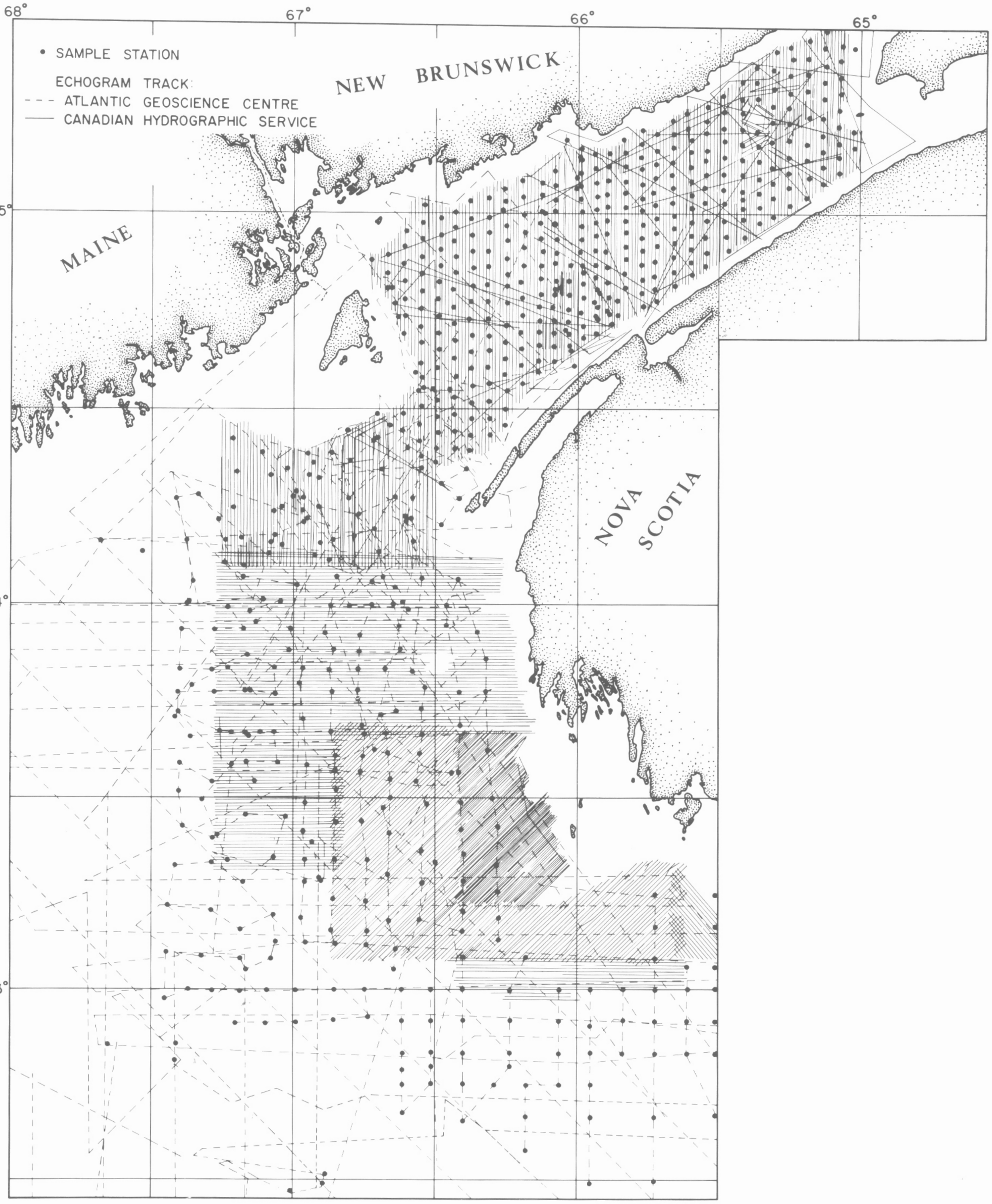


FIG. 1. Acoustic and bottom-sampling control across the eastern Gulf of Maine and Bay of Fundy map-area.

Figure 2.8. Sample and echosounder control for Marine Sciences offshore surficial geology maps series in the Gulf of Maine.

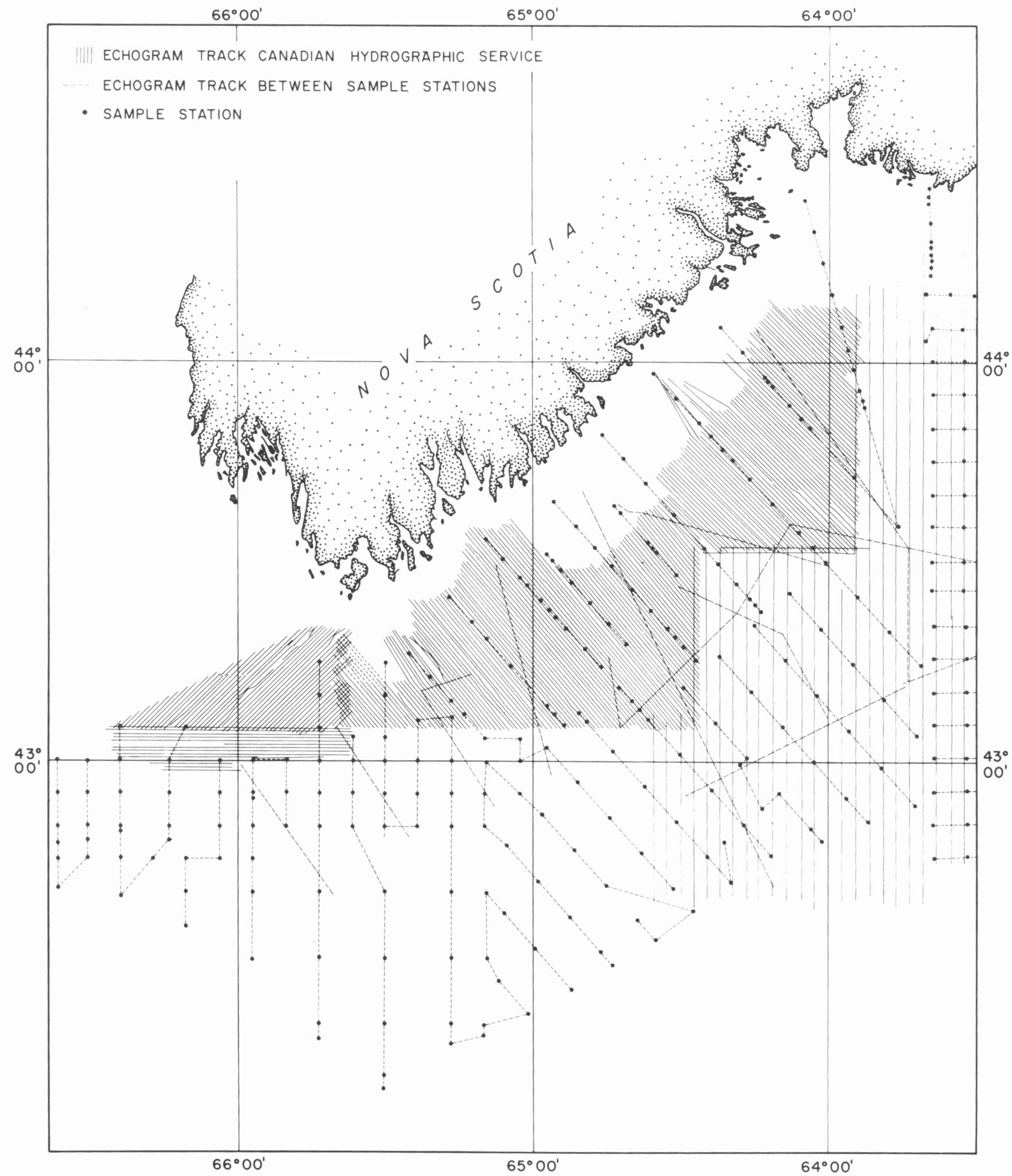


Figure 1. The acoustical and bottom-sampling control across the Yarmouth-Browns Bank Map-area.

Figure 2.9. Sample and echosounder control for Marine Sciences offshore surficial geology maps series in the Browns Bank and Roseway& LaHave Basin area.

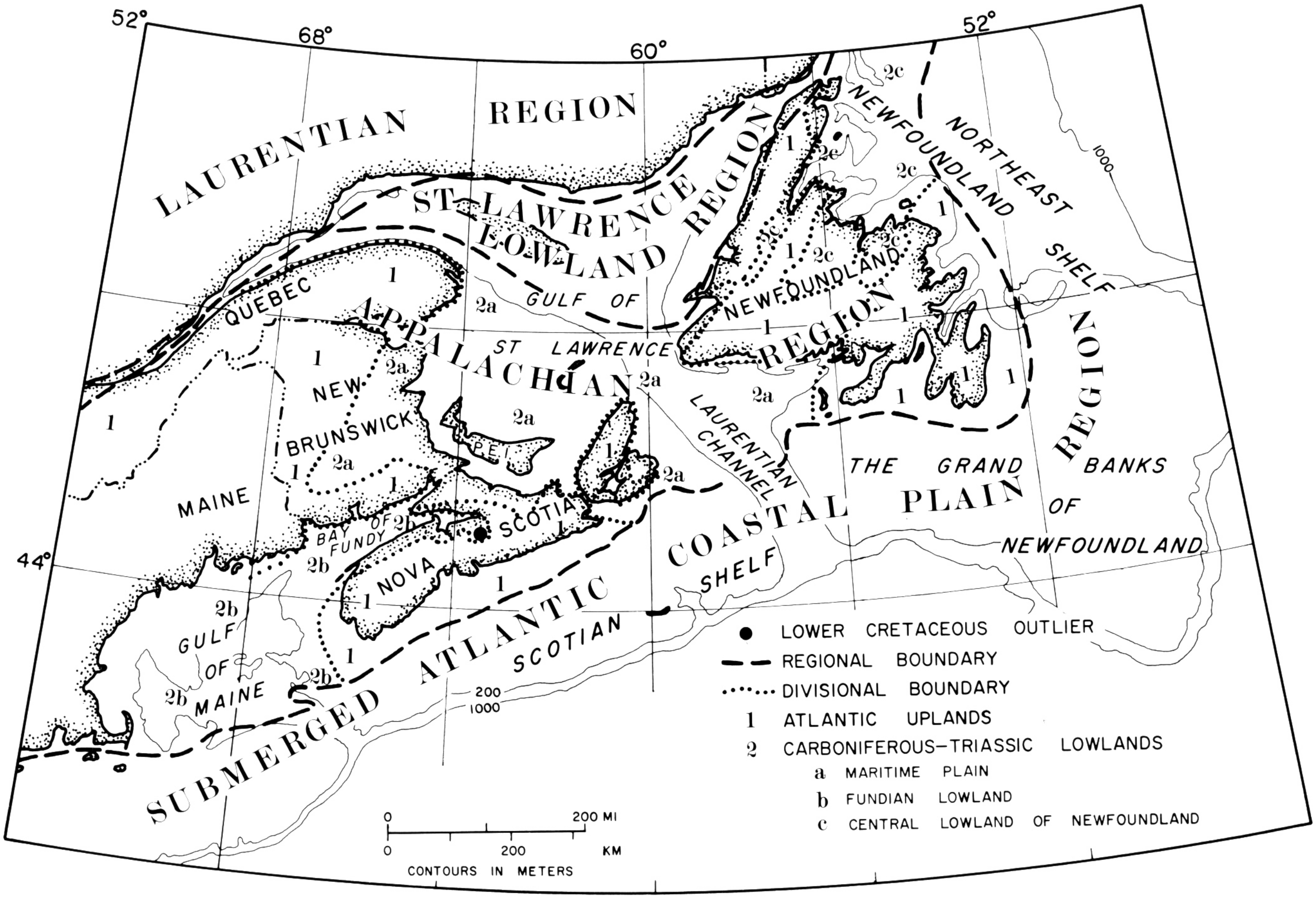


Figure 2.10. Atlantic Coastal Plain geomorphic provinces.

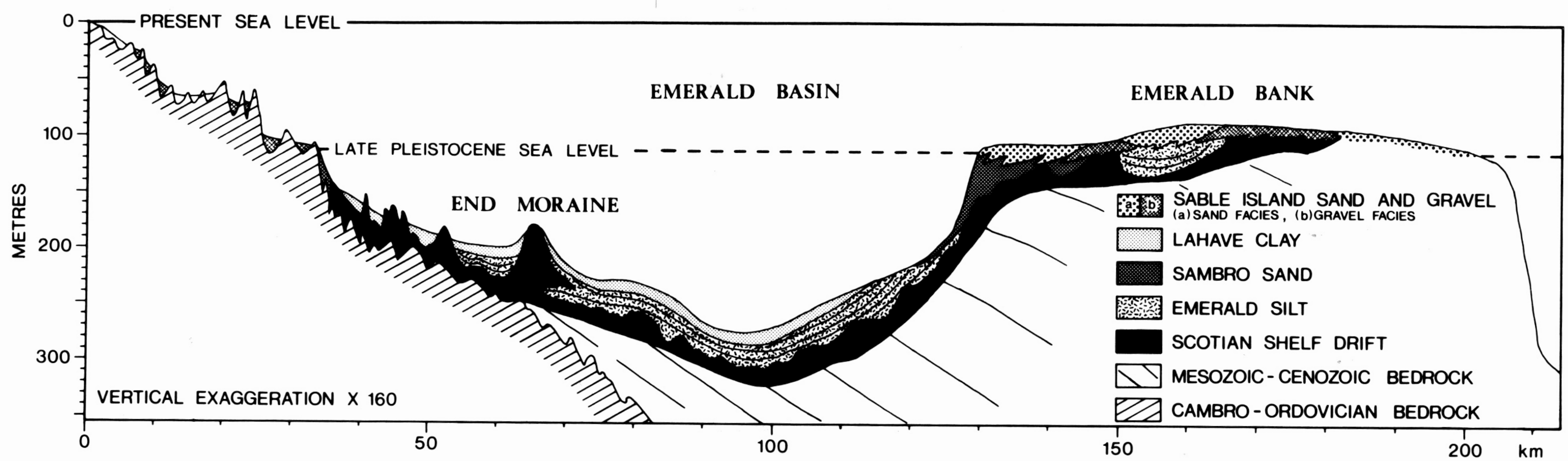


Figure 2. Diagrammatic cross-section of the Scotian Shelf across Emerald Basin and Emerald Bank showing the distribution and relationships among surficial formations, bedrock, and the last low sea level position (King, 1980).

Figure 2.11. Typical bedrock configuration and Quaternary stratigraphy in the inner-shelf basins and relationships with the end moraine complex.

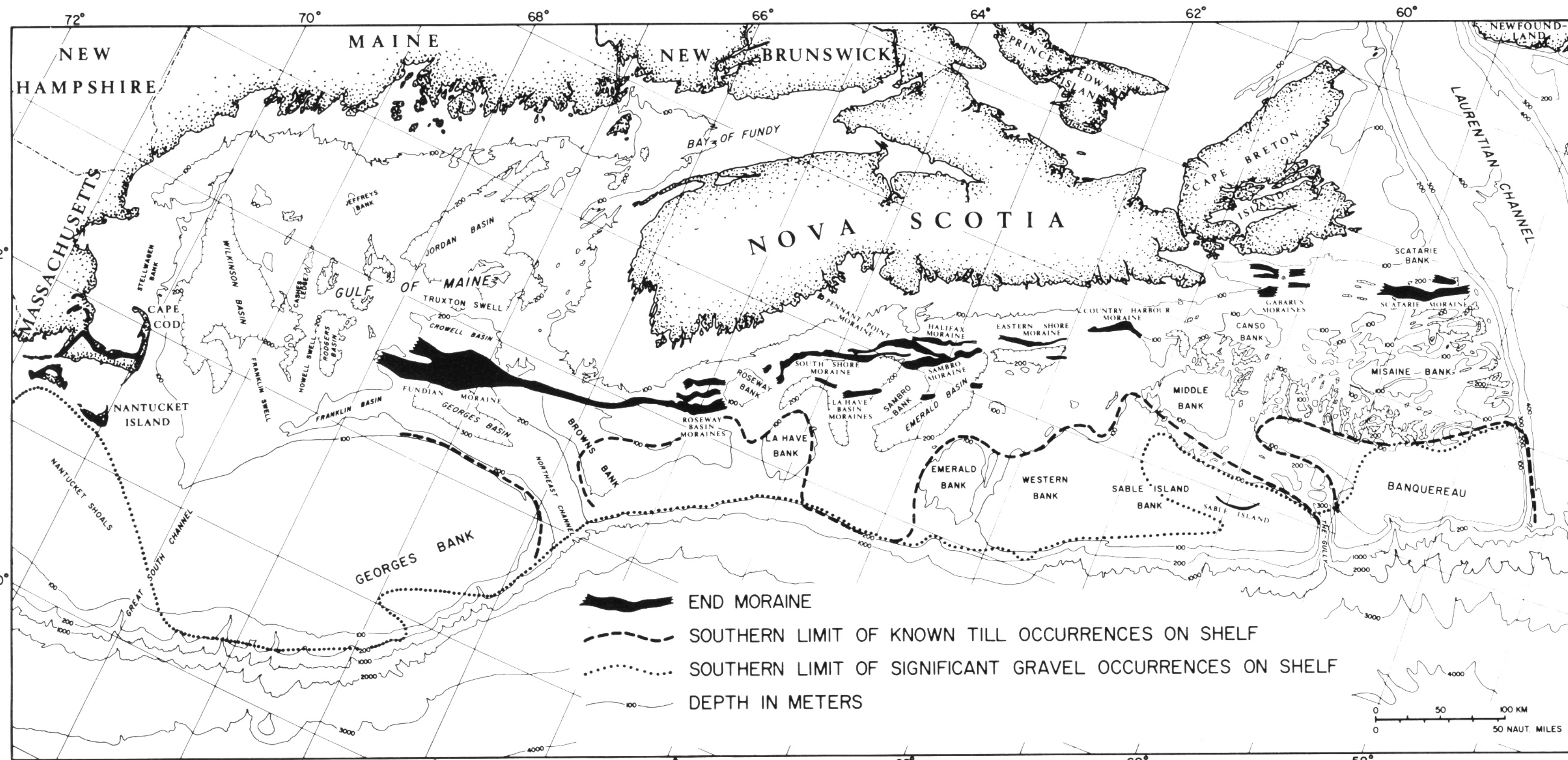


Figure 4. The Scotian Shelf end moraine complex and the southern boundaries of known till and significant gravel occurrences (areas with more than 10% gravel) on the Scotian Shelf and Georges Bank area (King et al., 1972). The moraines are now interpreted as regional, subglacial, ice shelf moraines. See text for explanation of their formation.

Figure 2.12. Overview of the Scotian Shelf end moraine complex.

Table 1. Table of Quaternary Formations

Epoch	Formation	Lithostratigraphy	Thickness	Seismostratigraphy
HOLOCENE	LaHave Clay	Greyish brown, soft, silty, clay grading to clayey silt, confined mainly to basins and depressions of shelf. Derived by winnowing of glacial sediments on banks and transported to basins. Time equivalent of Sable Island Sand and Gravel and Sambro Sand on banks	0-70m	Generally transparent without reflections. Some weak continuous coherent reflections in base of section becoming stronger in nearshore sandy facies and on Grand Banks of Newfoundland
	Sable Island Sand and Gravel	Fine to coarse, well sorted sand grading to subrounded to rounded gravels. Unconformably overlies Emerald Silt and Scotian Shelf Drift, and derived from these deposits through reworking during Holocene transgression above 120m present depth. Time equivalent of LaHave Clay in basins	0-50m generally veneer	Highly reflective seabed. Generally closely spaced continuous coherent reflections if deposit is of sufficient thickness to resolve
PLEISTOCENE	Sambro Sand	Silty sand grading locally to gravelly sand and well sorted sand. Deposited sublittorally with respect to the Pleistocene shoreline below 120m present depth. Time equivalent to basal LaHave Clay and upper Emerald Silt, facies B	0-20m generally veneer	Similar to Sable Island Sand and Gravel
	Emerald Silt, Facies C	Not well sampled	0-100m	Discontinuous coherent reflections; transitional between facies A Emerald Silt and glacial till
	Emerald Silt, facies B	Darkish greyish brown, poorly sorted clayey and sandy silt with some gravel. Poorly developed rhythmic banding; proglacial in origin	0-40m	Medium to low amplitude continuous coherent reflections, and to some degree a ponded sedimentational style
	Emerald Silt, facies A	Dark greyish brown, poorly sorted clayey and sandy silt, some gravel. Well developed rhythmic banding; subglacial in origin. Time equivalent to parts of Scotian Shelf Drift	0-100m	High amplitude continuous coherent reflections, highly conformable to substrate irregularities
	Scotian Shelf Drift	Very dark greyish brown, cohesive glacial till composed of poorly sorted sandy clay and silt with variable gravel	0-100m	Incoherent reflections, sometimes with scattered point source reflections

Table. Stratigraphic sub-division of the surficial (Quaternary age) sediments on the Scotian Shelf utilized in the 70's era Marine Sciences series offshore maps.

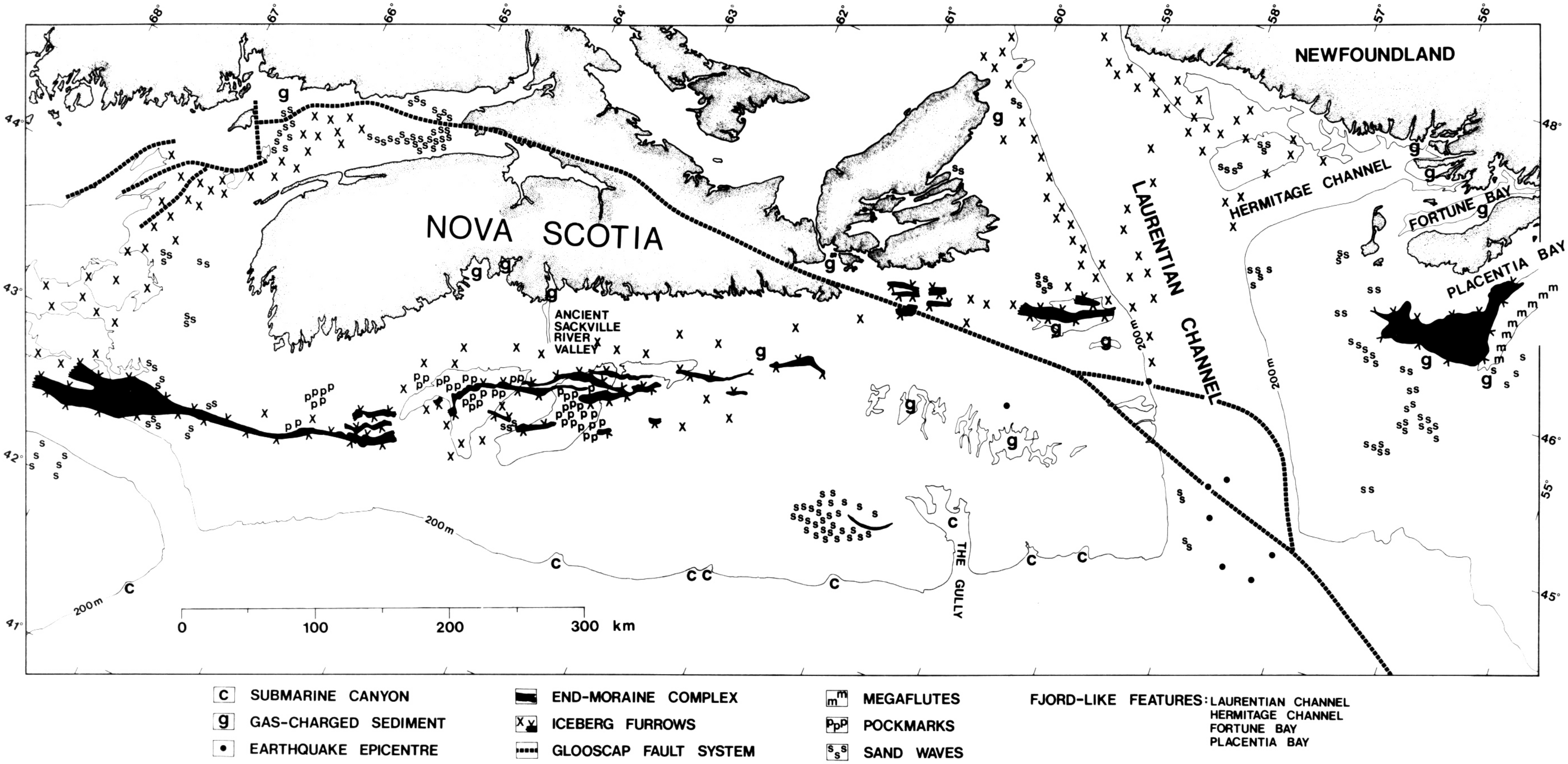


Figure 3.1. Overview of surficial features on the Scotian Shelf, many of which are pertinent to pipeline routing.

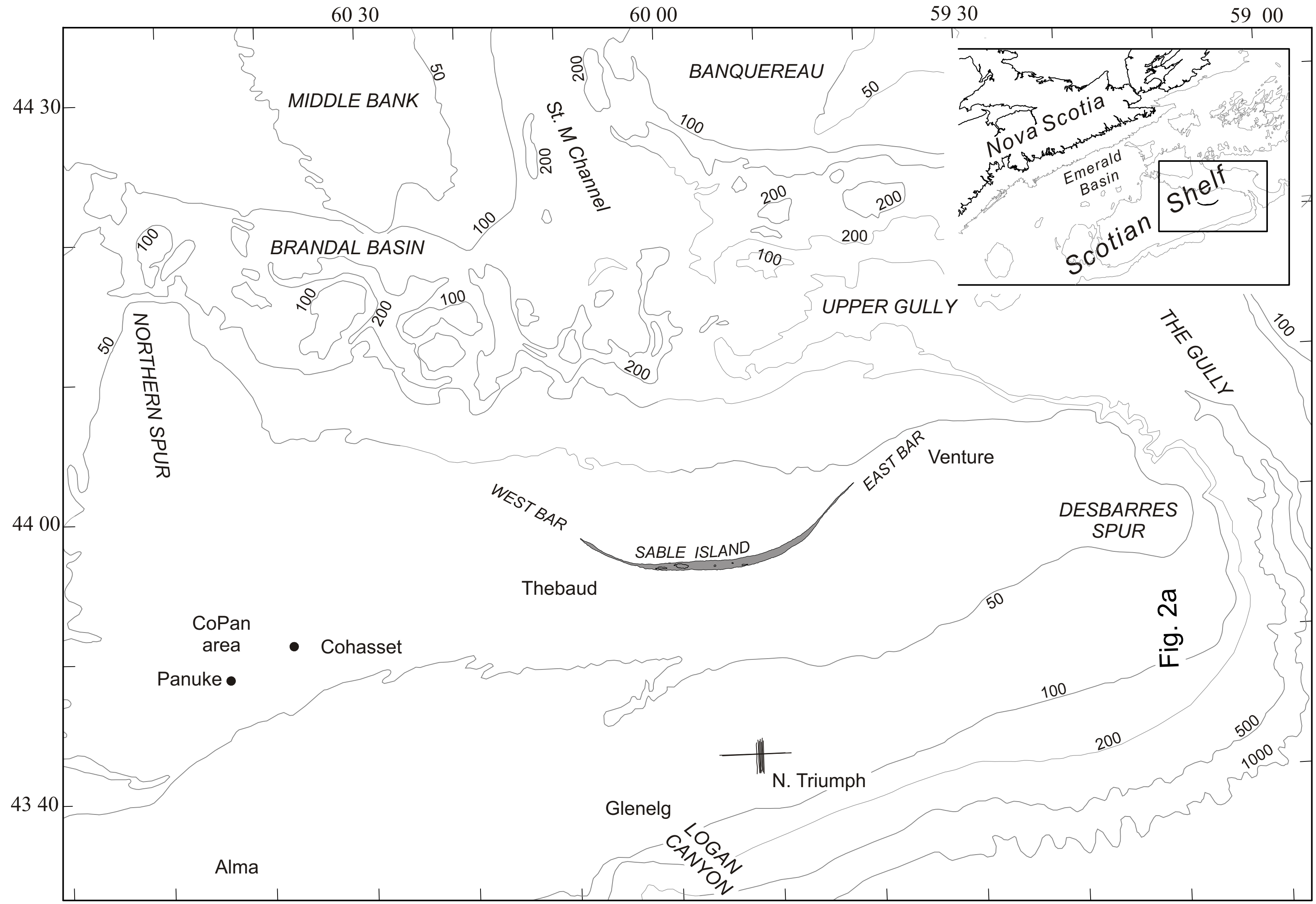


Figure 4.1. Geography of Sable Island Bank.

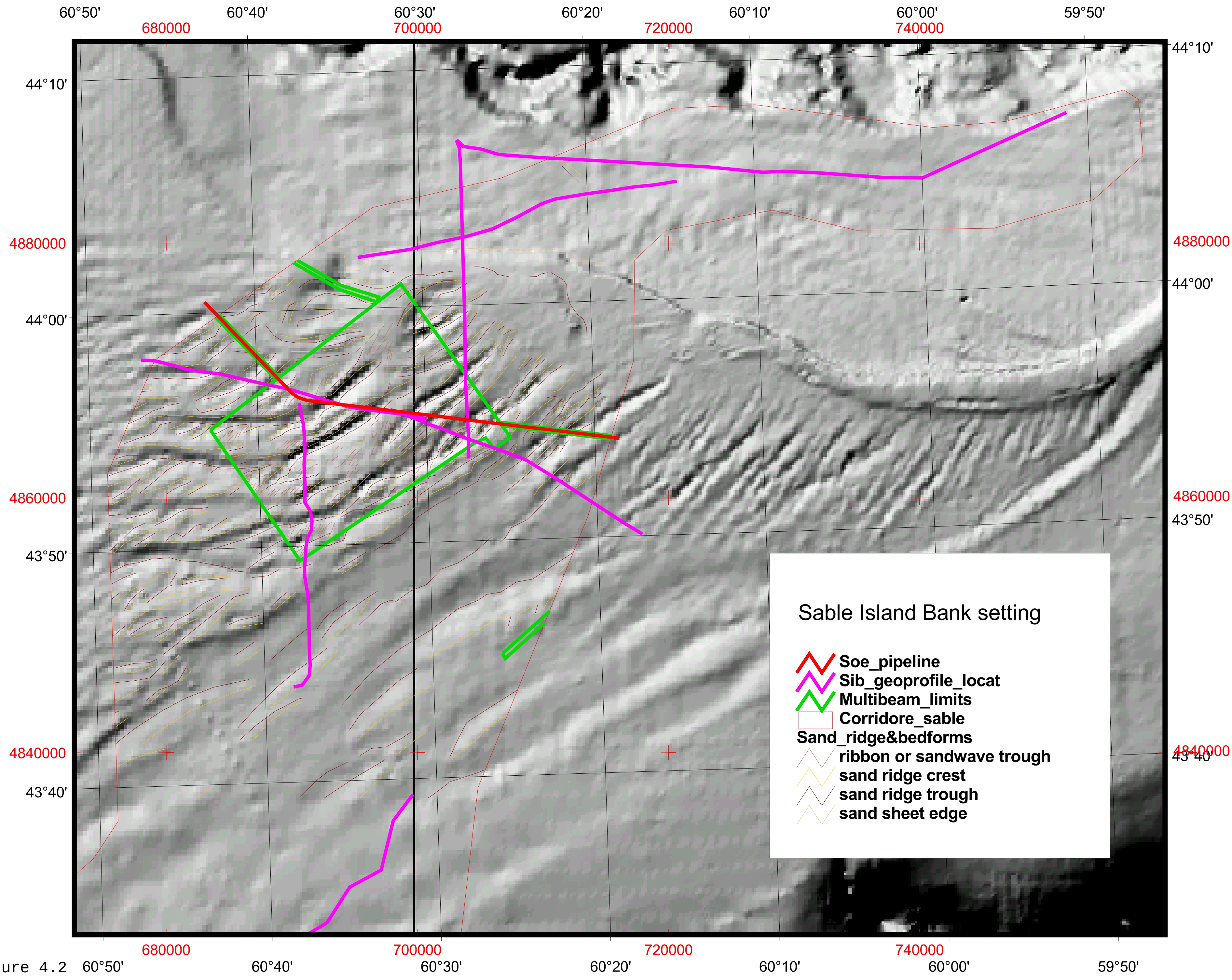

Sable Island Bank setting
Soe_pipeline
Sib_geoprofile_locat
Multibeam_limits
Corridore_sable
Sand_ridge&bedforms
ribbon or sandwave trough
sand ridge crest
sand ridge trough
sand sheet edge
60°50'
60°40'
60°30'
60°20'
60°10'
60°00'
59°50'
680000
700000
720000
740000
44°10'
44°00'
43°50'
43°40'
4880000
4860000
4840000

Figure 4.2

Figure 4.3. GSCA geolgic profile 86-035-49 and 50 on Sable Island Bank.

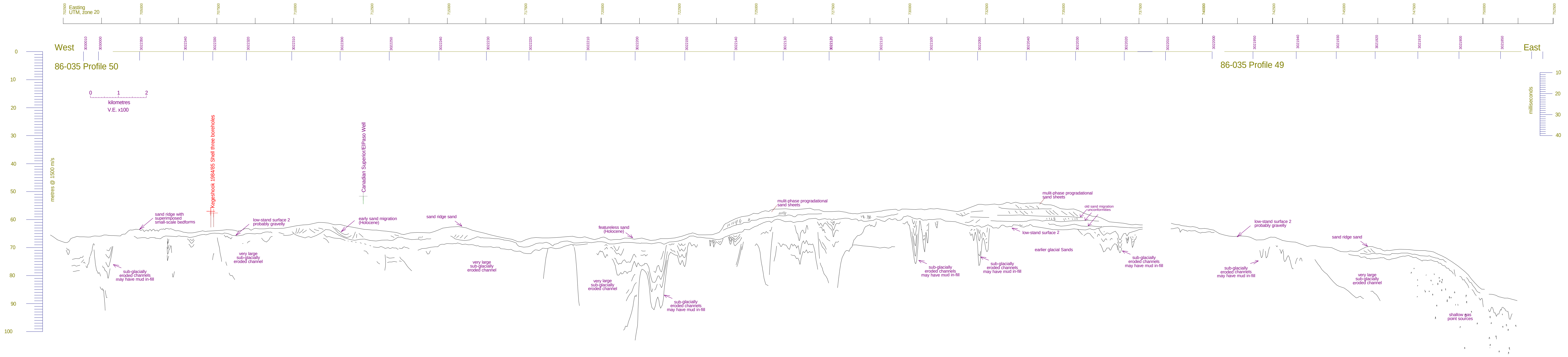


Figure 4.4. GSCA geolgic profile 87-042-11 on Sable Island Bank.

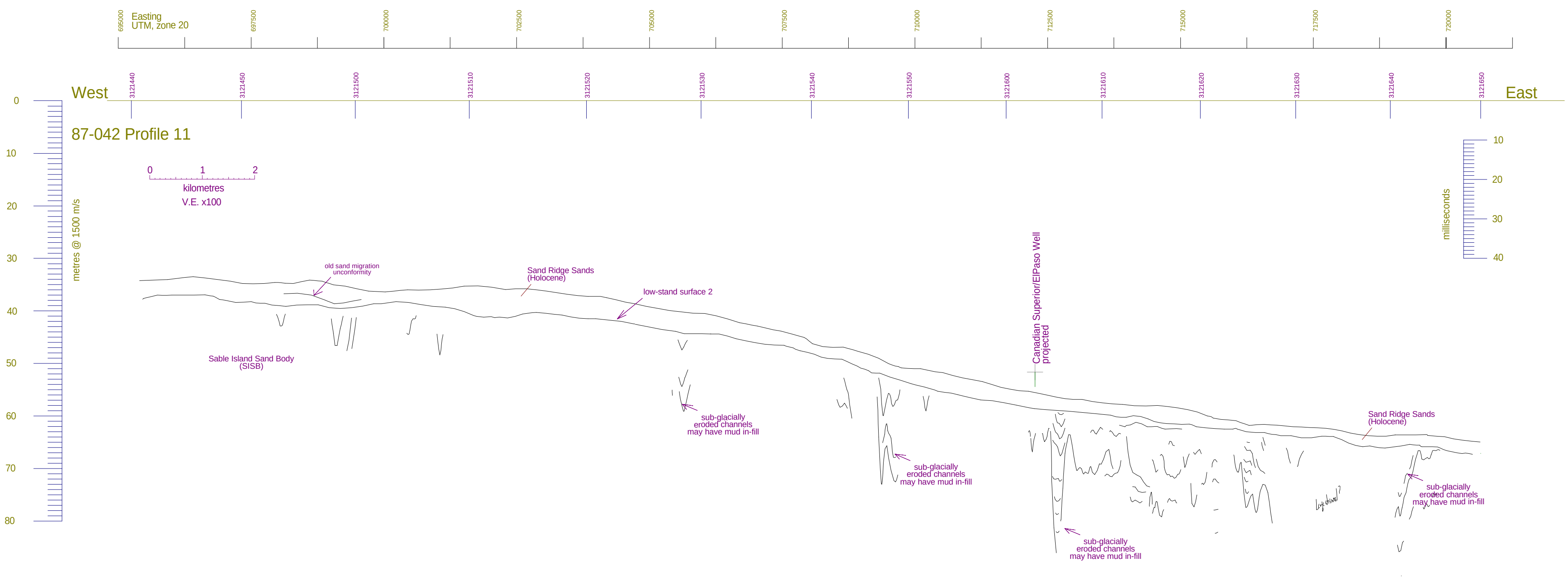


Figure 4.5. GSCA geolgic profile 89-039-13 on Sable Island Bank.

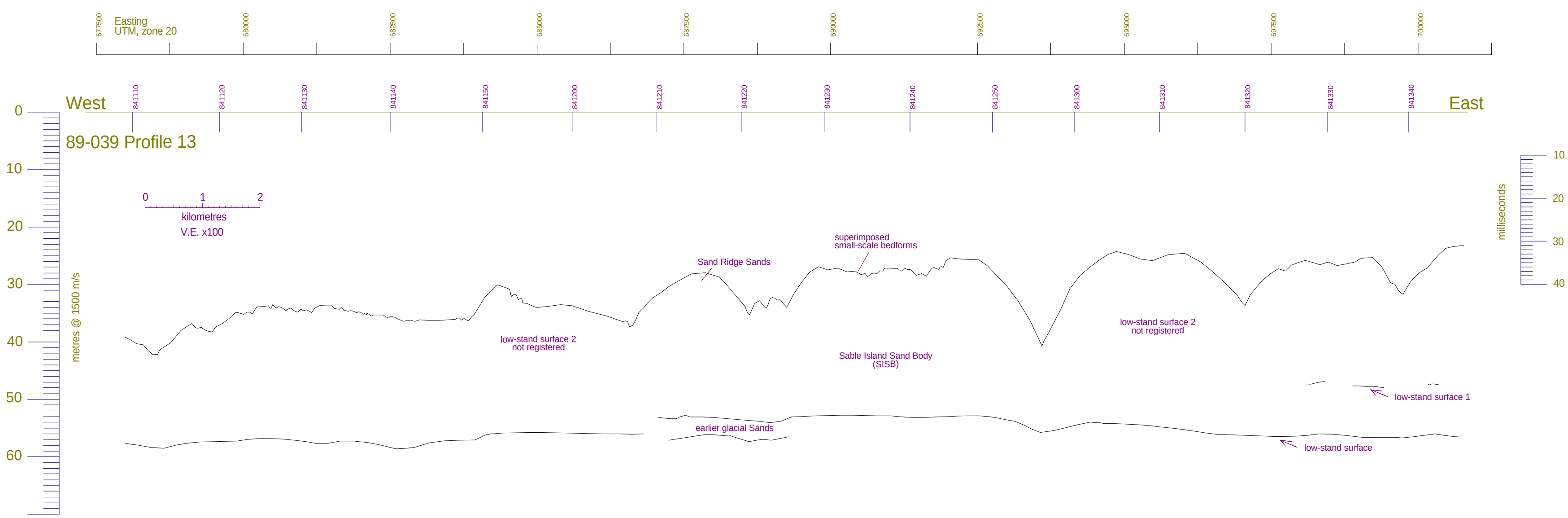
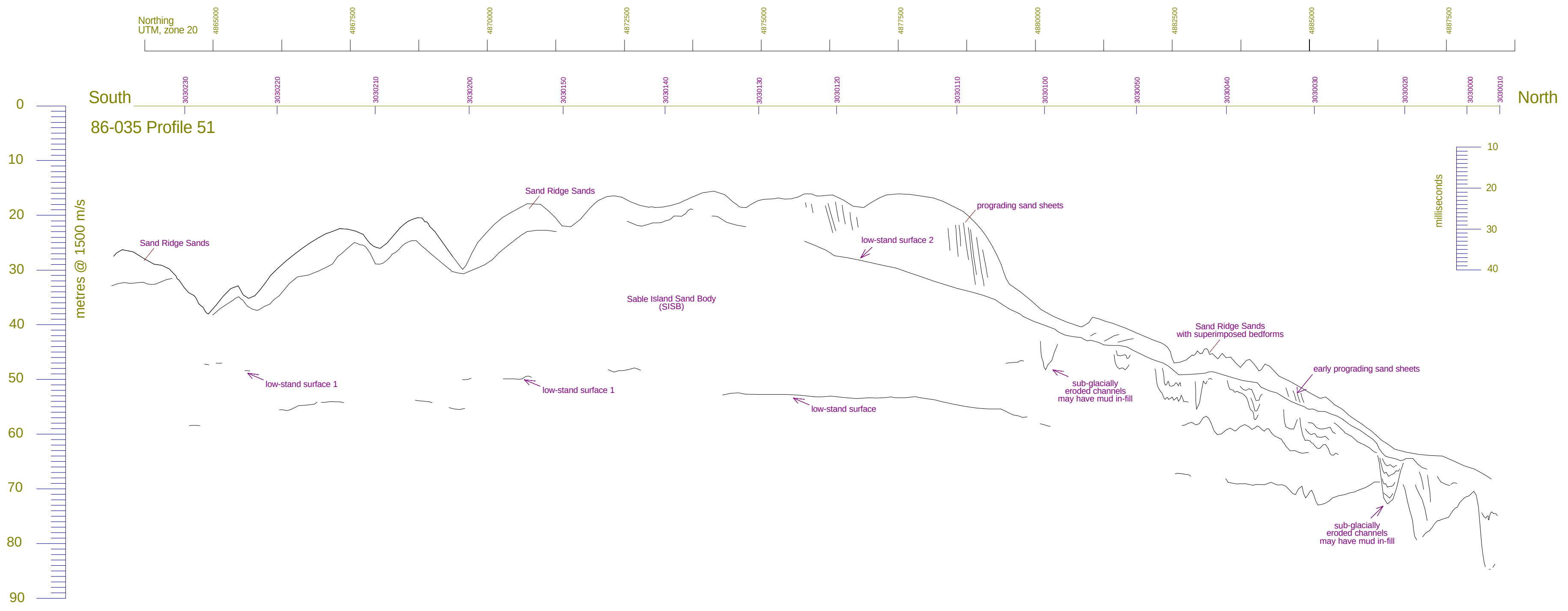
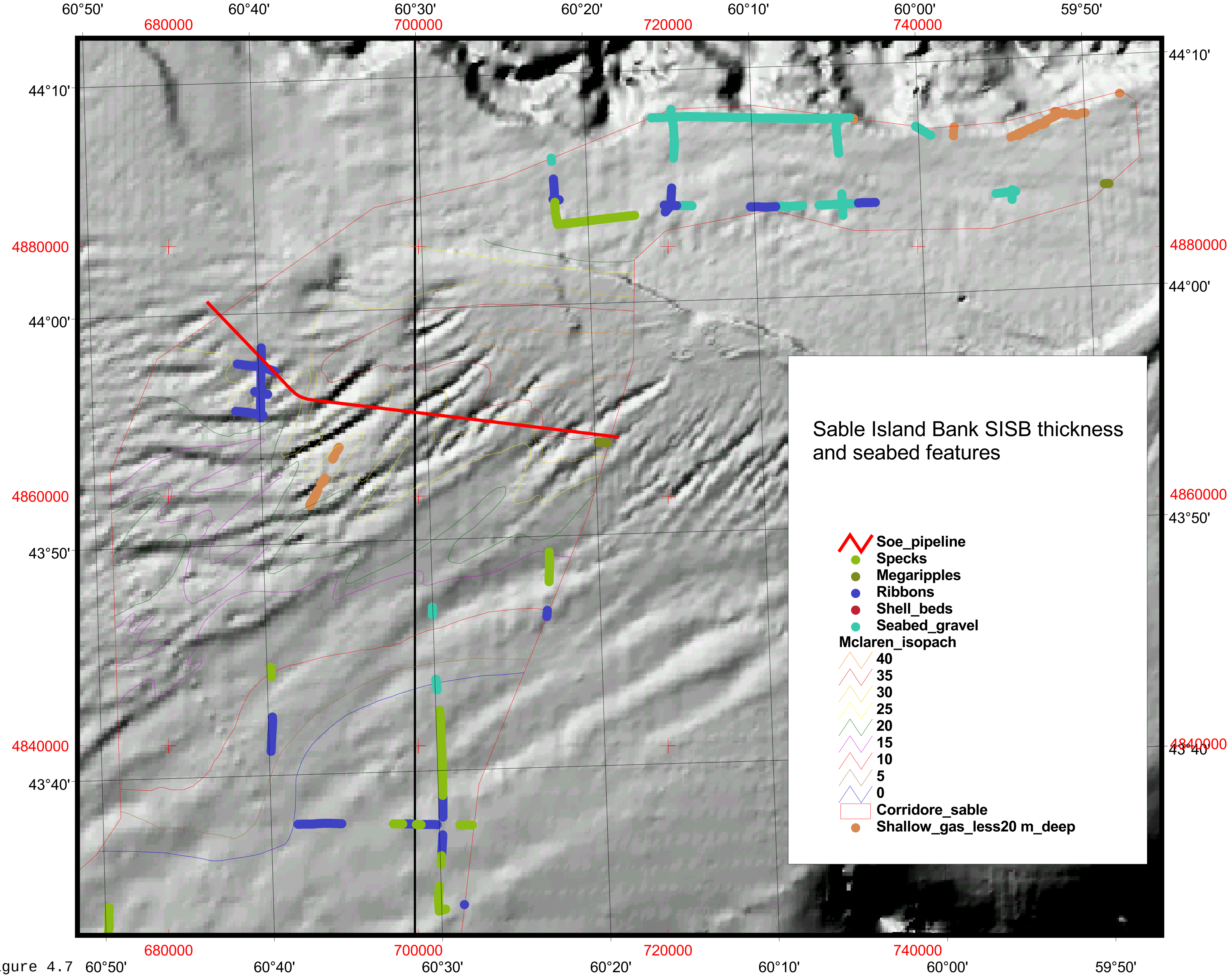


Figure 4.6. GSCA geolgic profile 86-035-51 on Sable Island Bank.

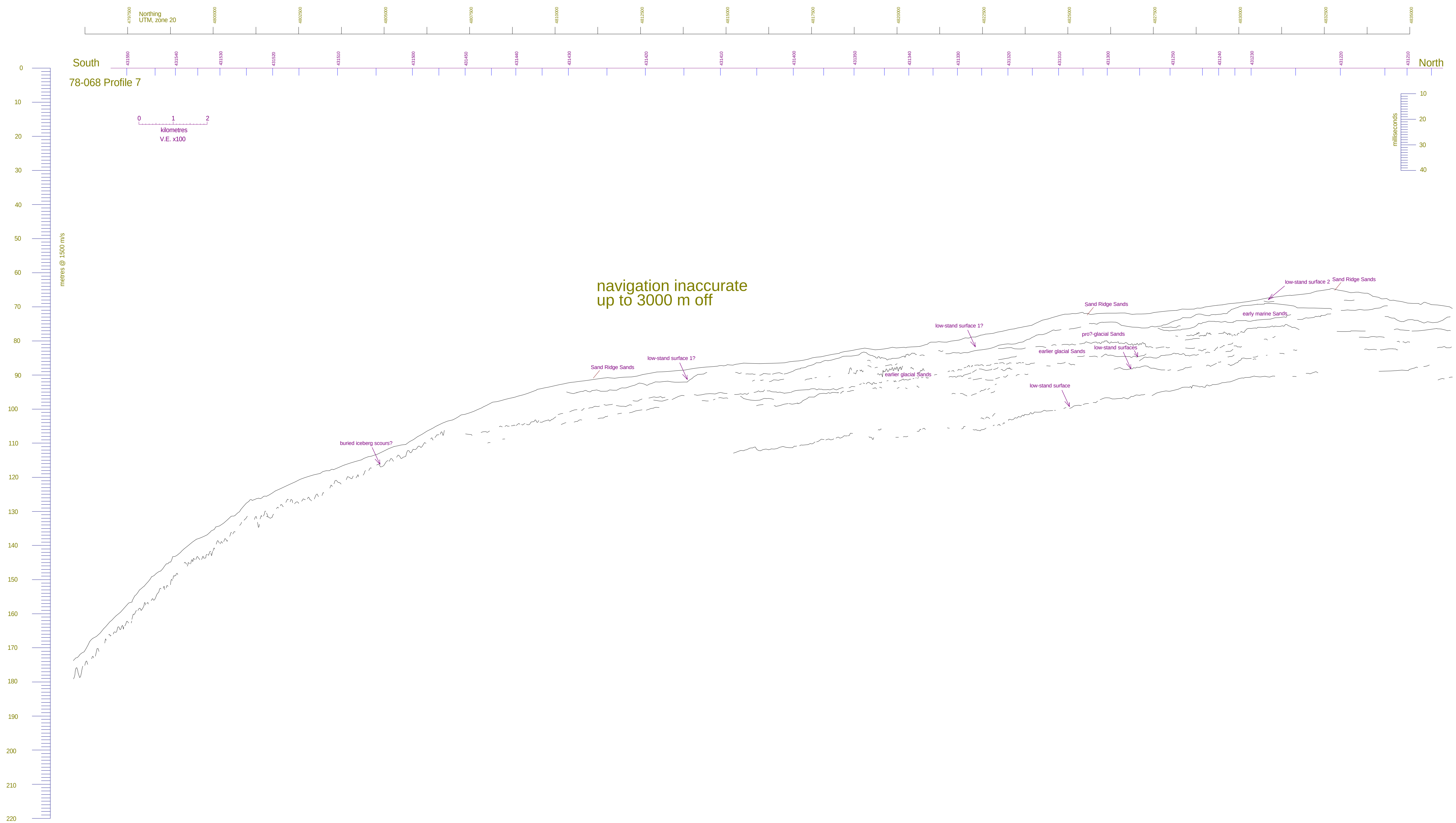


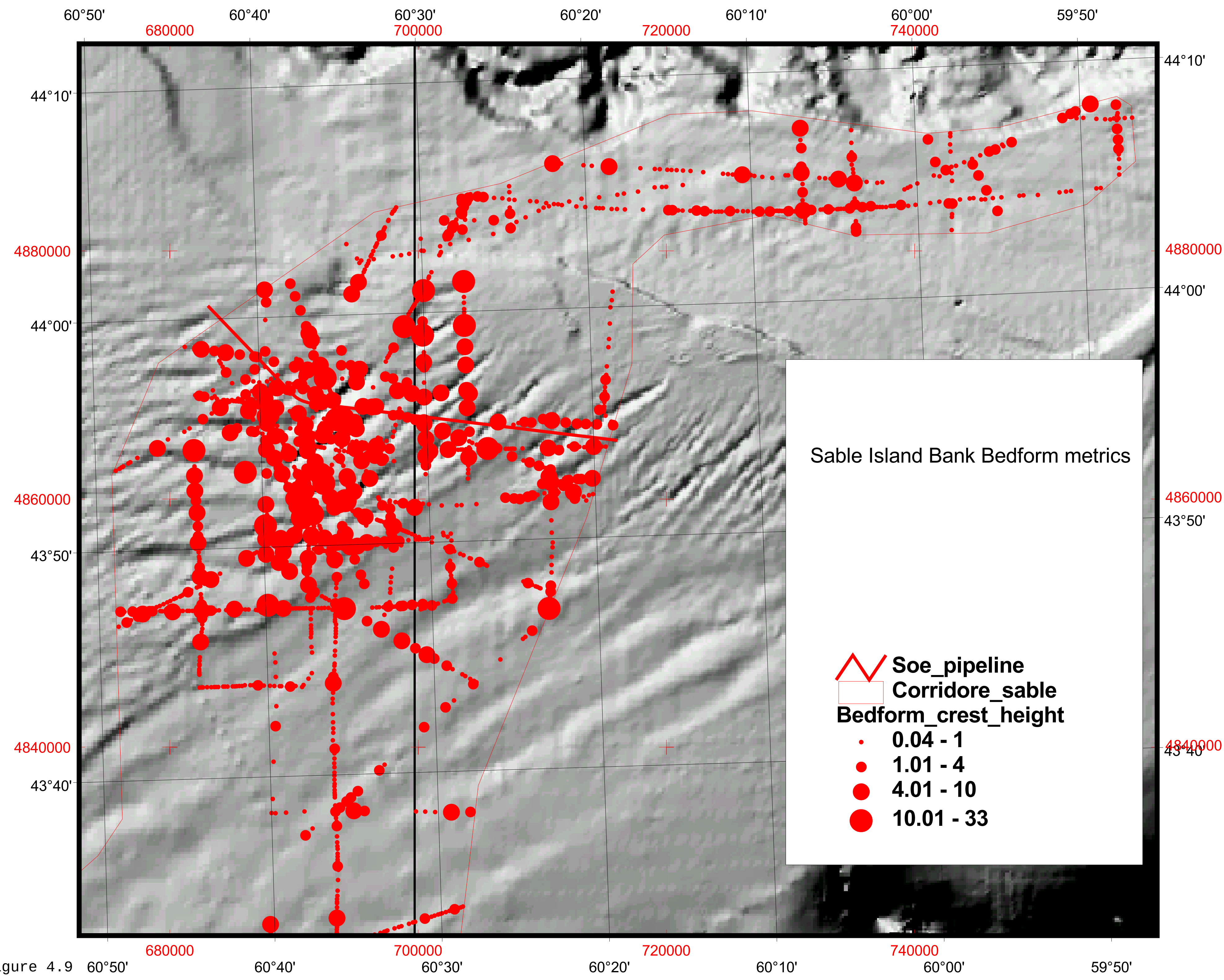


Sable Island Bank SISB thickness and seabed features
Soe_pipeline
Specks
Megaripples
Ribbons
Shell_beds
Seabed_gravel
Mclaren_isopach
40
35
30
25
20
15
10
5
0
Corridore_sable
Shallow_gas_less20 m_deep
60°50'
60°40'
60°30'
60°20'
60°10'
60°00'
59°50'
680000
700000
720000
740000
44°10'
44°00'
43°50'
43°40'
4880000
4860000
4840000

Figure 4.7

Figure 4.8. GSCA geolgic profile 78-068-7 on Sable Island Bank.





Sable Island Bank Bedform metrics
Soe_pipeline
Corridore_sable
Bedform_crest_height
0.04 - 1
1.01 - 4
4.01 - 10
10.01 - 33
60°50'
60°40'
60°30'
60°20'
60°10'
60°00'
59°50'
680000
700000
720000
740000
44°10'
44°00'
43°50'
43°40'
4880000
4860000
4840000

Figure 4.9

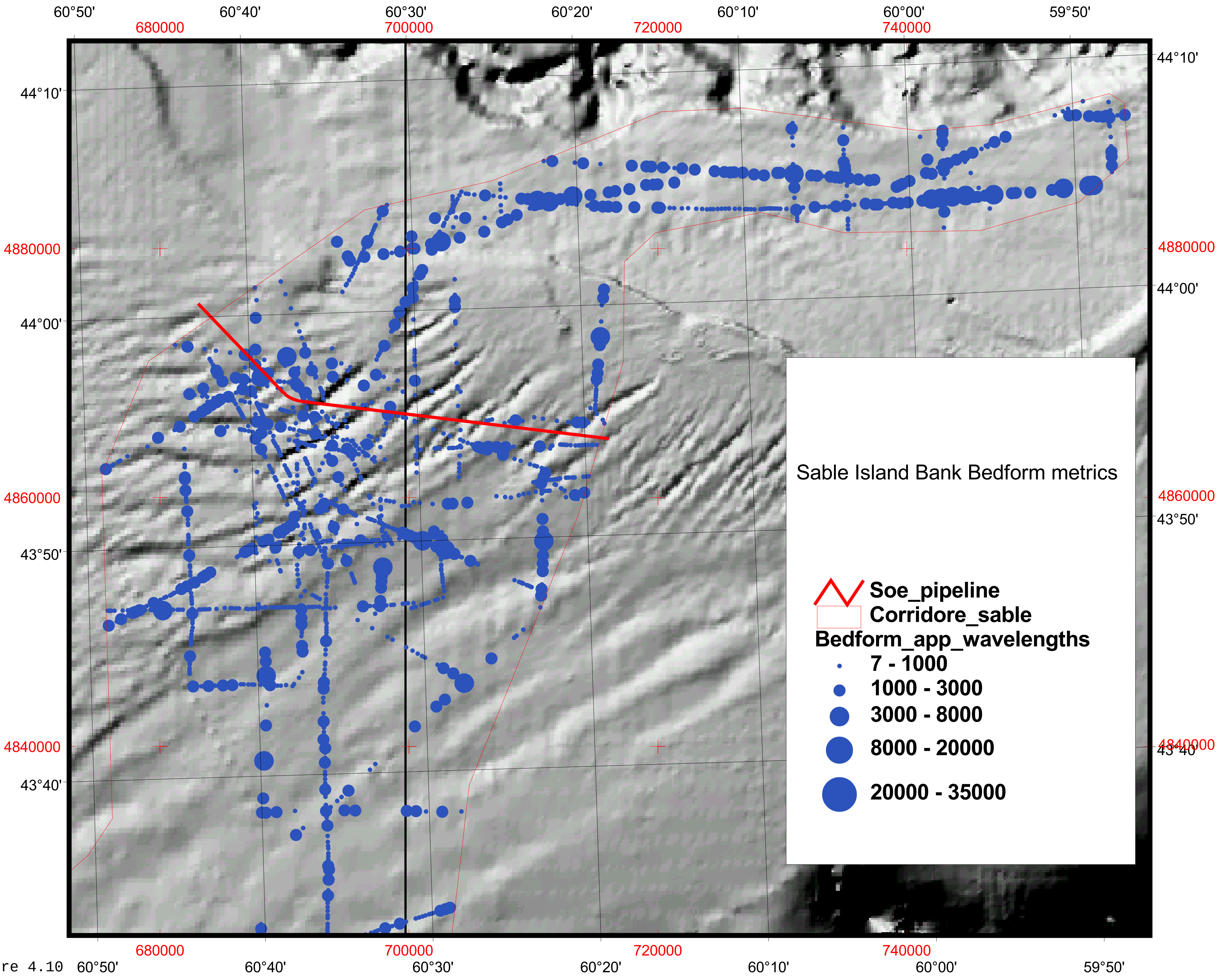

Sable Island Bank Bedform metrics
Soe_pipeline
Corridore_sable
Bedform_app_wavelengths
7 - 1000
1000 - 3000
3000 - 8000
8000 - 20000
20000 - 35000
60°50'
60°40'
60°30'
60°20'
60°10'
60°00'
59°50'
680000
700000
720000
740000
44°10'
44°00'
43°50'
43°40'
4880000
4860000
4840000

Figure 4.10

Figure 4.11. GSCA geolgic profile 85-019-36 on Sable Island Bank.

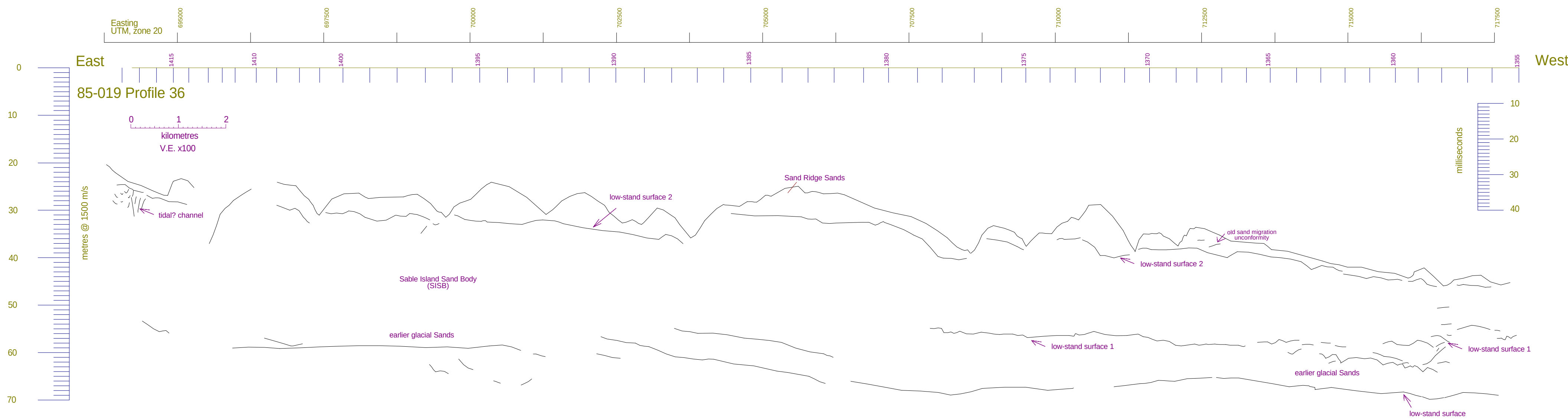
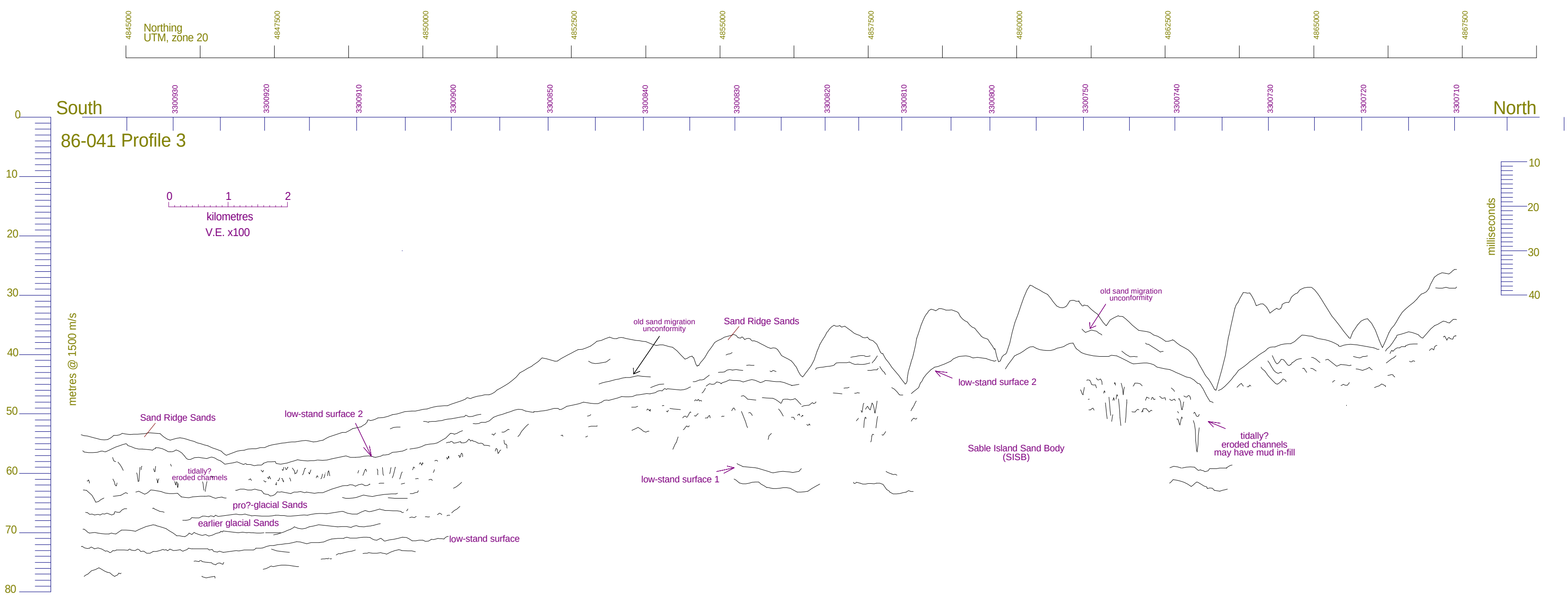


Figure 4.12. GSCA geolgic profile 86-041-3 on Sable Island Bank.



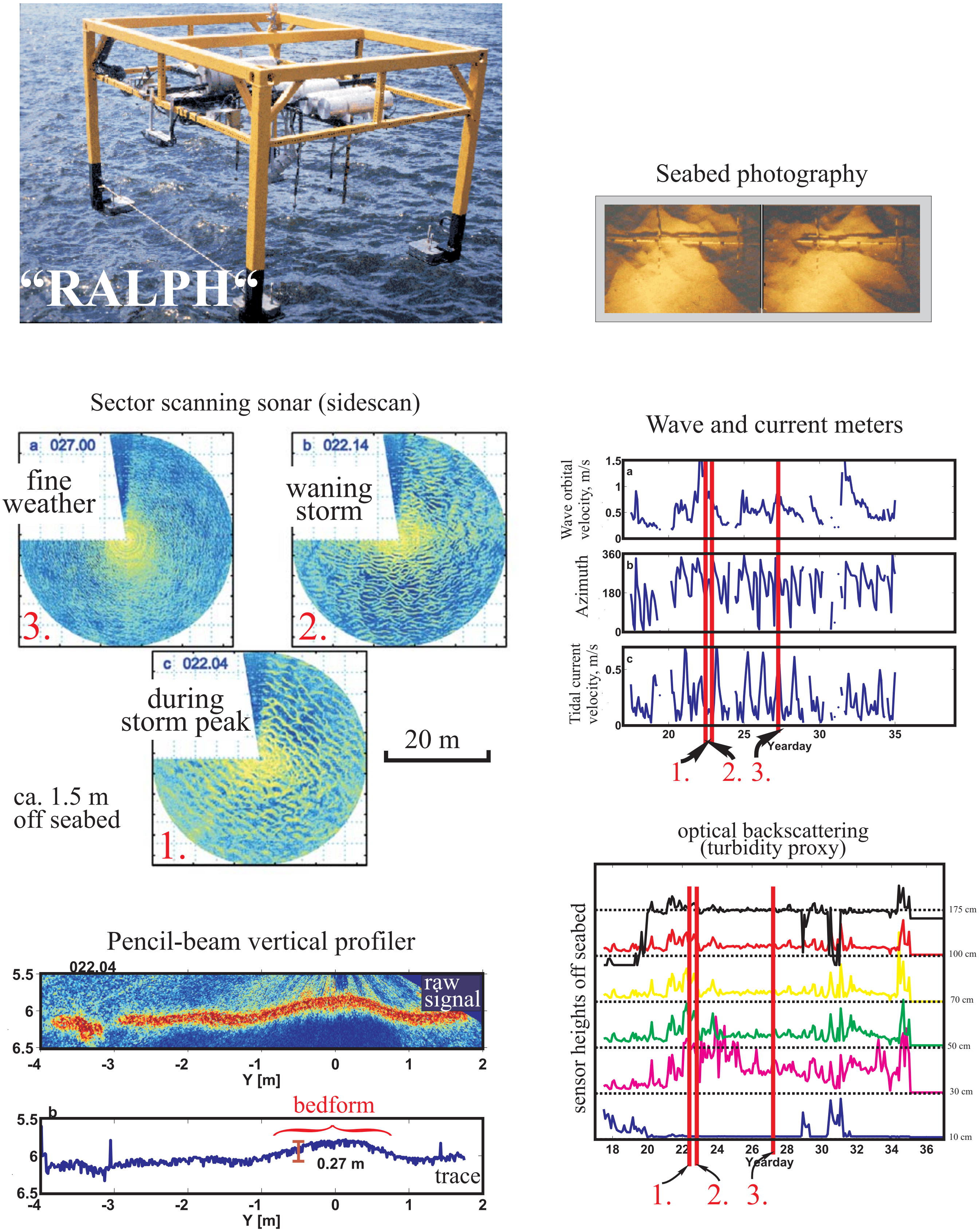


Figure 4.13 *In situ* seabed monitoring capabilities of GSCA-devleoped "RALPH".

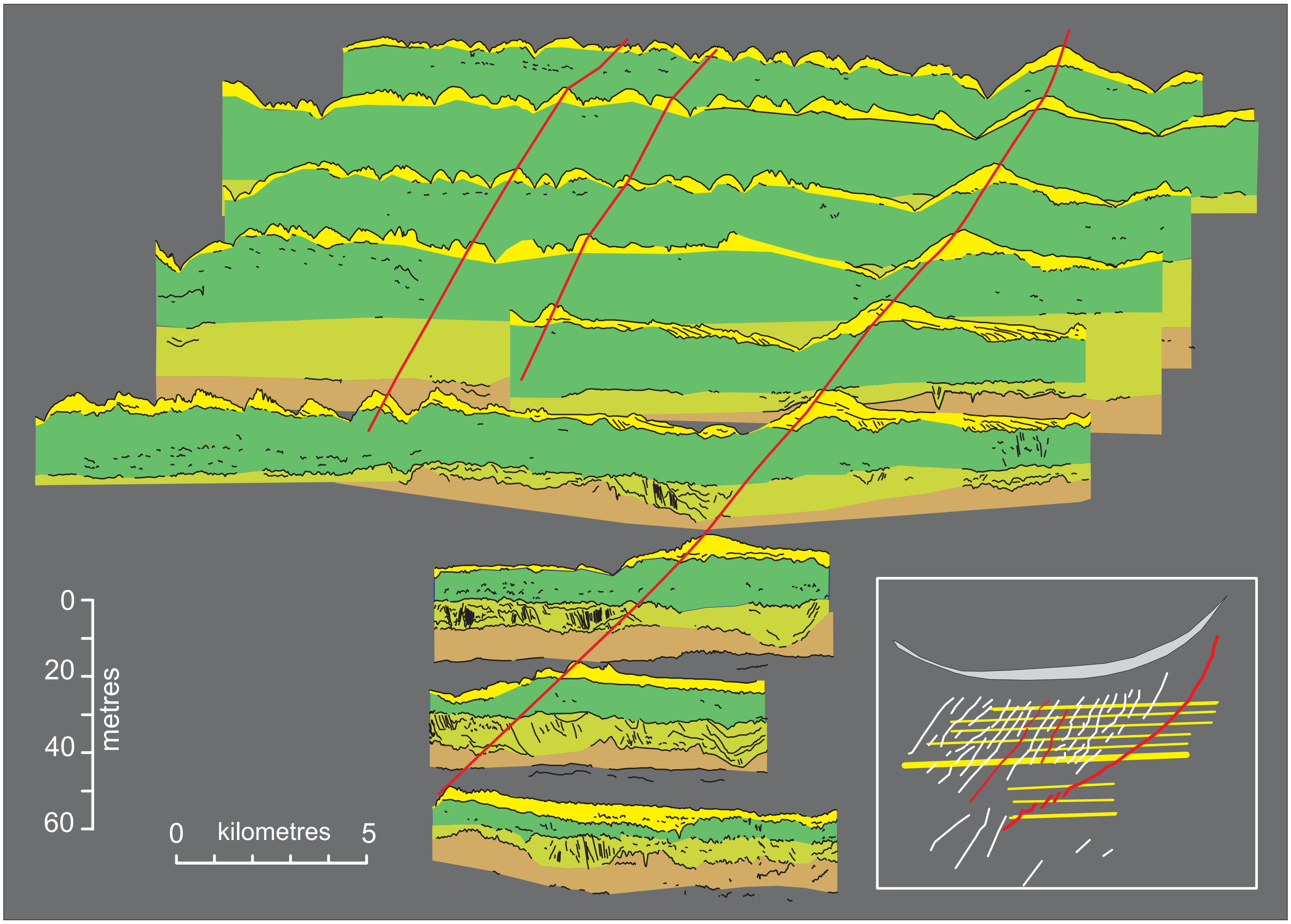
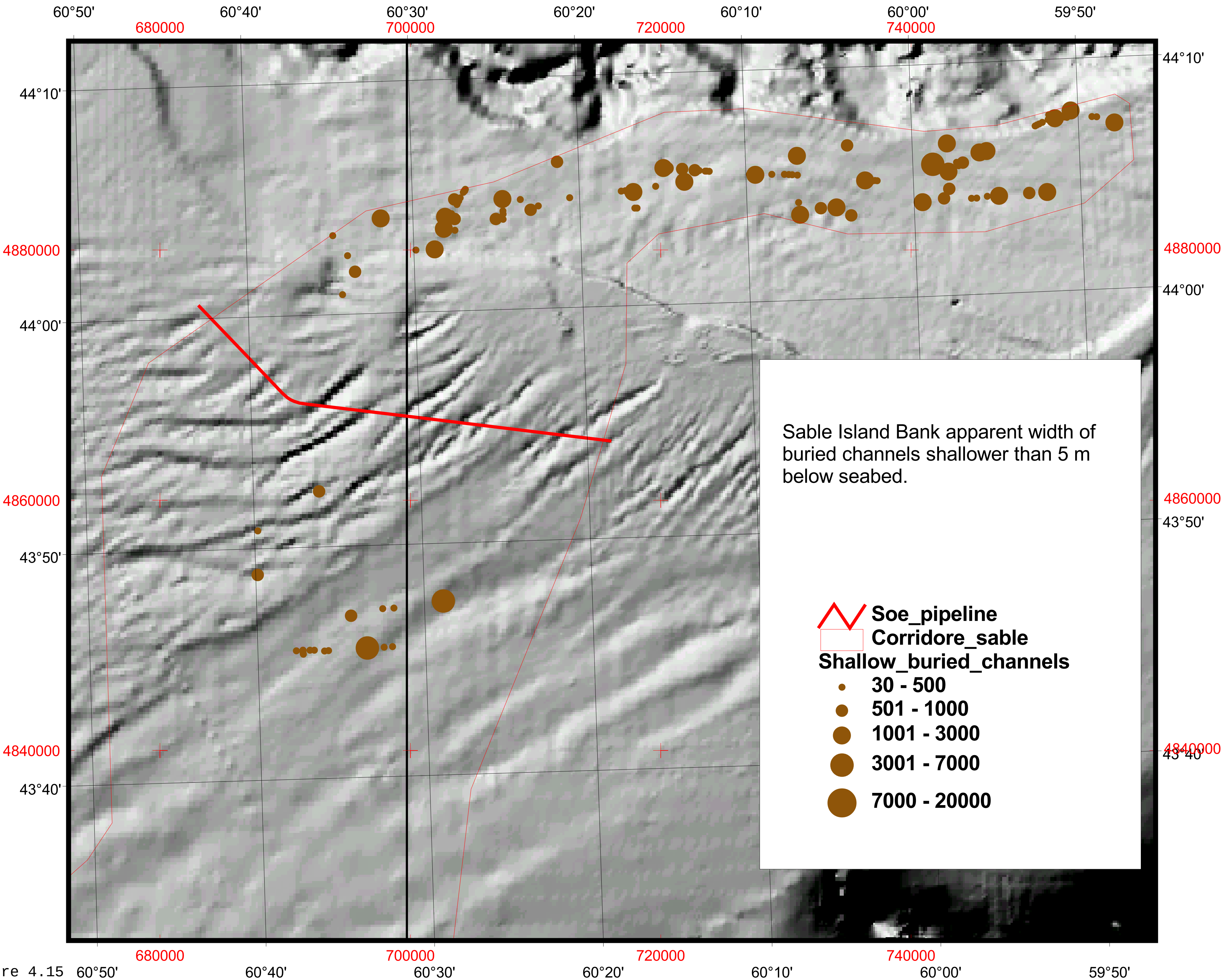


Figure 4.1.4. Series of geologic profiles located south of Sable Island, interpreted from high resolution seismic profiles and arranged in a fence diagram (locations are yellow lines in map insert). Water depth ranges from about 50m in the south to 25m in the north. The yellow upper unit comprises the shoreface-connected sand ridge field overlying relatively quiescent proglacial sands (dark green) which, in turn, overlie high energy proglacial sands (light green). Traces of ridge crests are shown in white in the insert except those shown in red which are also delineated on the profiles. Early eastward sand migration is evident in the deeper area (near base of yellow unit). Most ridges show trough erosion to well below the level of their bases directly under their crests. The largest (most easterly) ridge, named the Harcort-Cameron Ridge, has evolved in the long term, with progressive sea-level rise, not by migratingof the crest, but by progressively cutting into the basal material. This has important implications for understanding ridge migration on the shorter term.


Sable Island Bank apparent width of buried channels shallower than 5 m below seabed.
Soe_pipeline
Corridore_sable
Shallow_buried_channels
30 - 500
501 - 1000
1001 - 3000
3001 - 7000
7000 - 20000
Figure 4.15

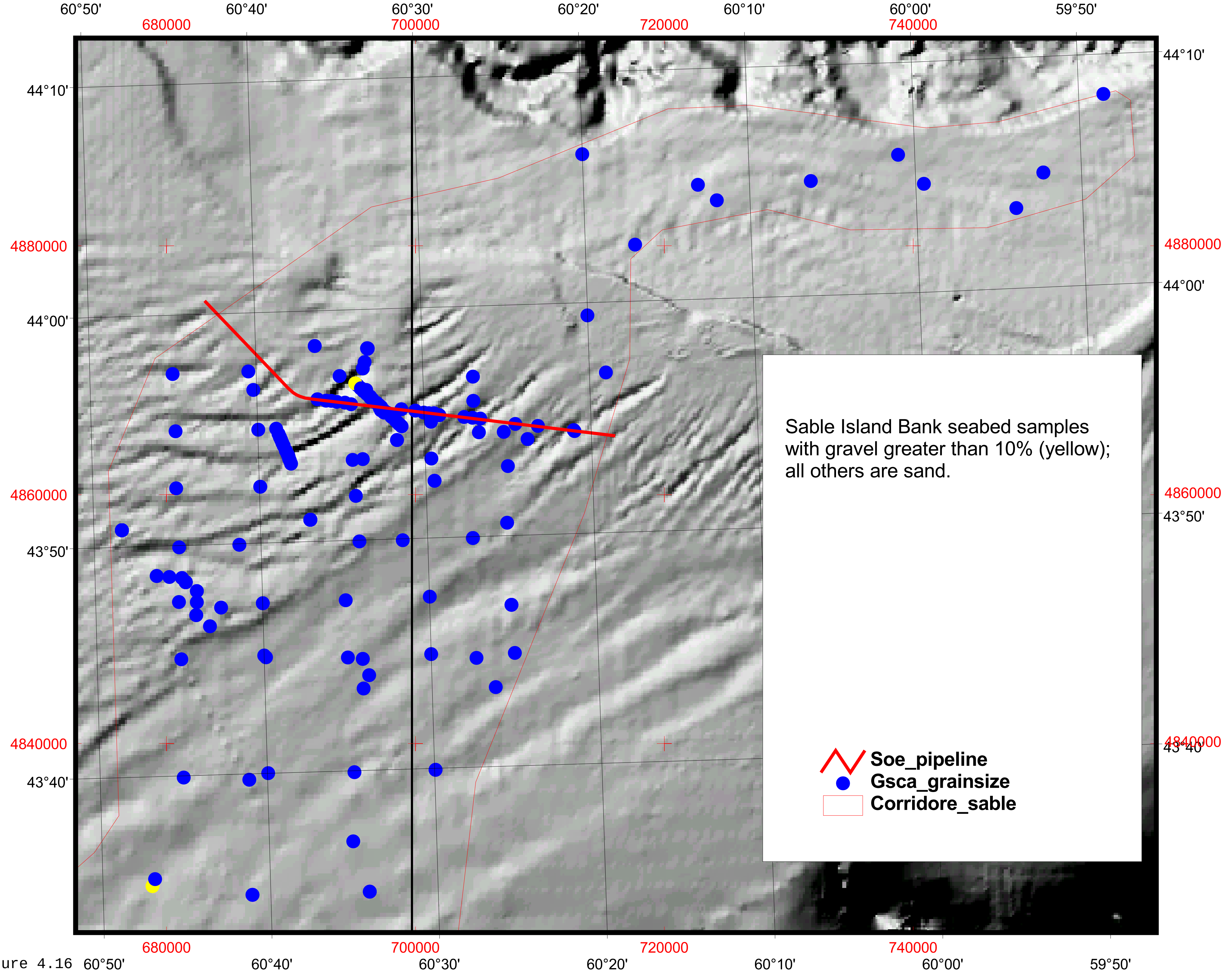
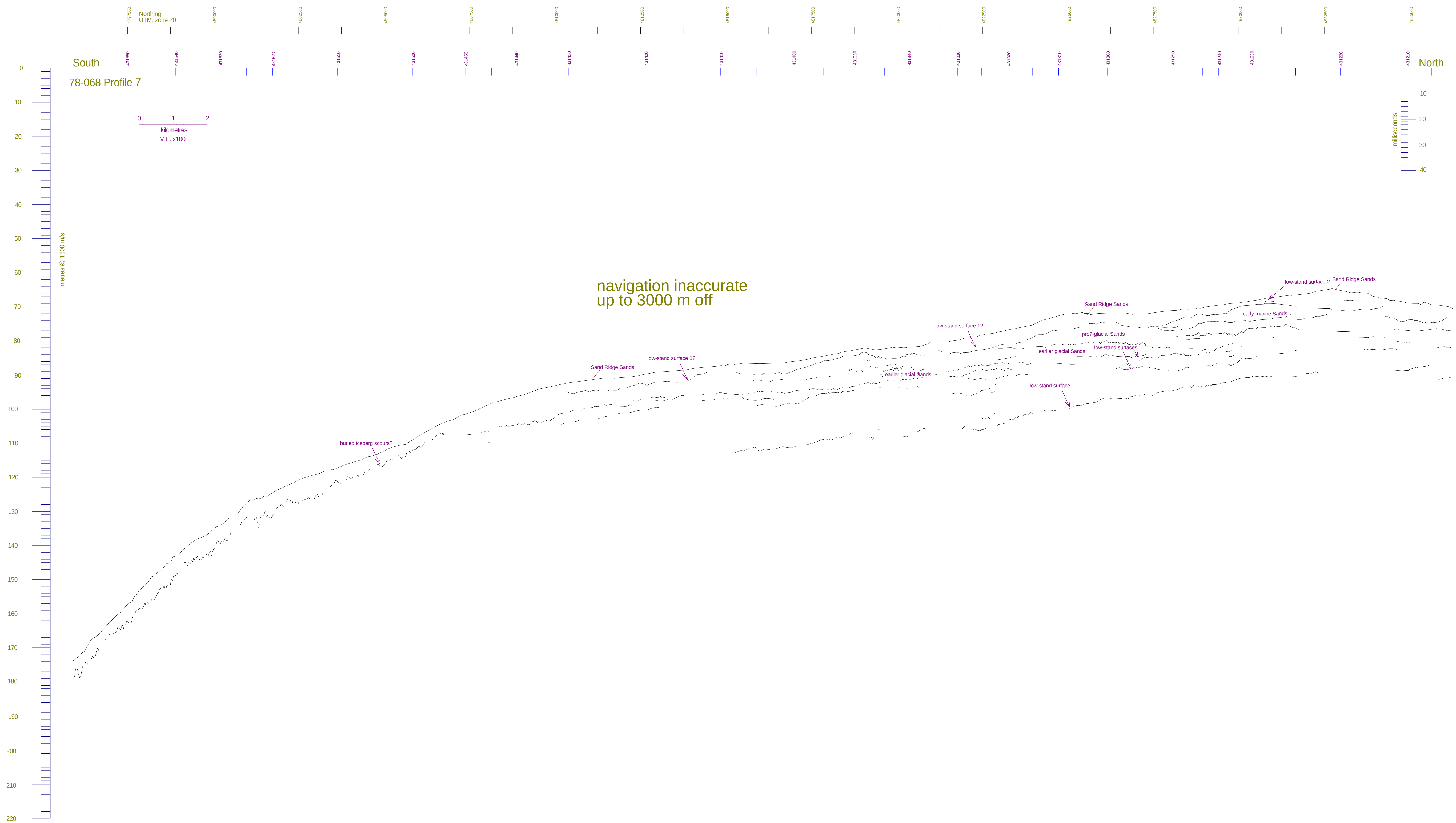

60°50'
680000
60°40'
60°30'
700000
60°20'
720000
60°10'
740000
60°00'
59°50'
44°10'
4880000
44°00'
4860000
43°50'
4840000
43°40'
Sable Island Bank seabed samples with gravel greater than 10% (yellow); all others are sand.
Soe_pipeline
Gsca_grainsize
Corridore_sable

Figure 4.16

Figure 5.1. GSCA geologic profile 78-068-7 on Sable Island Bank.



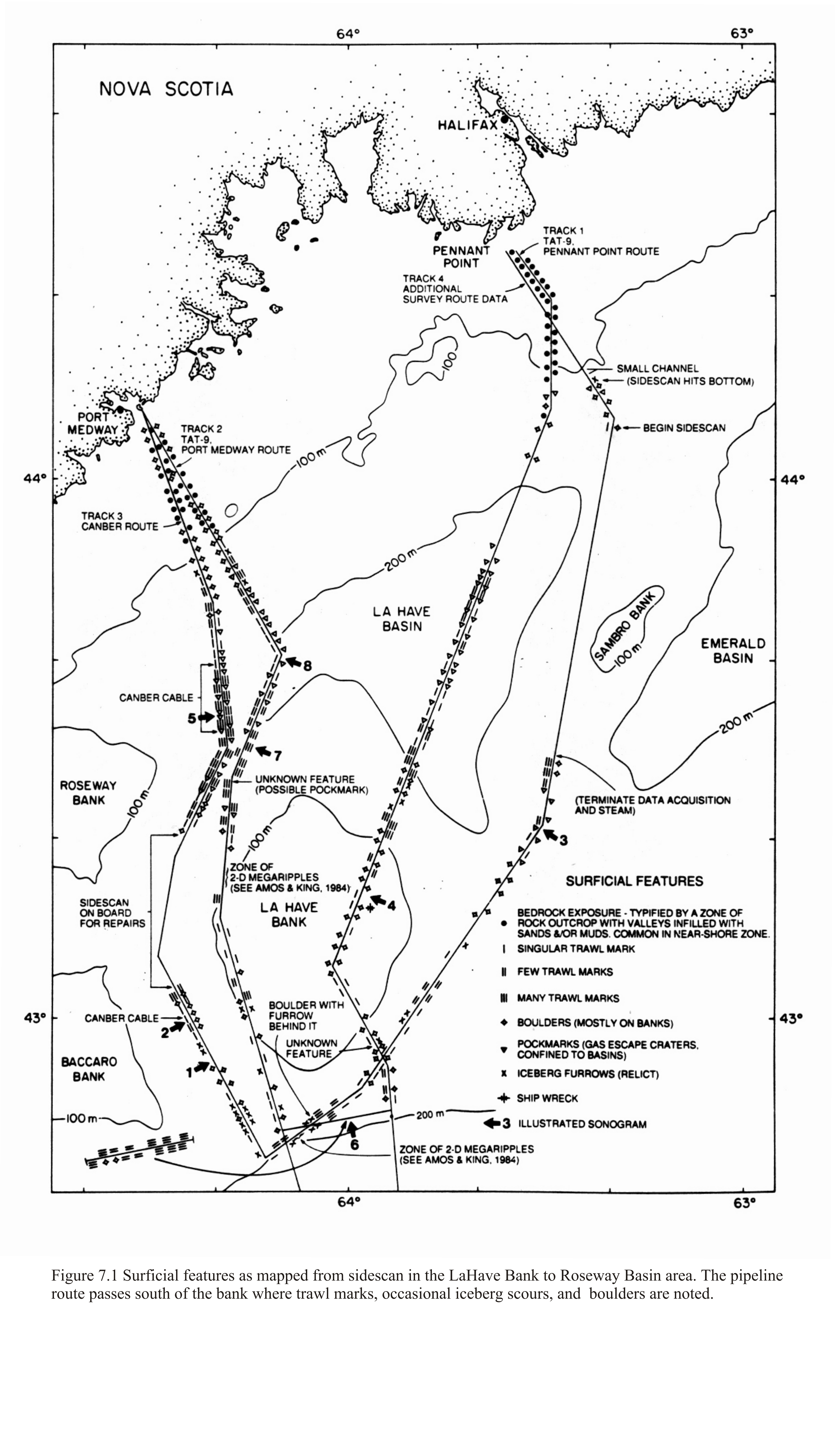


Figure 7.1 Surficial features as mapped from sidescan in the LaHave Bank to Roseway Basin area. The pipeline route passes south of the bank where trawl marks, occasional iceberg scours, and boulders are noted.

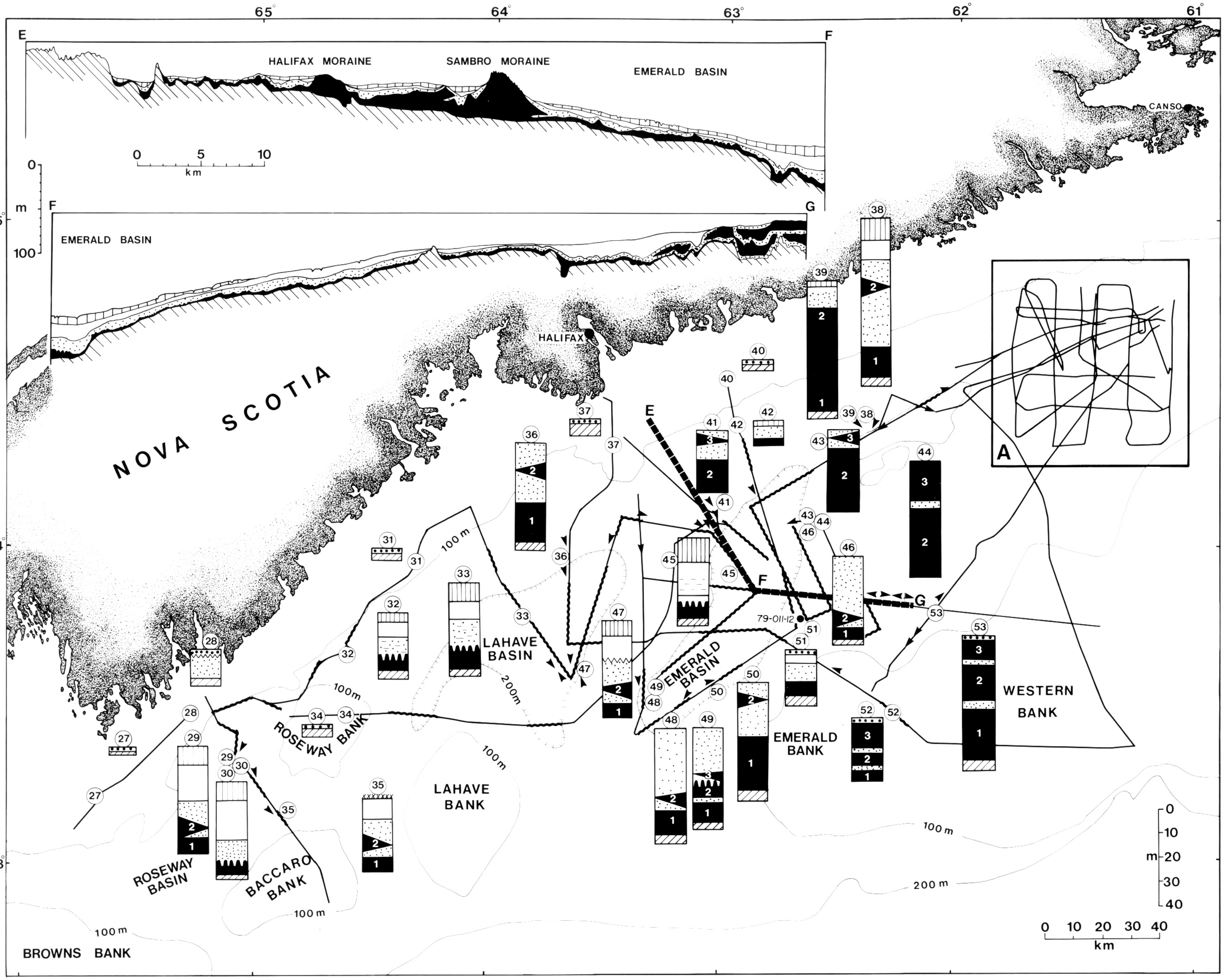


Figure 8.1. Quaternary sediments on western Scotian Shelf. The column sections are derived from seismic profiles and show the presences, thickness, and some features (till tongues and buried ribbed moraines) at various locations, commonly where short cores also exist.

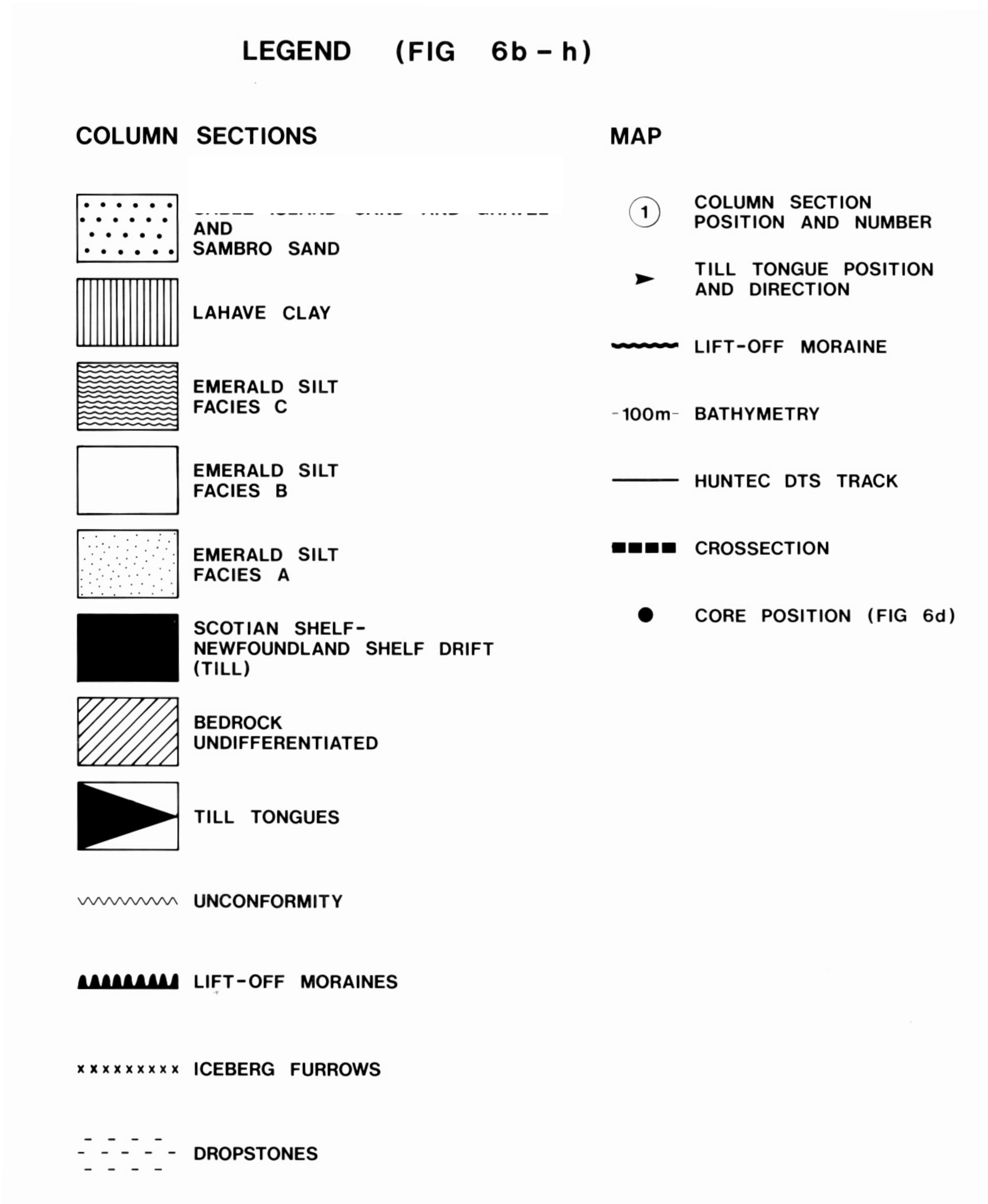


Figure 8.2. Index for column section maps in the preceeding figure.

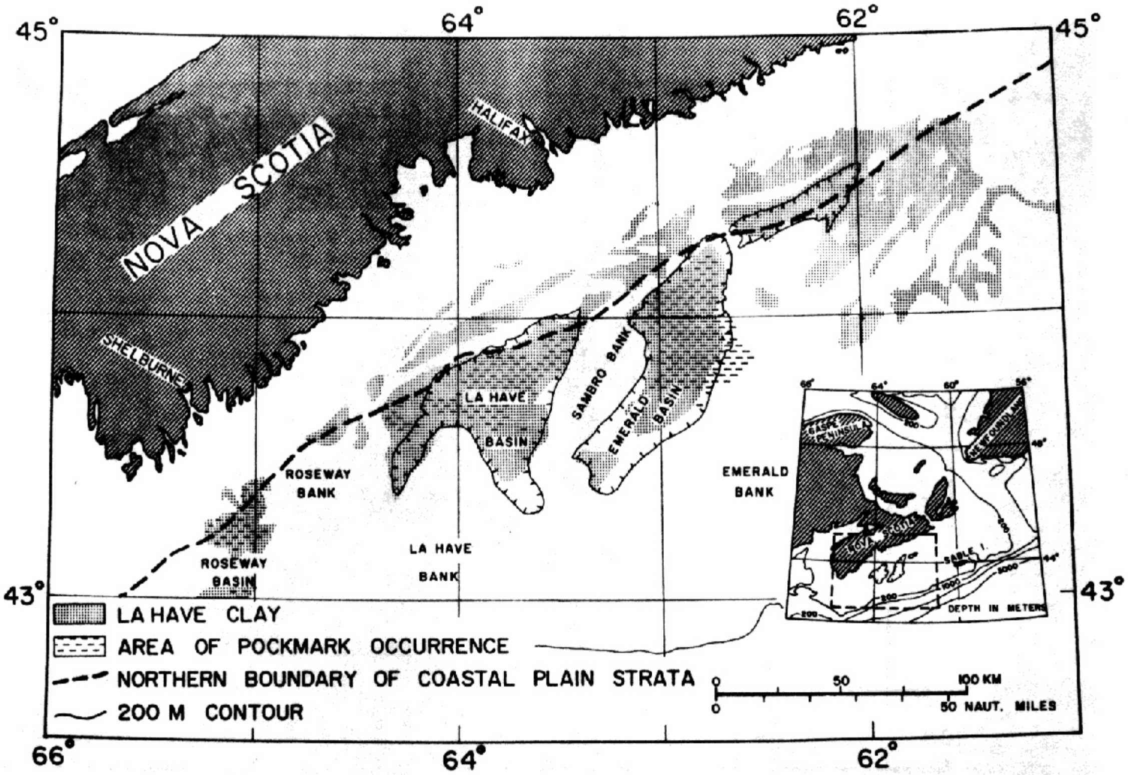


Fig. 3. The distribution of pockmarks on the Scotian Shelf in relation to the LaHave clay and to the northern limit of coastal plain strata.

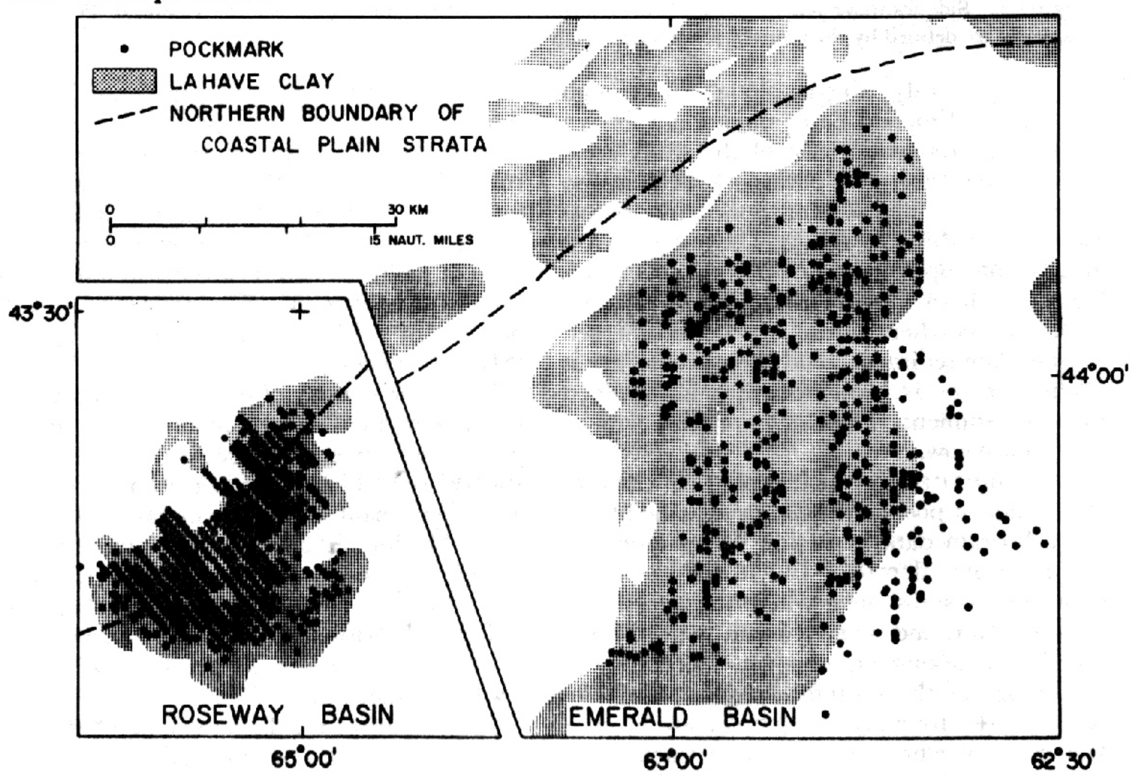


Figure 4. The distribution and relative abundance of pockmarks in Roseway and Emerald Basins. These pockmarks were plotted at 0.93- to 3.7-km intervals. It is estimated that the plot represents about 1 percent of the pockmarks that actually occur.

Figure 8.3 Pockmark distribution in Roseway and Emerald Basins. Estimates in Roseway Basin are 200 per square kilometre; smaller, unobserved features would be more plentiful.

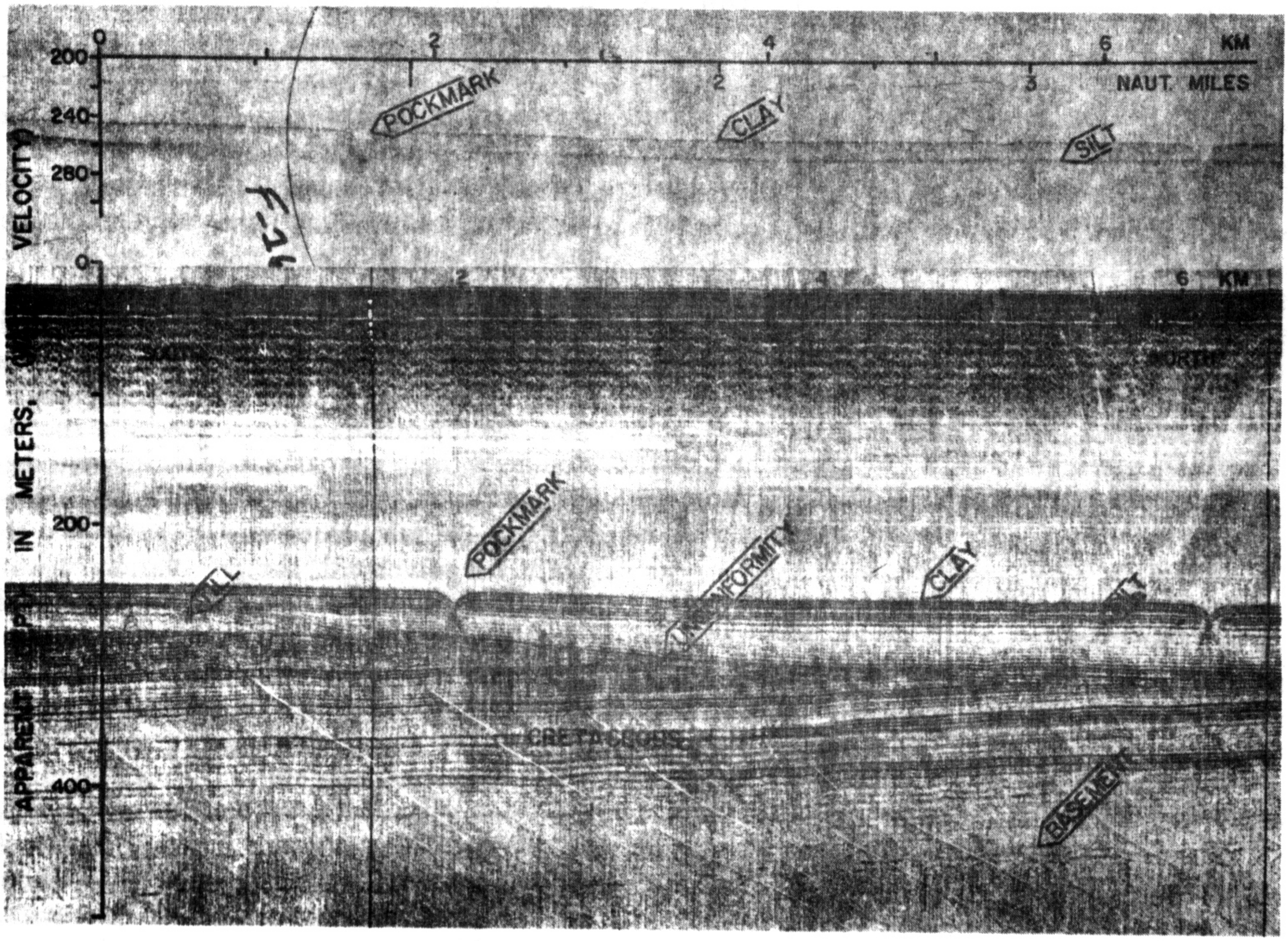


Figure 5. Continuous, seismic-reflection profile (lower) and accompanying echogram (upper) across pockmarks in LaHave Basin. The seismic record illustrates the nature and relationship of the unconsolidated sediment, and the unconformity developed across the underlying coastal plain strata. The record was obtained with a Bolt Associates Marine Profiler (air gun) Model 600A fitted with a 1-cu-in. chamber and operated at a pressure of 1500 psi.

Figure 8.4 Pockmarks in LaHave Basin from echogram (above) and air gun (below) profiles..

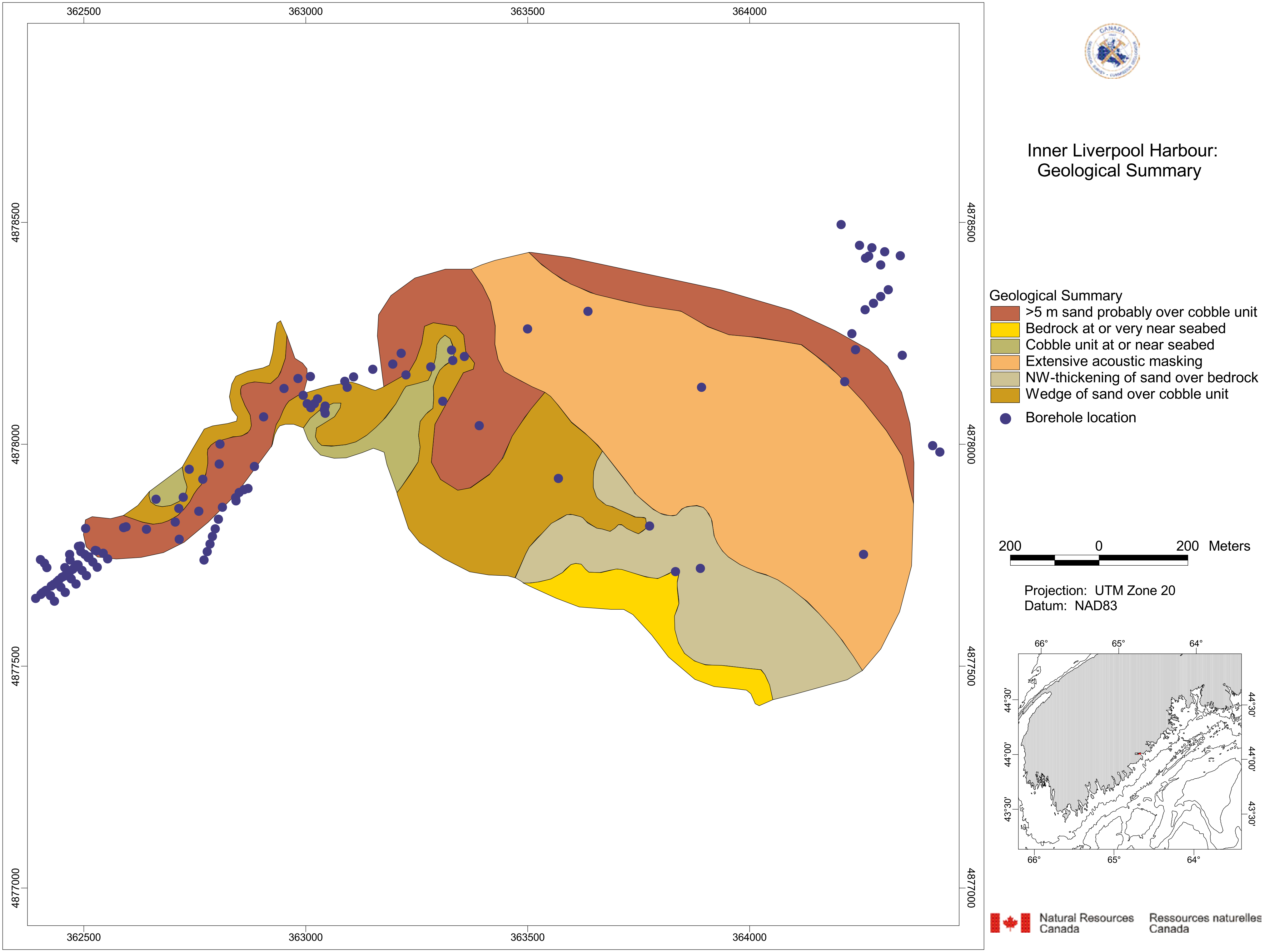

Inner Liverpool Harbour:
Geological Summary
Geological Summary
>5 m sand probably over cobble unit
Bedrock at or very near seabed
Cobble unit at or near seabed
Extensive acoustic masking
NW-thickening of sand over bedrock
Wedge of sand over cobble unit
Borehole location
200 0 200 Meters
Projection: UTM Zone 20
Datum: NAD83
362500
363000
363500
364000
4878500
4878000
4877500
4877000
66°
65°
64°
44°30'
44°00'
43°30'
Natural Resources Canada
Ressources naturelles Canada

Figure 10.1

Cruise	DAYTIME	time		Latitude	Longitude	Emerald Silt	Sand	Sand & Gravel patches	Gravel	Till	Bedrock	LaHave Clay	Boulders	Soils greater than 10m	Soils greater than 5m	megaripples	ripples	ribbons	shallow gas	pockmarks	anthropogenic undiff	trawl or anchor marks	comments
	nb layback applied in wrong direction	no data=	-9999	layback= move UP data relative to time		applied huntec layback=20sec applied ss laybackto part=1min+10s	applied ss layback=1min+10sec	applied ss layback=1min+10sec	applied ss layback=1min+10sec	applied ss layback=1min+10sec	applied ss layback=1min+10sec	applied huntec layback=20sec	applied ss layback=1min+10sec	applied airgun layback=10sec	applied huntec layback=20sec	applied ss layback=1min+10sec				applied huntec layback=20sec			
						subcrop=<1m 1 = subcrop 2 = outcrop	0 = none 1 = sand 2 = thin sand			0 = none 1 = till 2 = thin till 3 = subcrop		1 = clay 2 = thin cla	1 = scattered 2 = dense 3 = very dense			0 = none 1 = well defined 2 = low relief							
95030	294230000	230000	2300	43.68004	-64.50089	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
95030	294230010	230010	2300.1	43.68023	-64.50082	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230020	230020	2300.2	43.68041	-64.50076	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230030	230030	2300.3	43.6806	-64.50071	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230040	230040	2300.4	43.68081	-64.50066	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230050	230050	2300.5	43.68102	-64.50062	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230100	230100	2301	43.68125	-64.50059	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230110	230110	2301.1	43.68147	-64.50059	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230120	230120	2301.2	43.68169	-64.50059	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230130	230130	2301.3	43.68191	-64.50059	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230140	230140	2301.4	43.68214	-64.50059	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230150	230150	2301.5	43.6824	-64.50057	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230200	230200	2302	43.68265	-64.50056	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230210	230210	2302.1	43.68289	-64.50054	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230220	230220	2302.2	43.68312	-64.50053	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230230	230230	2302.3	43.68336	-64.50052	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230240	230240	2302.4	43.68359	-64.5005	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
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95030	294230310	230310	2303.1	43.68427	-64.50052	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230320	230320	2303.2	43.68449	-64.50053	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230330	230330	2303.3	43.6847	-64.50055	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230340	230340	2303.4	43.68491	-64.5006	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230350	230350	2303.5	43.68512	-64.50064	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
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95030	294230410	230410	2304.1	43.68553	-64.50073	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230420	230420	2304.2	43.68571	-64.50077	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230430	230430	2304.3	43.68591	-64.50082	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
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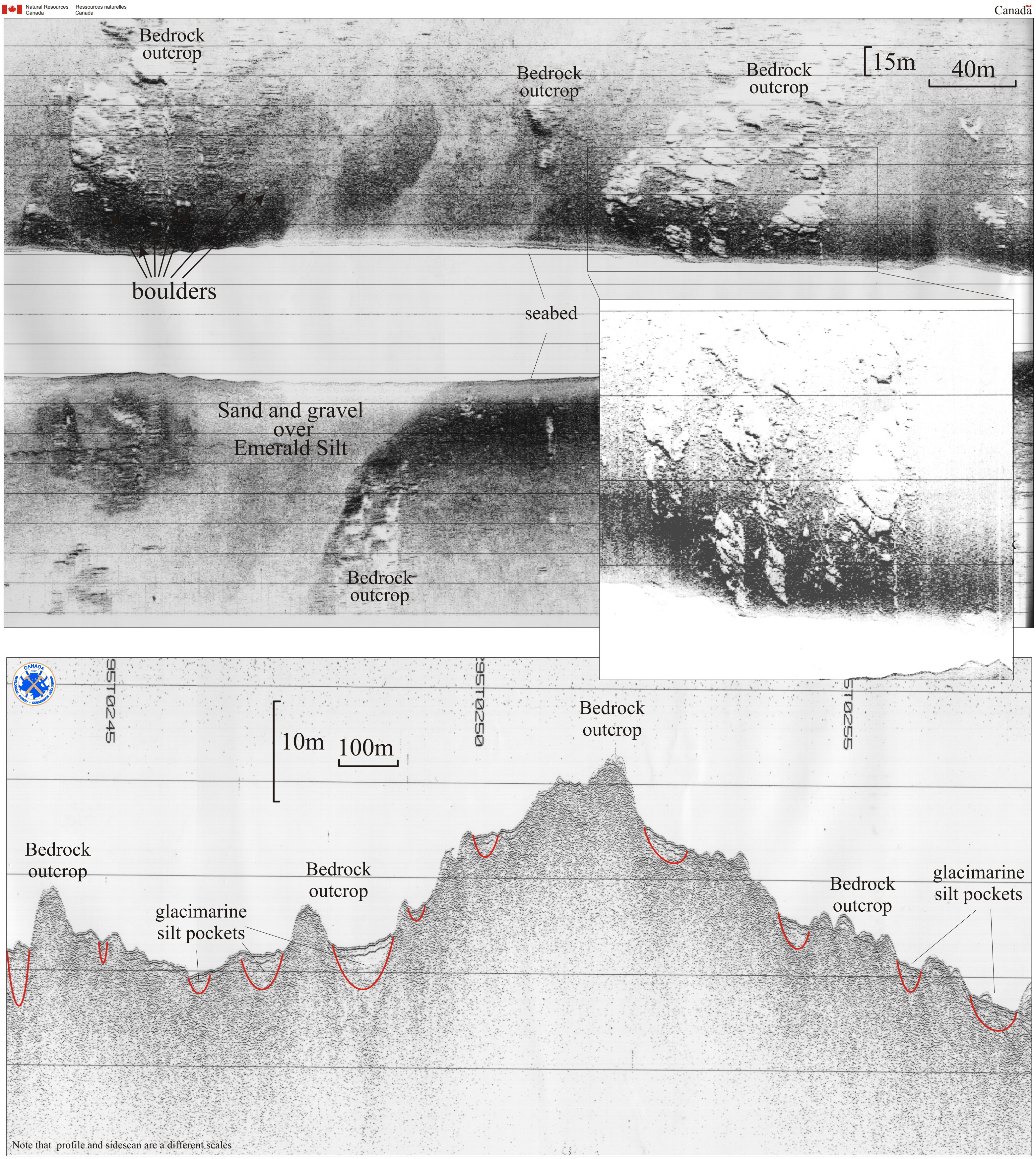
95030	294230500	230500	2305	43.68647	-64.50098	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230510	230510	2305.1	43.68664	-64.50102	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230520	230520	2305.2	43.68682	-64.50106	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230530	230530	2305.3	43.68699	-64.50111	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230540	230540	2305.4	43.68717	-64.50114	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230550	230550	2305.5	43.68733	-64.50118	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
95030	294230600	230600	2306	43.6875	-64.50123	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230610	230610	2306.1	43.68765	-64.50127	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230620	230620	2306.2	43.68782	-64.50131	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230630	230630	2306.3	43.688	-64.50137	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230640	230640	2306.4	43.68815	-64.5014	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230650	230650	2306.5	43.68834	-64.50145	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230700	230700	2307	43.68851	-64.5015	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230710	230710	2307.1	43.68866	-64.50152	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1
95030	294230720	230720	2307.2	43.68885	-64.50157	1	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1

Figure 10.2



95-030 Huntec and 330kHz sidescan, 295/0250

E. King, 2002

Figure 10.3. Sidescan and Huntec boomer (sub-bottom profiler) images offshore Liverpool (ca. 100 m water depth) showing bedrock-dominated ridges with interspersed pockets of sand-covered Emerald Silt. Insert blow-up depicts

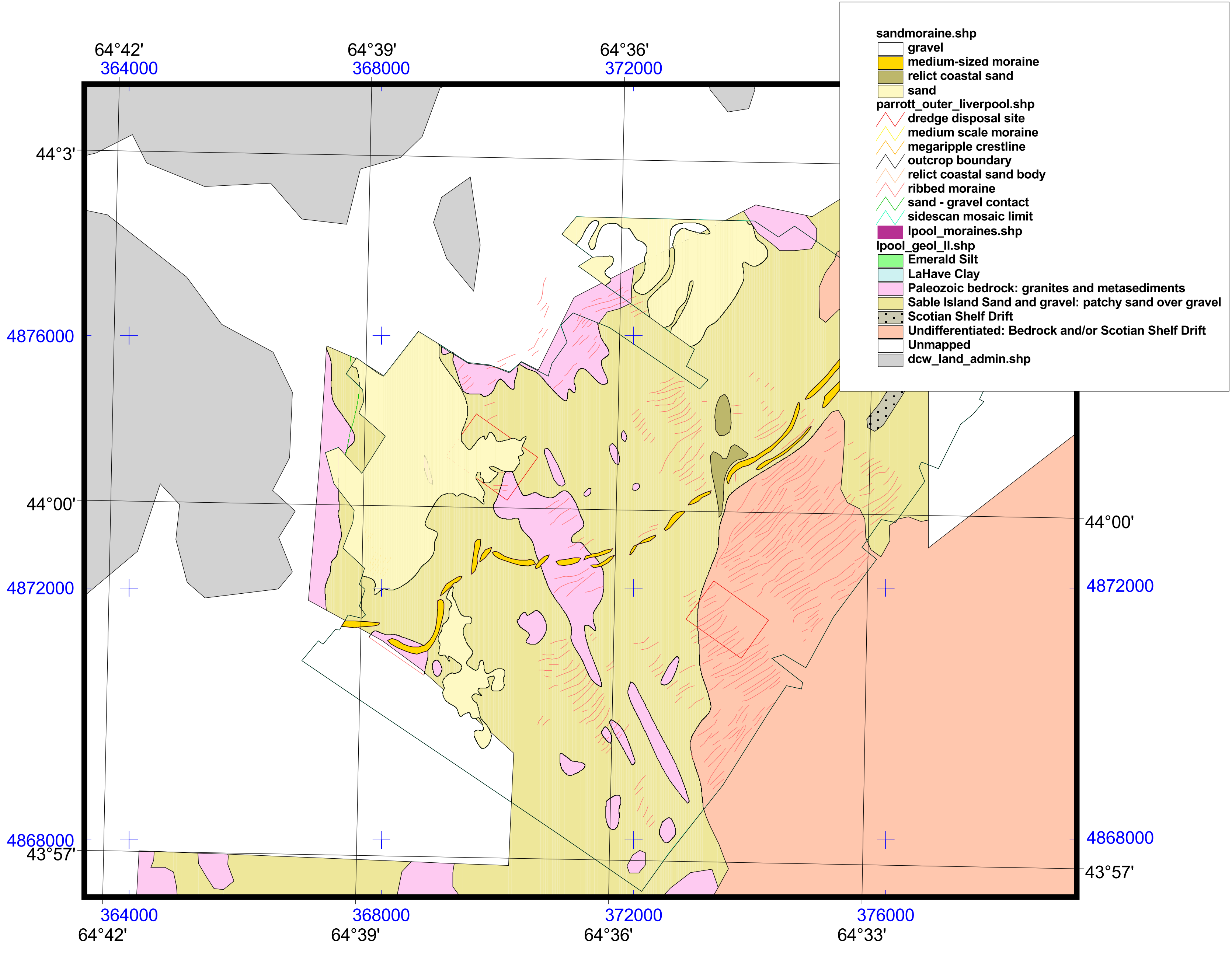


Figure 10.4. Surficial geology compilation offshore Liverpool, NS.

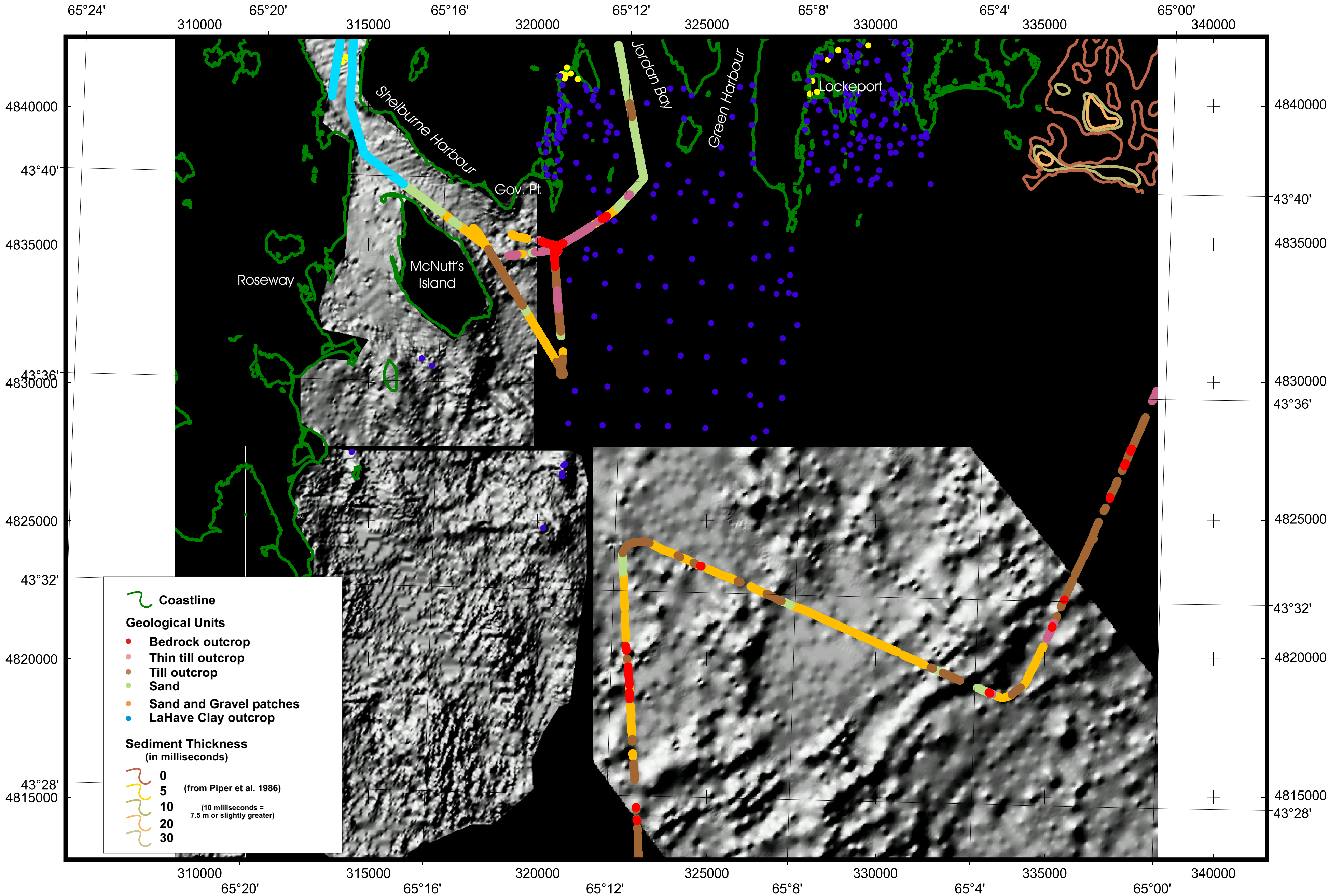
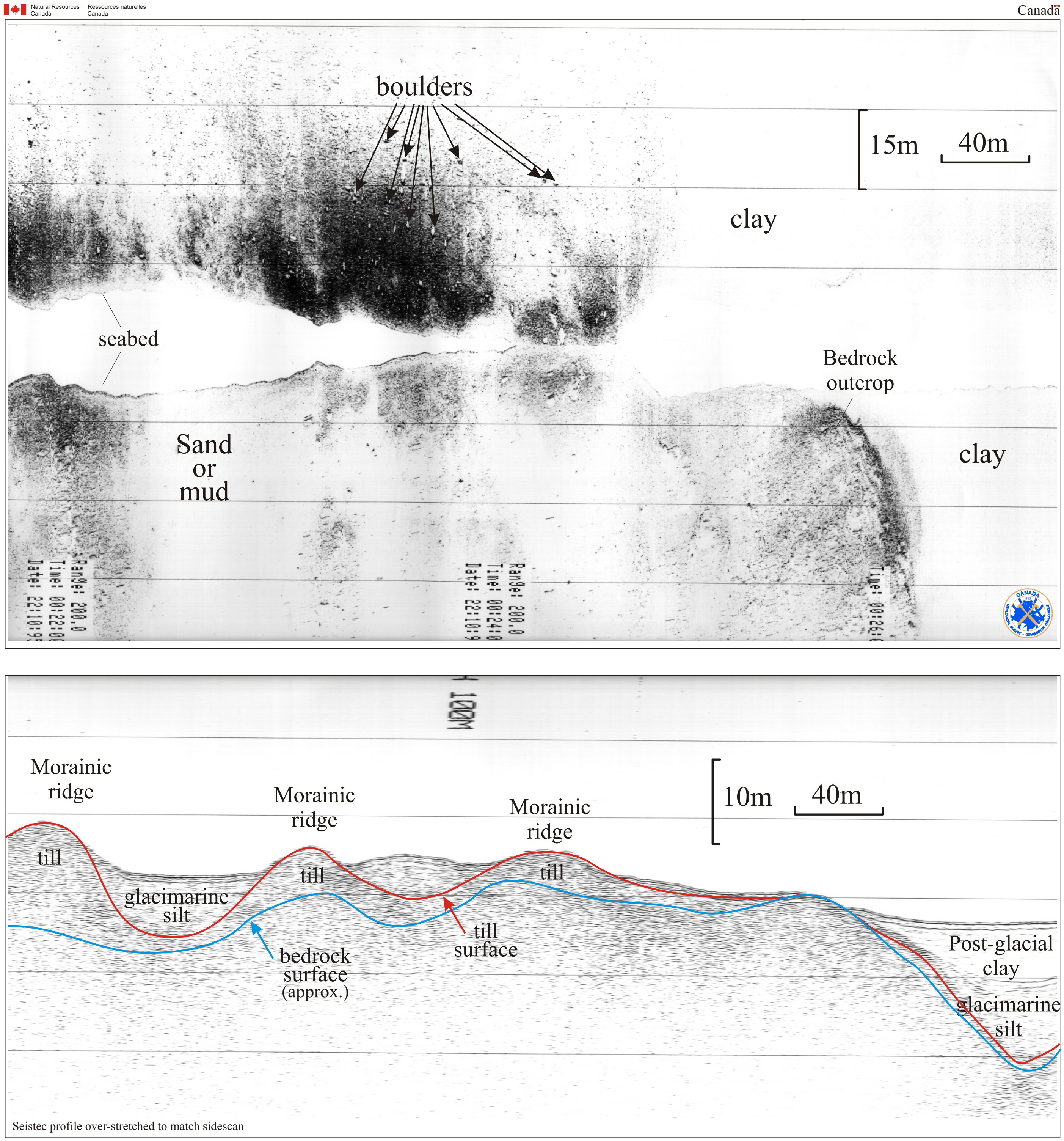


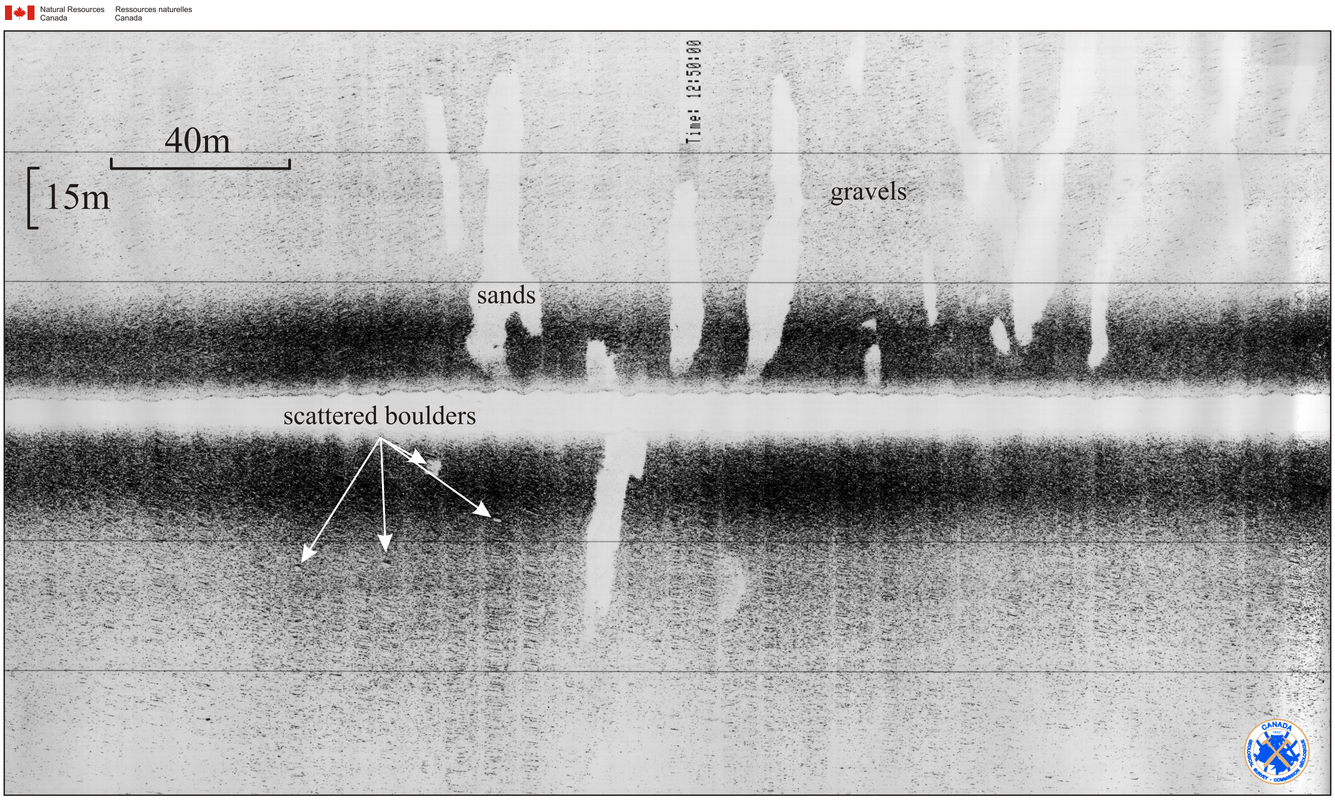
Figure 10.5. Shaded relief map off Shelburne with superimposed interpretation of sediment types from the geophysics tracks. The Lockeport image is not shown.



95-030 Seistec and 550kHz sidescan, 295/0020

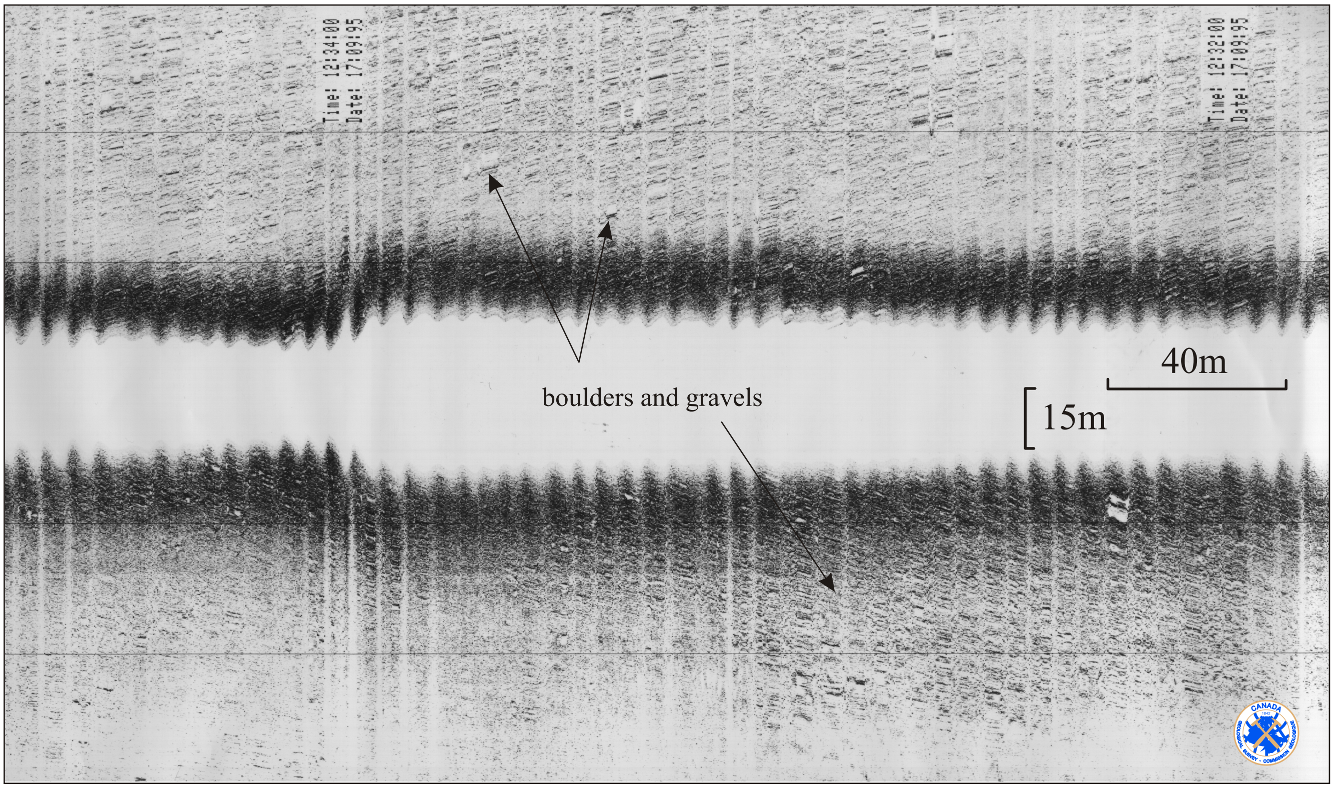
E. King, 2002

Figure 10.6. Sidescan and seistec (sub-bottom profiler) images offshore Liverpool (ca. 100 m water depth) showing variations in surficial and sub-surface sediment types and dense boulder distribution on the moraine tops.



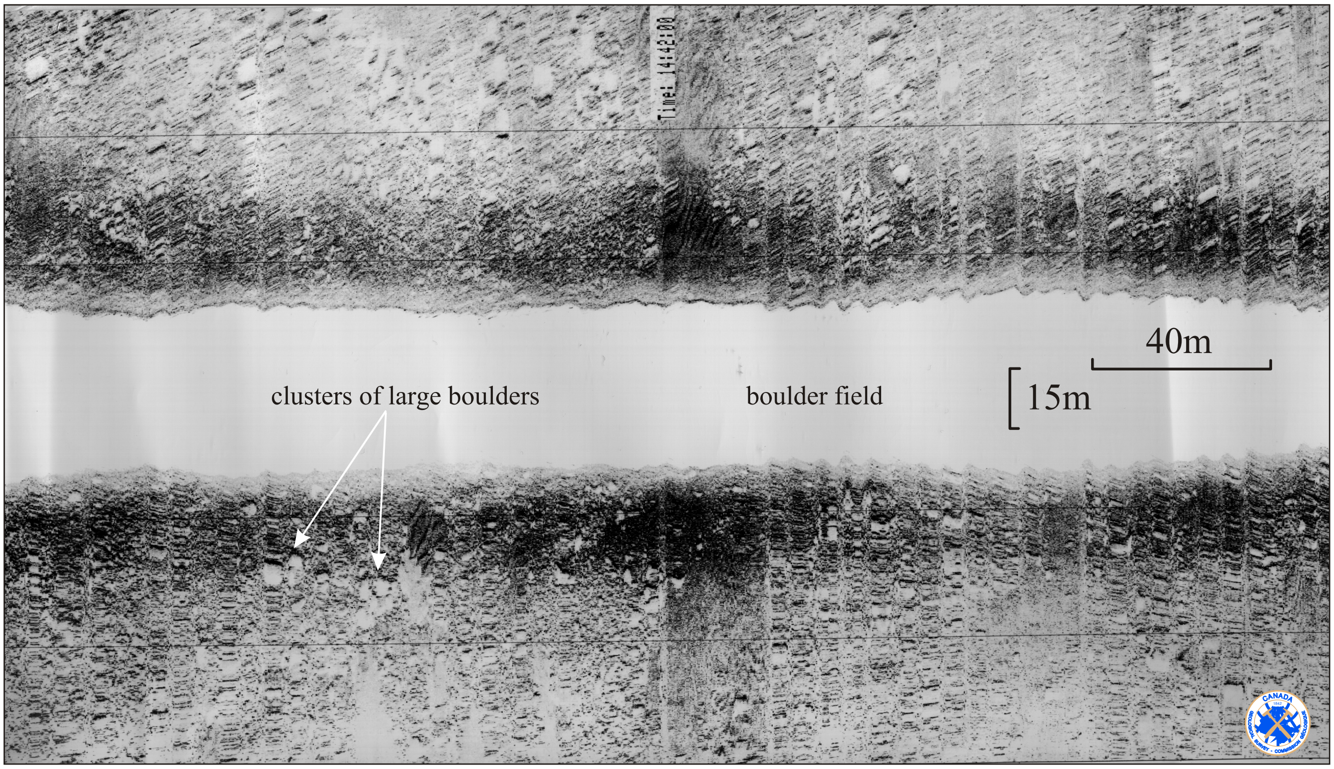
Scattered boulders
Klein Sidescan 595
GSCA cruise 95149 day 262

Figure 10.7. Sidescan image offshore Shelburne showing typical scattered boulder distribution in an area of very thin sand over a gravel lag (developed on Emerald Silt). The sand has been worked into low relief bedforms.



Medium density boulders
Klein Sidescan 595
GSCA cruise 95149 day 262

Figure 10.8. Sidescan image offshore Shelburne showing variations in surficial and sub-surface sediment types and dense boulder distribution on the moraine tops.



Very dense boulders
Klein Sidescan 595
GSCA cruise 95149 day 262

Figure 10.9. Sidescan image offshore Shelburne showing a very dense boulder distribution.

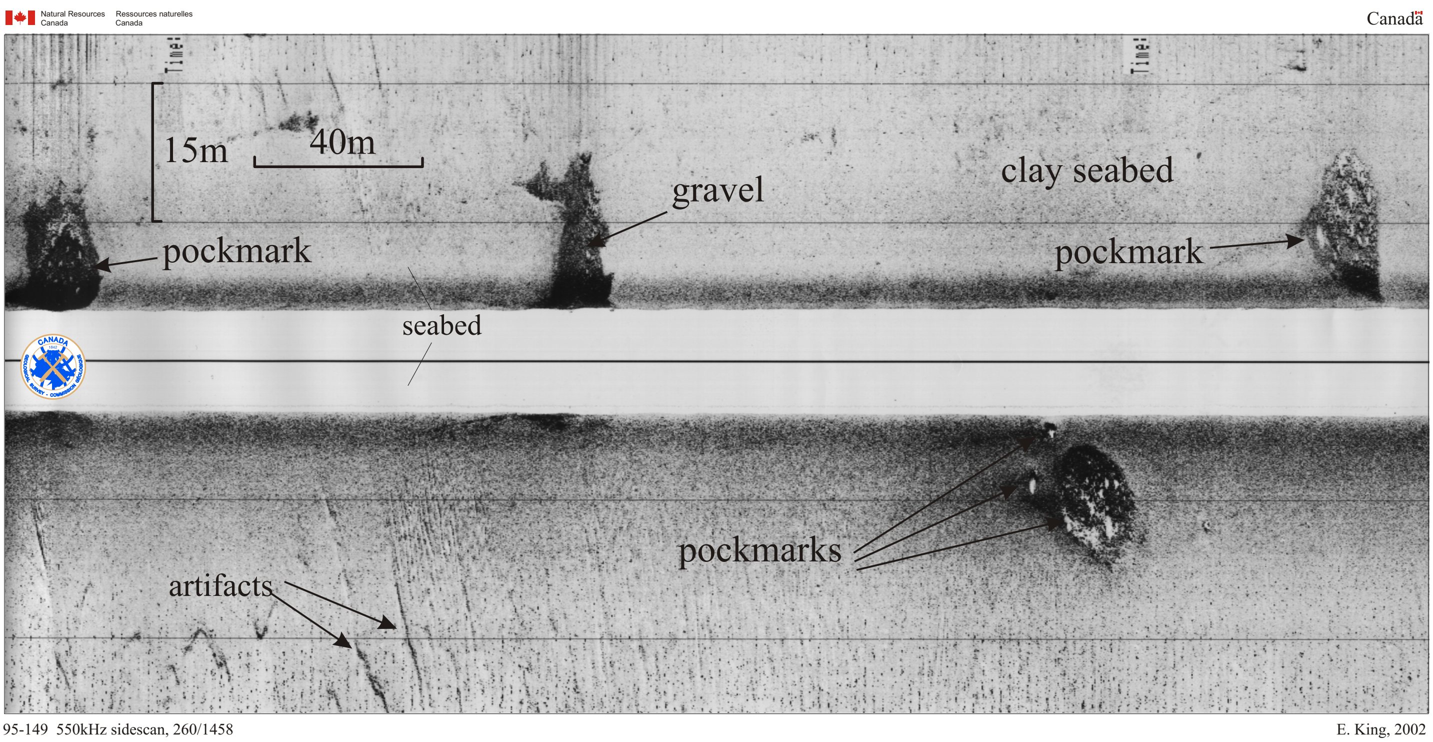
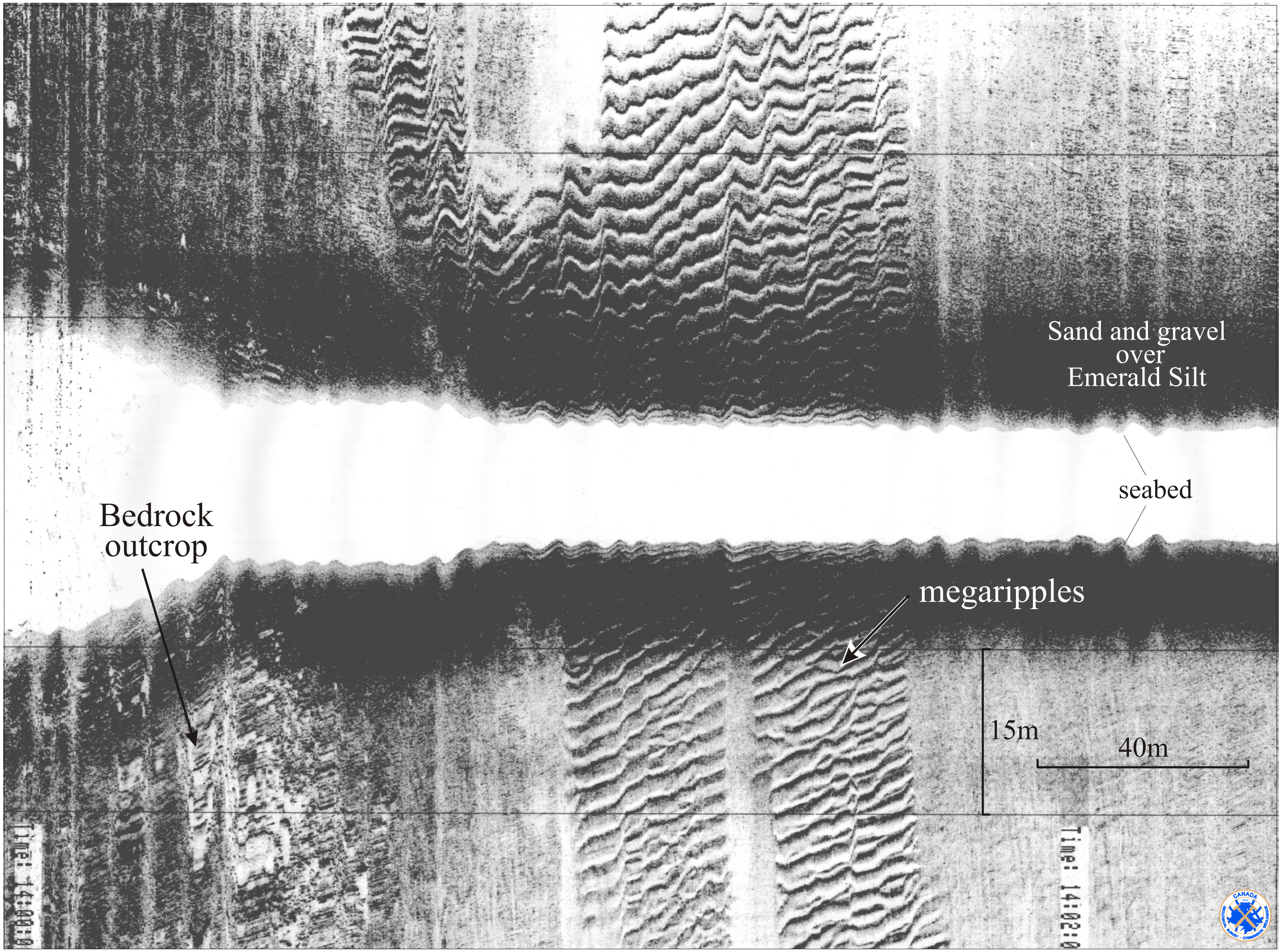


Figure 10.10 Sidescan image in Shelburne Harbour (north of McNutt's Island) showing "hard-bottomed" pockmarks eroded in clay and exposing gravels at their base.



95-149 500kHz sidescan, 260/1402

E. King, 2002

Figure 10.11. Sidescan image offshore Shelburne (east of McNutt's Island) showing megaripples developed in sand-covered Emerald Silt. Typically the bedforms are associated with topographic highs which apparently concentrate bottom flow as does this outcropping bedrock ridge.

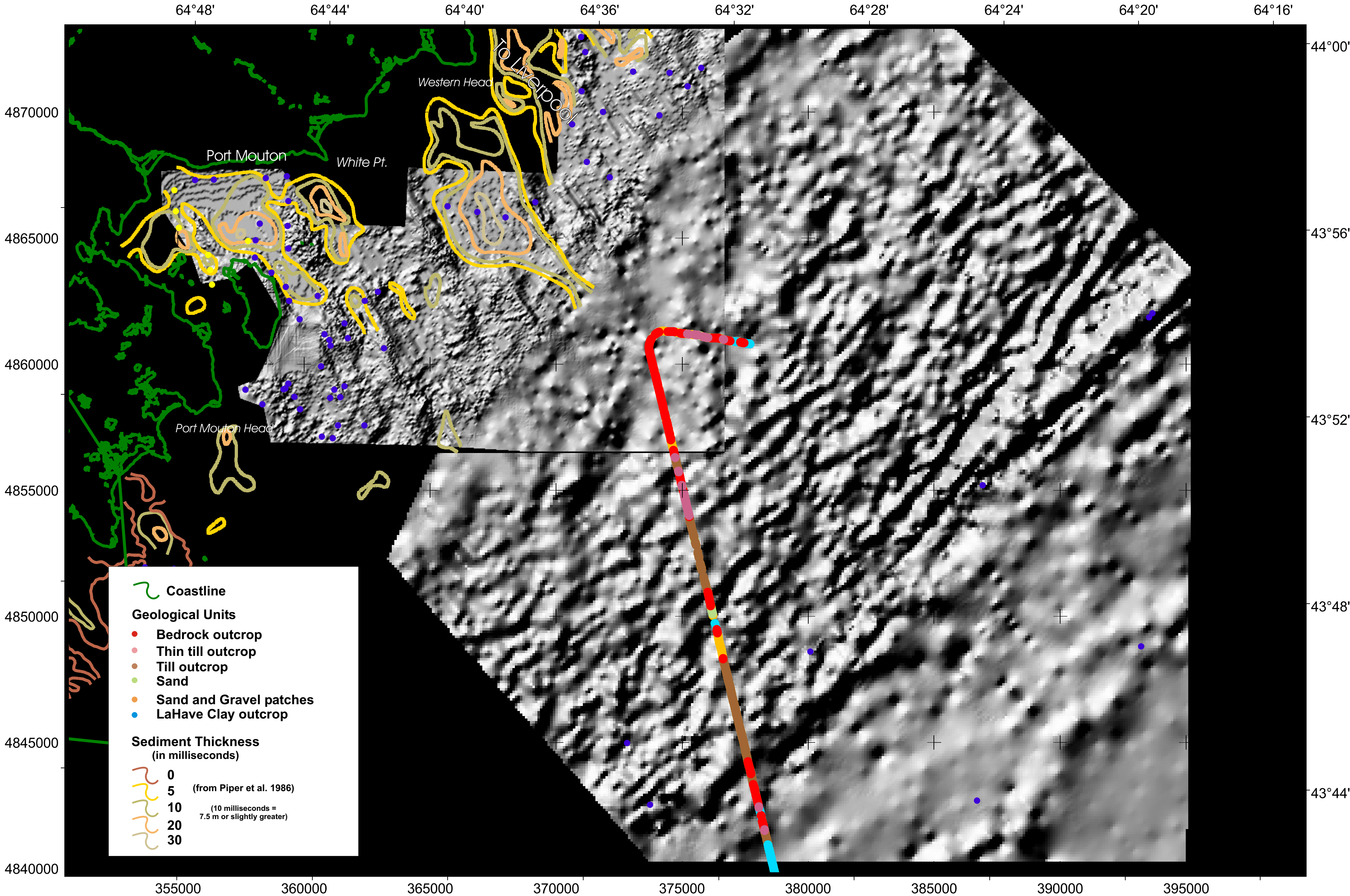


Figure 10.12. Shaded relief images offshore Liverpool with superimposed interpretation from geophysical tracks and sediment thickness map of Piper et al. (1986).

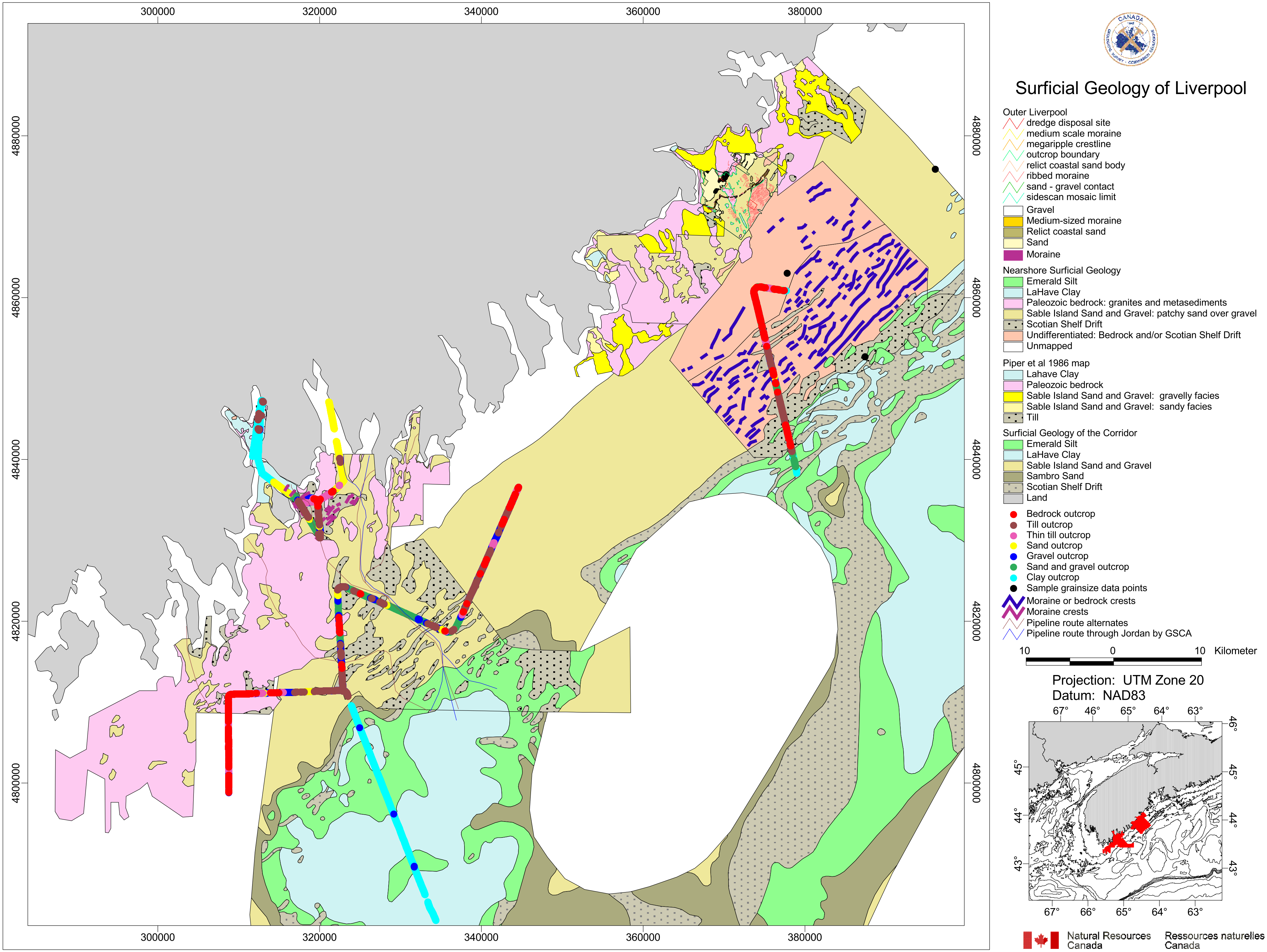

Surficial Geology of Liverpool
Outer Liverpool
dredge disposal site
medium scale moraine
megaripple crestline
outcrop boundary
relict coastal sand body
ribbed moraine
sand - gravel contact
sidescan mosaic limit
Gravel
Medium-sized moraine
Relict coastal sand
Sand
Moraine
Nearshore Surficial Geology
Emerald Silt
LaHave Clay
Paleozoic bedrock: granites and metasediments
Sable Island Sand and Gravel: patchy sand over gravel
Scotian Shelf Drift
Undifferentiated: Bedrock and/or Scotian Shelf Drift
Unmapped
Piper et al 1986 map
Lahave Clay
Paleozoic bedrock
Sable Island Sand and Gravel: gravelly facies
Sable Island Sand and Gravel: sandy facies
Till
Surficial Geology of the Corridor
Emerald Silt
LaHave Clay
Sable Island Sand and Gravel
Sambro Sand
Scotian Shelf Drift
Land
Bedrock outcrop
Till outcrop
Thin till outcrop
Sand outcrop
Gravel outcrop
Sand and gravel outcrop
Clay outcrop
Sample grainsize data points
Moraine or bedrock crests
Moraine crests
Pipeline route alternates
Pipeline route through Jordan by GSCA
10 0 10 Kilometer
Projection: UTM Zone 20
Datum: NAD83
300000 320000 340000 360000 380000
4880000 4860000 4840000 4820000 4800000
67° 66° 65° 64° 63°
46° 45° 44° 43°
Natural Resources Canada
Ressources naturelles Canada

Figure 10.13

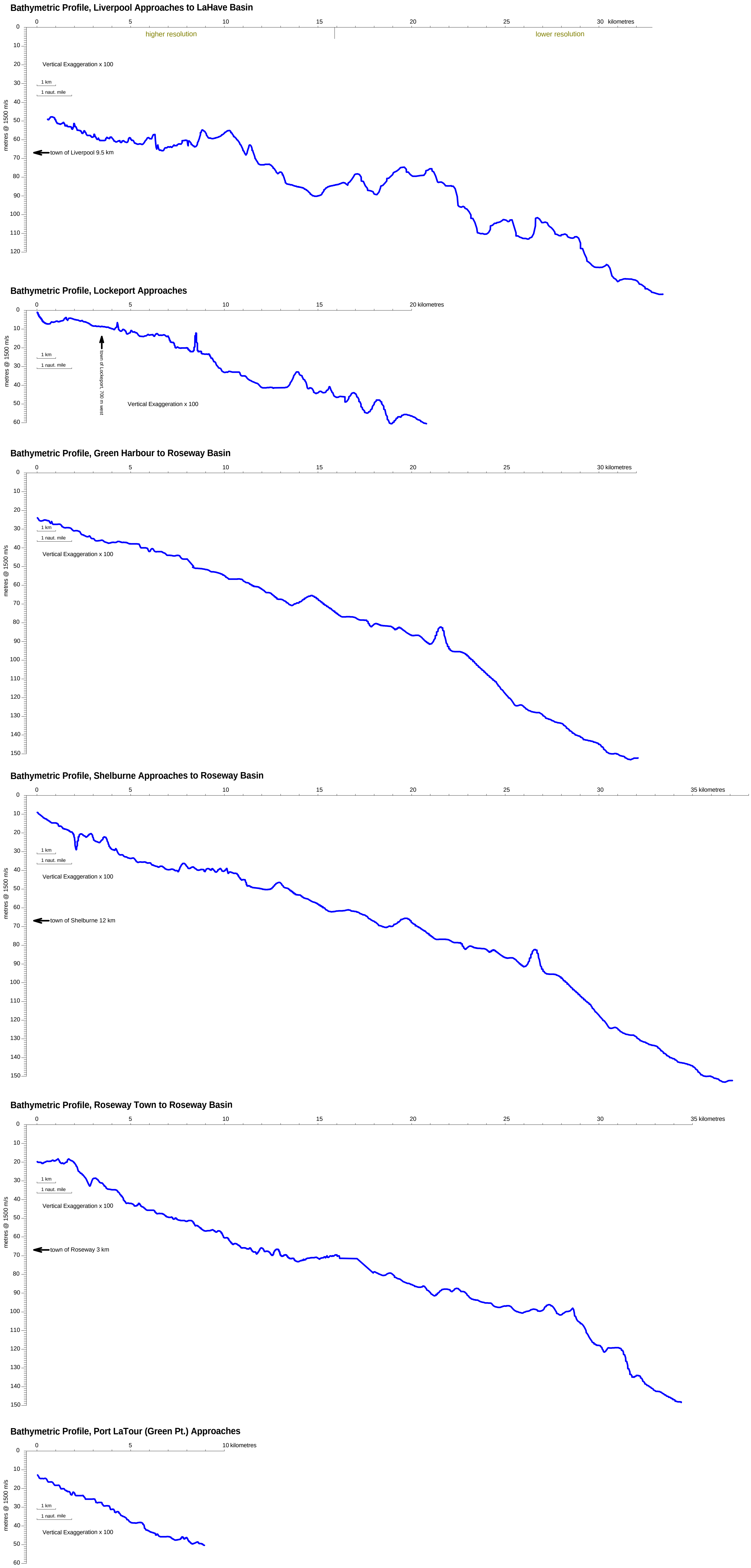

Bathymetric Profile, Liverpool Approaches to LaHave Basin
higher resolution
lower resolution
kilometres
Vertical Exaggeration x 100
1 km
1 naut. mile
metres @ 1500 m/s
town of Liverpool 9.5 km
Bathymetric Profile, Lockeport Approaches
20 kilometres
town of Lockeport, 700 m west
Vertical Exaggeration x 100
Bathymetric Profile, Green Harbour to Roseway Basin
30 kilometres
Vertical Exaggeration x 100
Bathymetric Profile, Shelburne Approaches to Roseway Basin
35 kilometres
town of Shelburne 12 km
Vertical Exaggeration x 100
Bathymetric Profile, Roseway Town to Roseway Basin
35 kilometres
town of Roseway 3 km
Vertical Exaggeration x 100
Bathymetric Profile, Port LaTour (Green Pt.) Approaches
10 kilometres
Vertical Exaggeration x 100

Figure 10.14

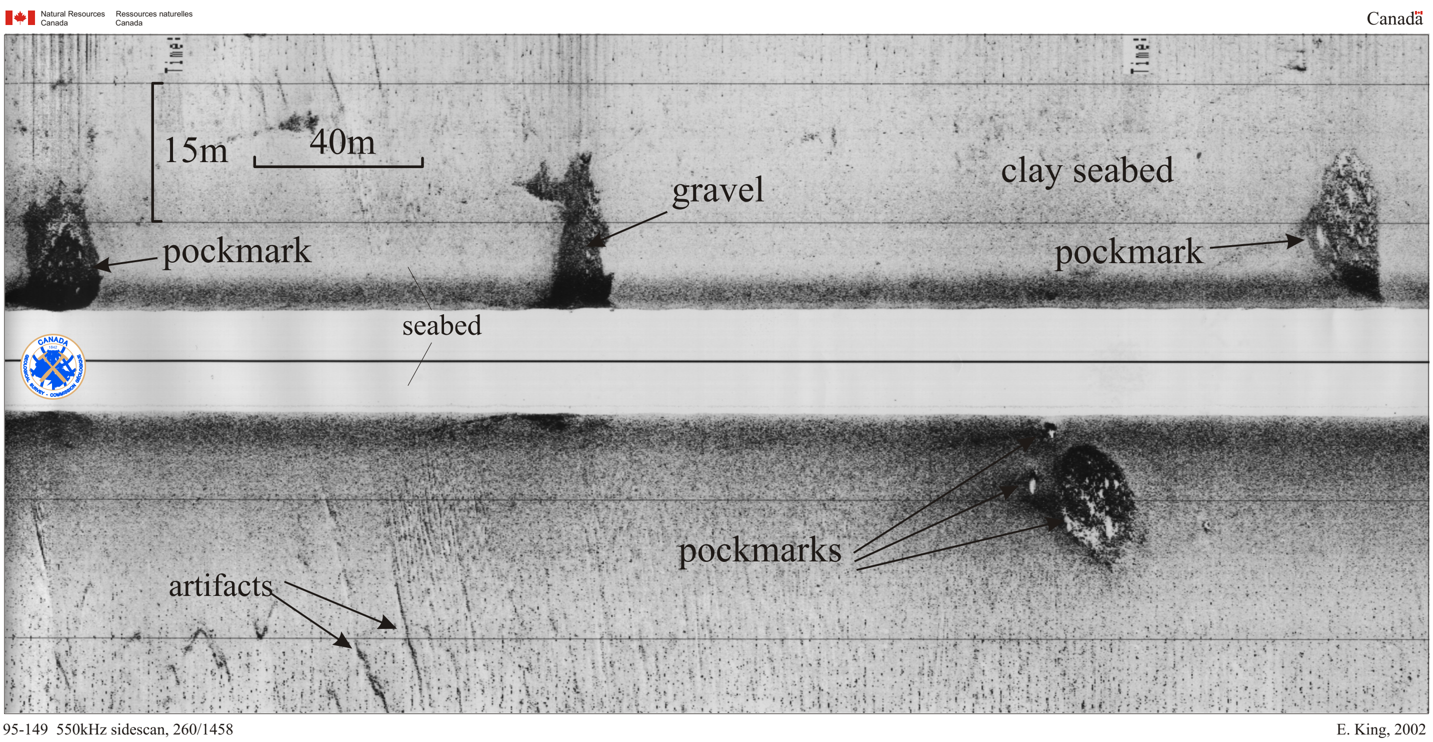


Figure 10.15. Sidescan image in Shelburne Harbour (north of McNutt's Island) showing "hard-bottomed" pockmarks eroded in clay and exposing gravels at their base.

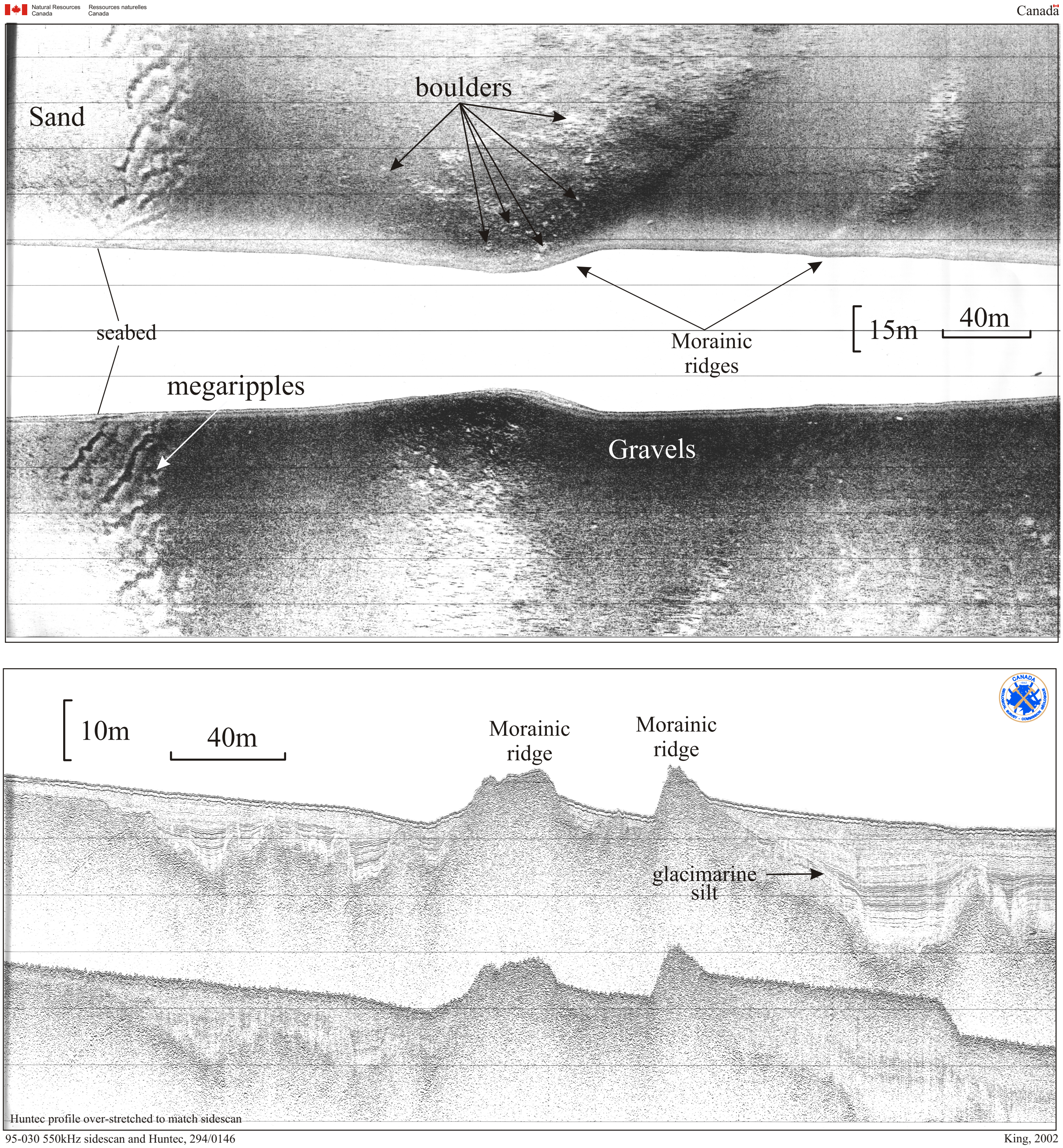
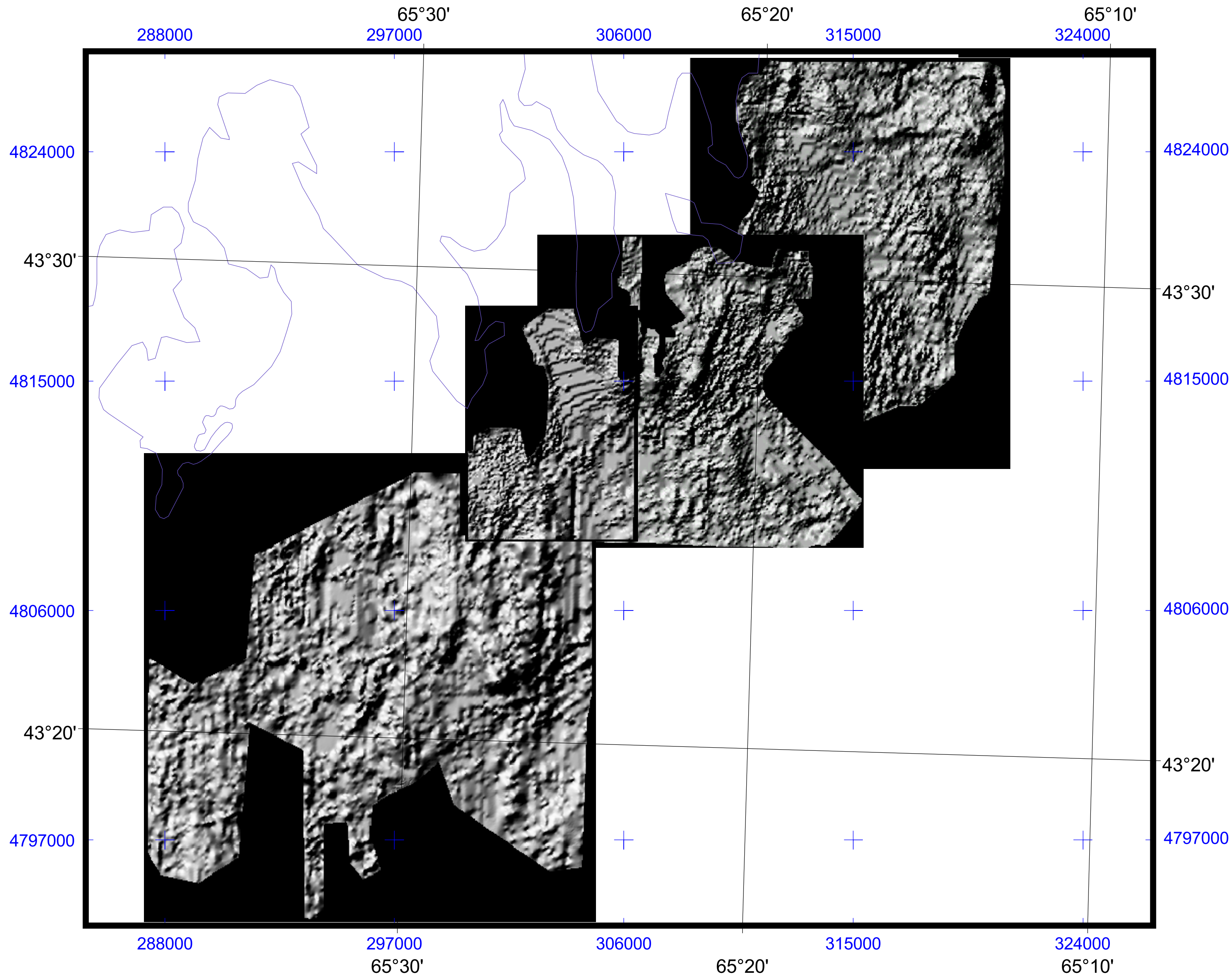


Figure 10.16. Sidescan and Huntec boomer images from Shelburne Harbour (north of McNutt's Island) showing "hard-bottomed" gas escape-formed pockmarks eroded in clay and exposing gravels at their base.



Shaded relief of Roseway to Port La Tour

Figure 10.17

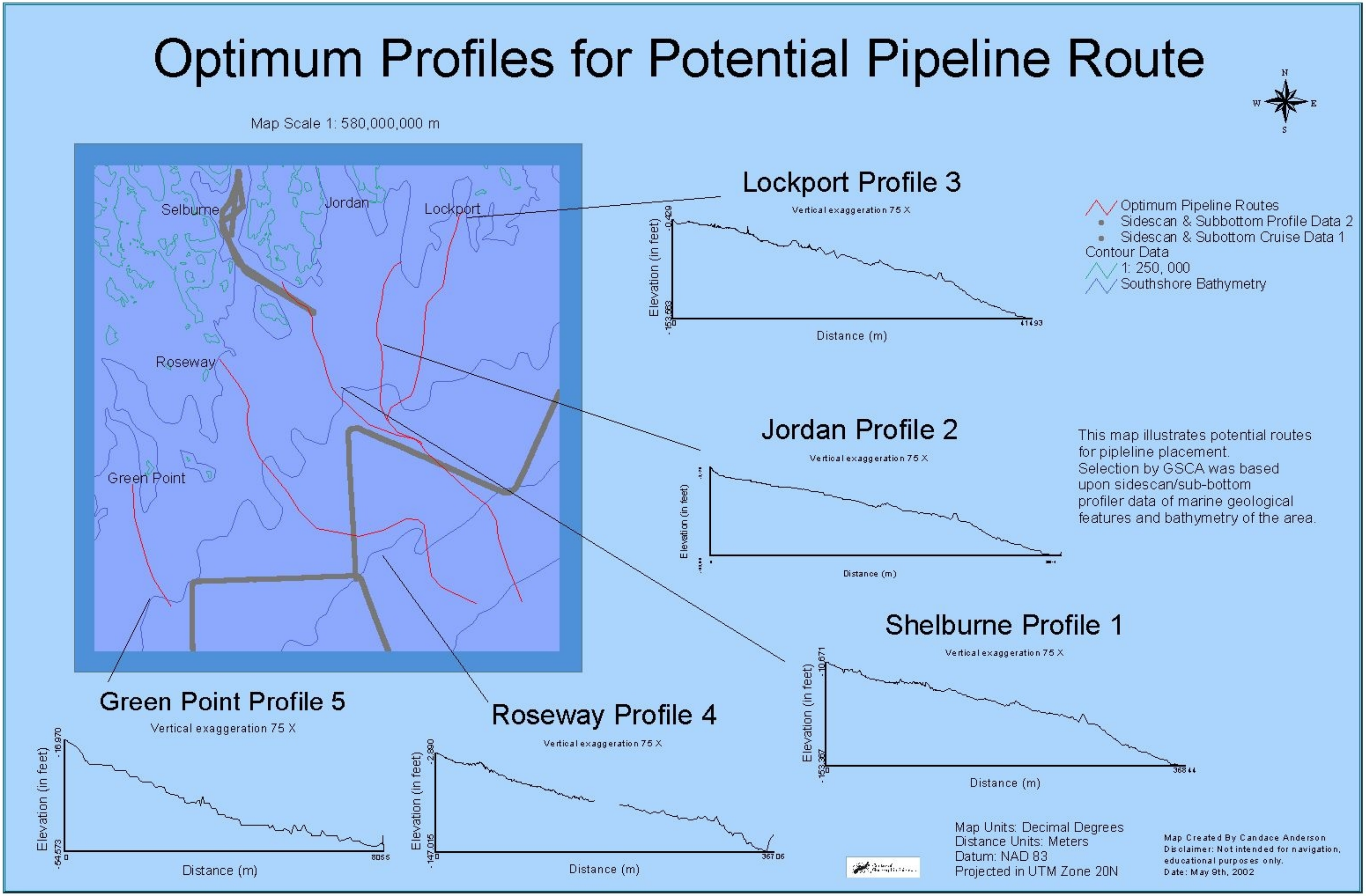


Figure 10.18. Comparison of bathymetric profiles, generated from the CHS image data, from various traverses across the area offshore Shelburne. The traverses attempt to mitigate perceived pipeline hazards. Similar profiles are presented in the preceding illustrations (at greater detail). Compiled by C. Anderson COGS (Center of Geographic Sciences, Nova Scotia) student major project, 2002.

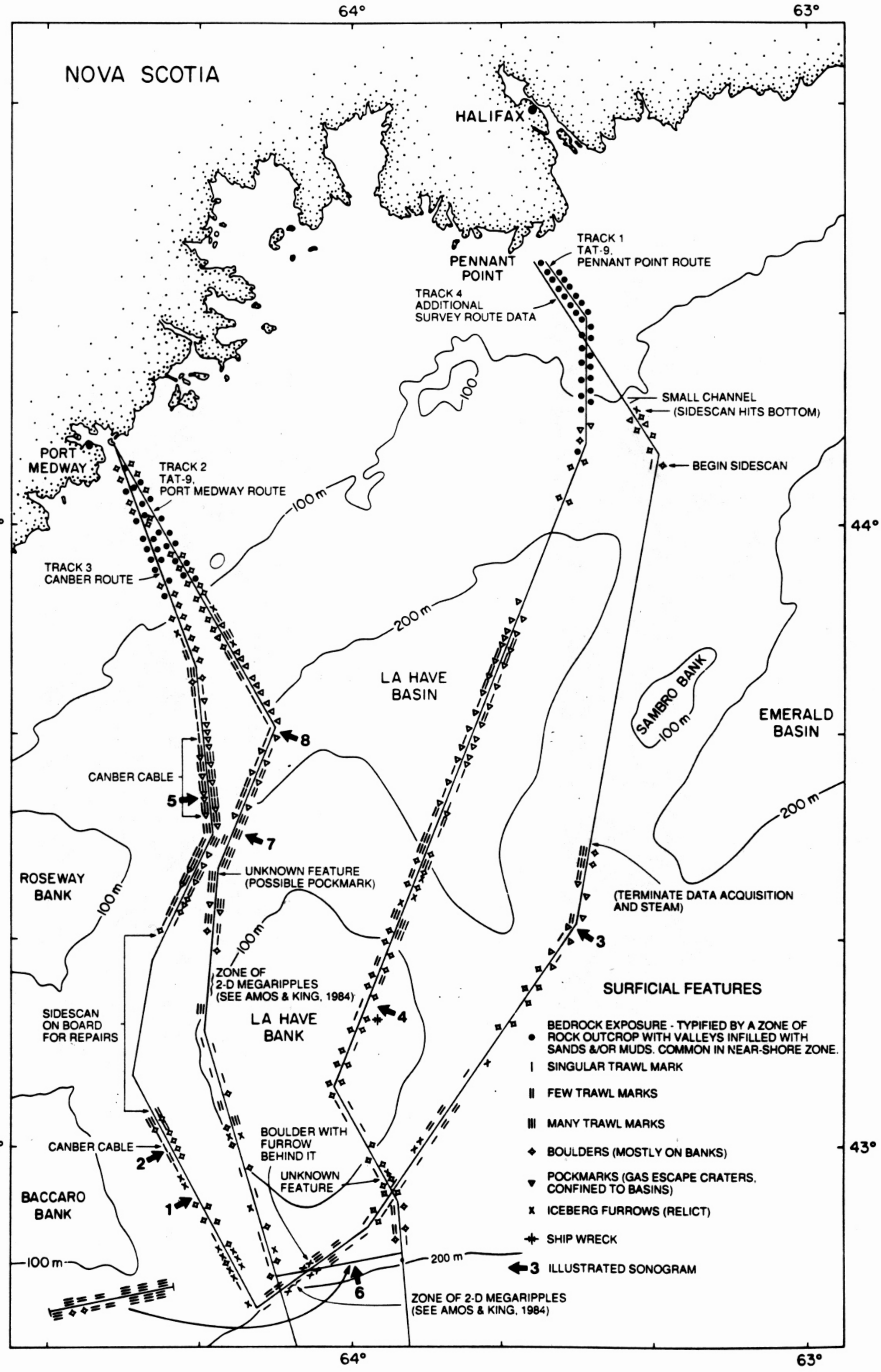


Figure 11.1 Surficial features as mapped from sidescan in the LaHave Bank to Roseway Basin area. The pipeline route passes south of the bank where trawl marks, occasional iceberg scours, and boulders are noted.

Photo 33 (43°13.5'N, 65°02.5'W, 160 m)
The surface sediments in Roseway Basin, as in other basins, are fine-grained and muddy. In the area from which this photograph was taken, the sediment is a poorly sorted clayey and sandy silt of the Emerald Silt formation. It is heavily pelletised and has numerous tubes and burrows, suggesting the presence of a rich infauna. Pockmarks also occur in Roseway Basin.

Photo 34 (43°53.5'N, 62°52.2'W, 264 m)
In this deepest part of Emerald Basin the sediment is LaHave Clay. This photograph shows the fine-grained surface texture of biologically created mounds, depressions, holes, burrows and deposits (compare with Photo 29, also from Emerald Basin). As in other areas of similar sediment, a rich infauna is probably present. Comparison with Photo 33 from Roseway Basin suggests that although both are inhabited by numerous organisms within the sediments, the communities are different.

Photo 33

Figure 12.1 Seabed photograph from Roseway Basin with sediment and faunal descriptions.

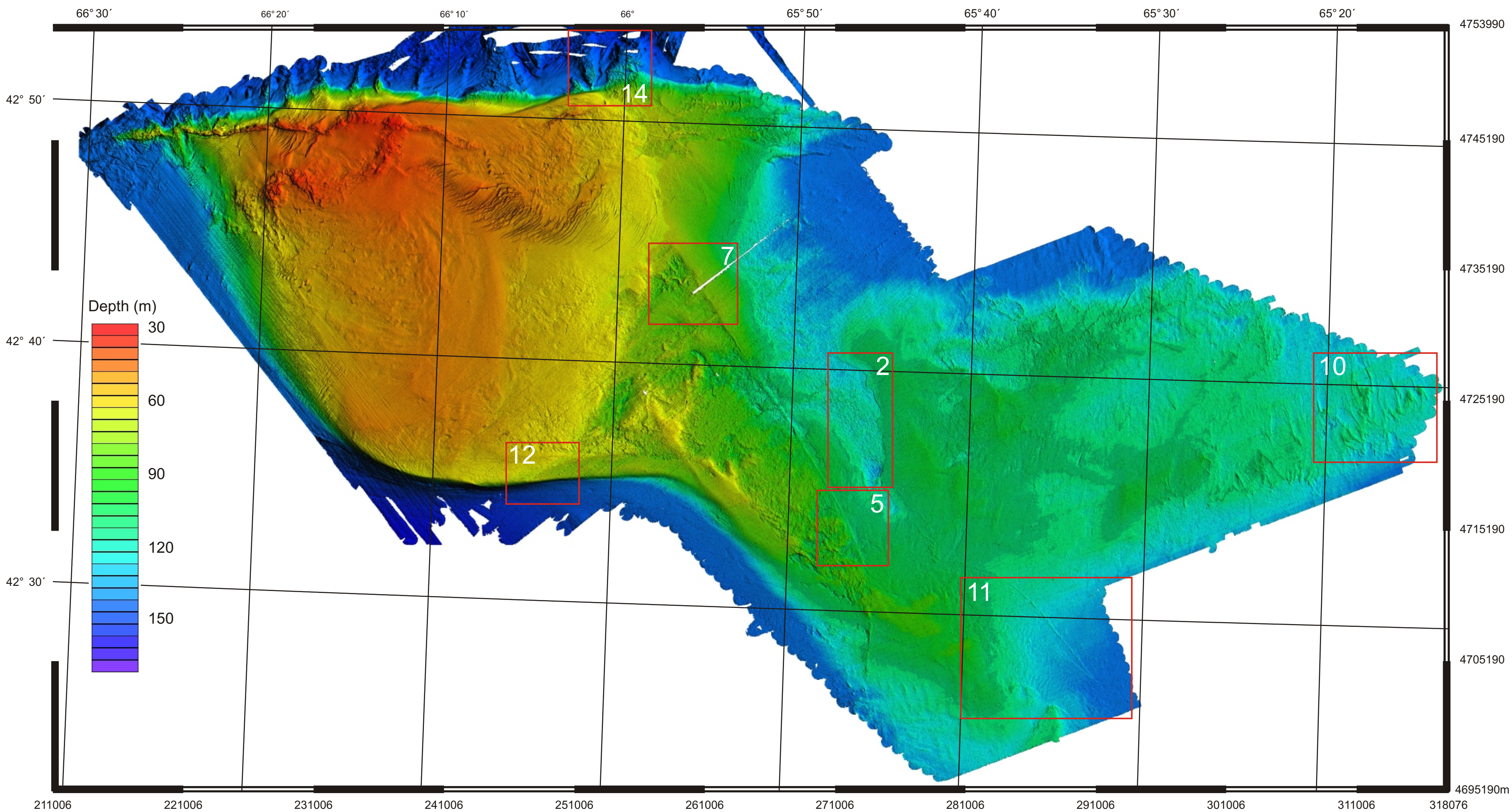
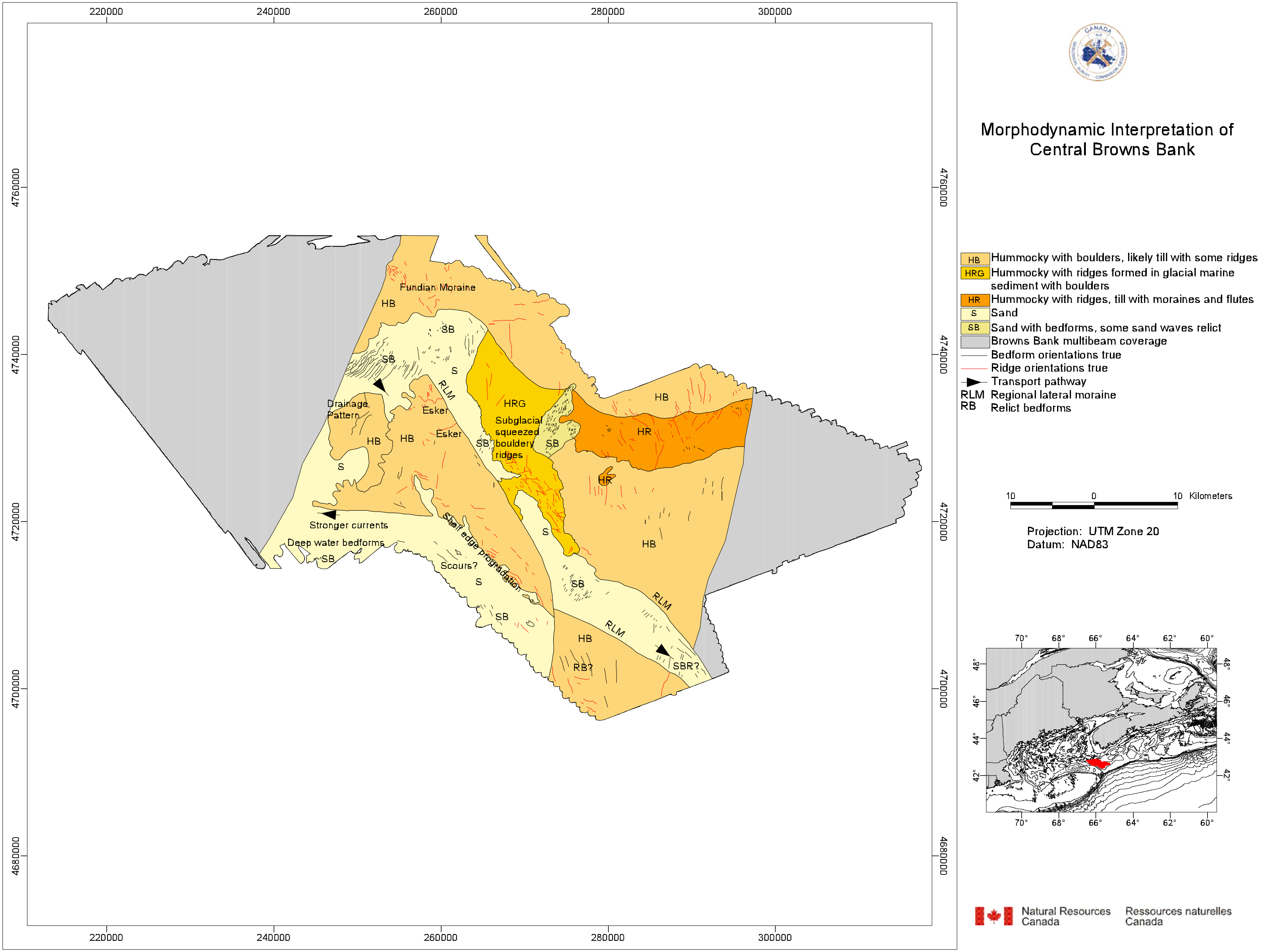


Figure 14.1. Multibeam image of Browns Bank (from Todd et al. 1999).



Morphodynamic Interpretation of Central Browns Bank
HB Hummocky with boulders, likely till with some ridges
HRG Hummocky with ridges formed in glacial marine sediment with boulders
HR Hummocky with ridges, till with moraines and flutes
S Sand
SB Sand with bedforms, some sand waves relict
Browns Bank multibeam coverage
Bedform orientations true
Ridge orientations true
Transport pathway
RLM Regional lateral moraine
RB Relict bedforms
10 0 10 Kilometers
Projection: UTM Zone 20
Datum: NAD83
Fundian Moraine
Drainage Pattern
Esker
Subglacial squeezed bouldery ridges
Stronger currents
Deep water bedforms
Shelf edge progradation
Scours?
RB?
SBR?
Natural Resources Canada
Ressources naturelles Canada

Figure 14.2

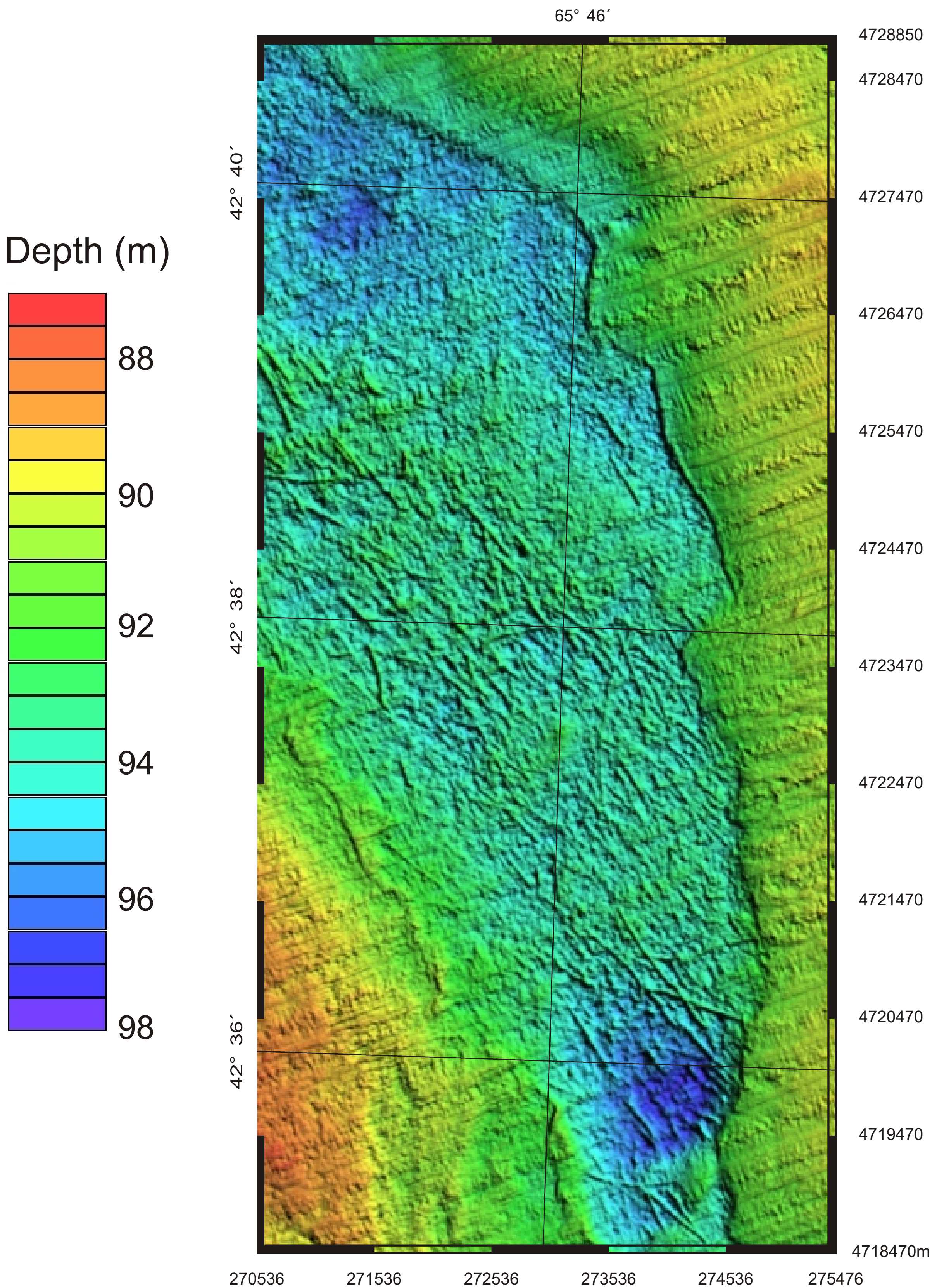


Figure 14.3. Multibeam image from Browns Bank showing criss-crossing ridges interpreted as subglacial "squeezed crevasse" forms (modified from Todd et al. 1999).

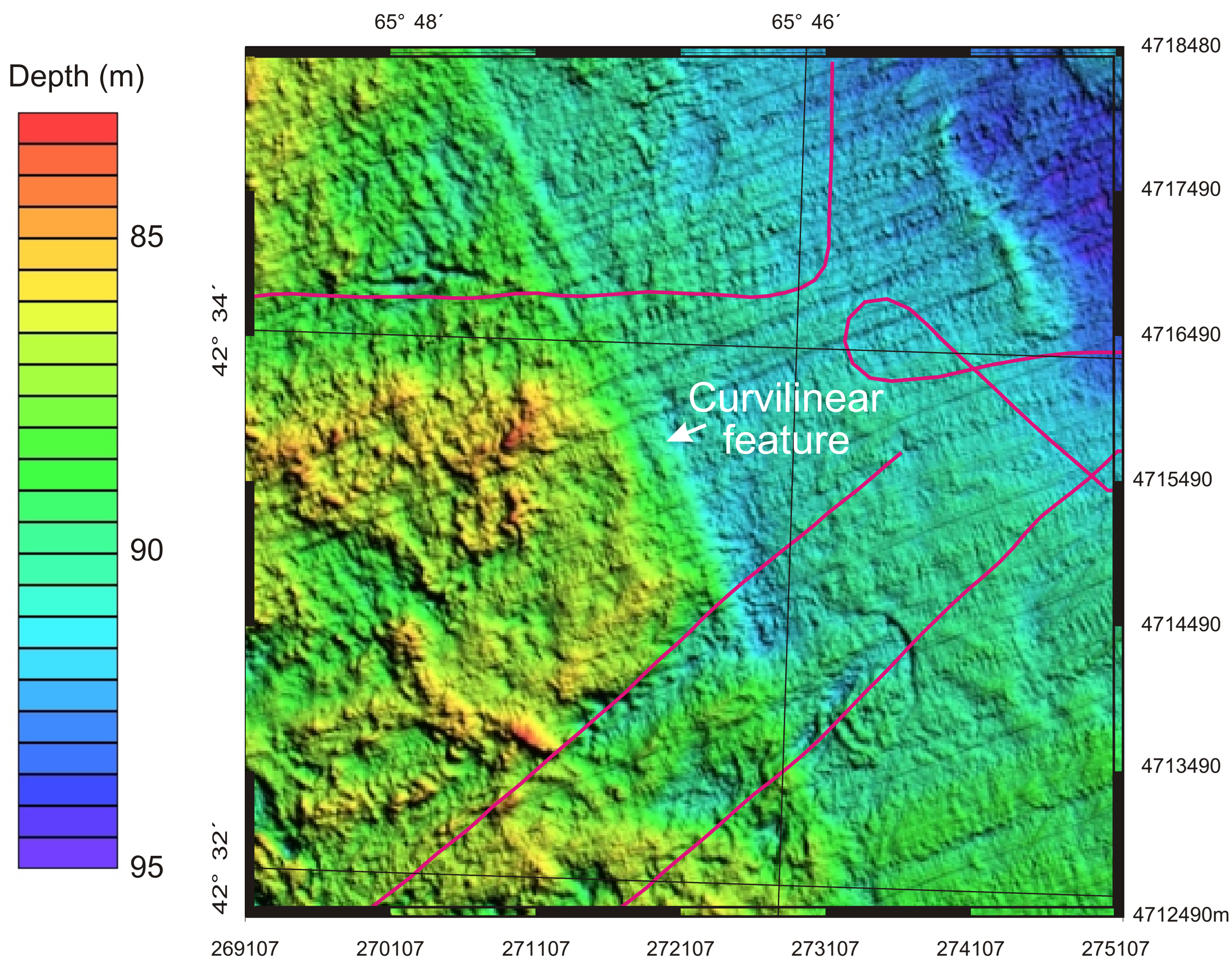


Figure 14.4. Multibeam image from Browns Bank showing the linear ridge interpreted as a lateral moraine (modified from Todd et al. 1999).

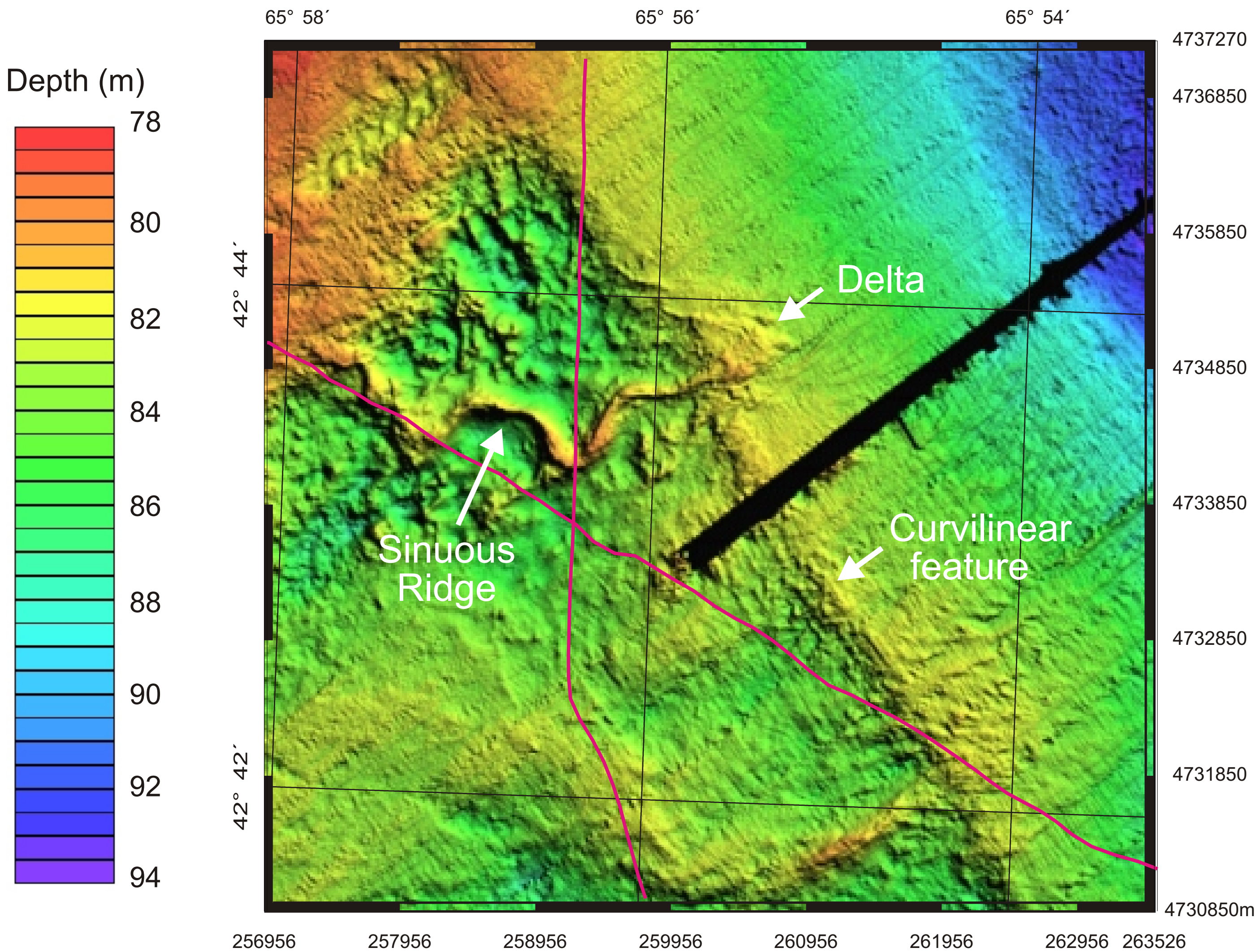


Figure 14.5. Multibeam image from Browns Bank showing the linear ridge interpreted as a lateral moraine and the sinuous esker with accompanying delta (modified from Todd et al. 1999).

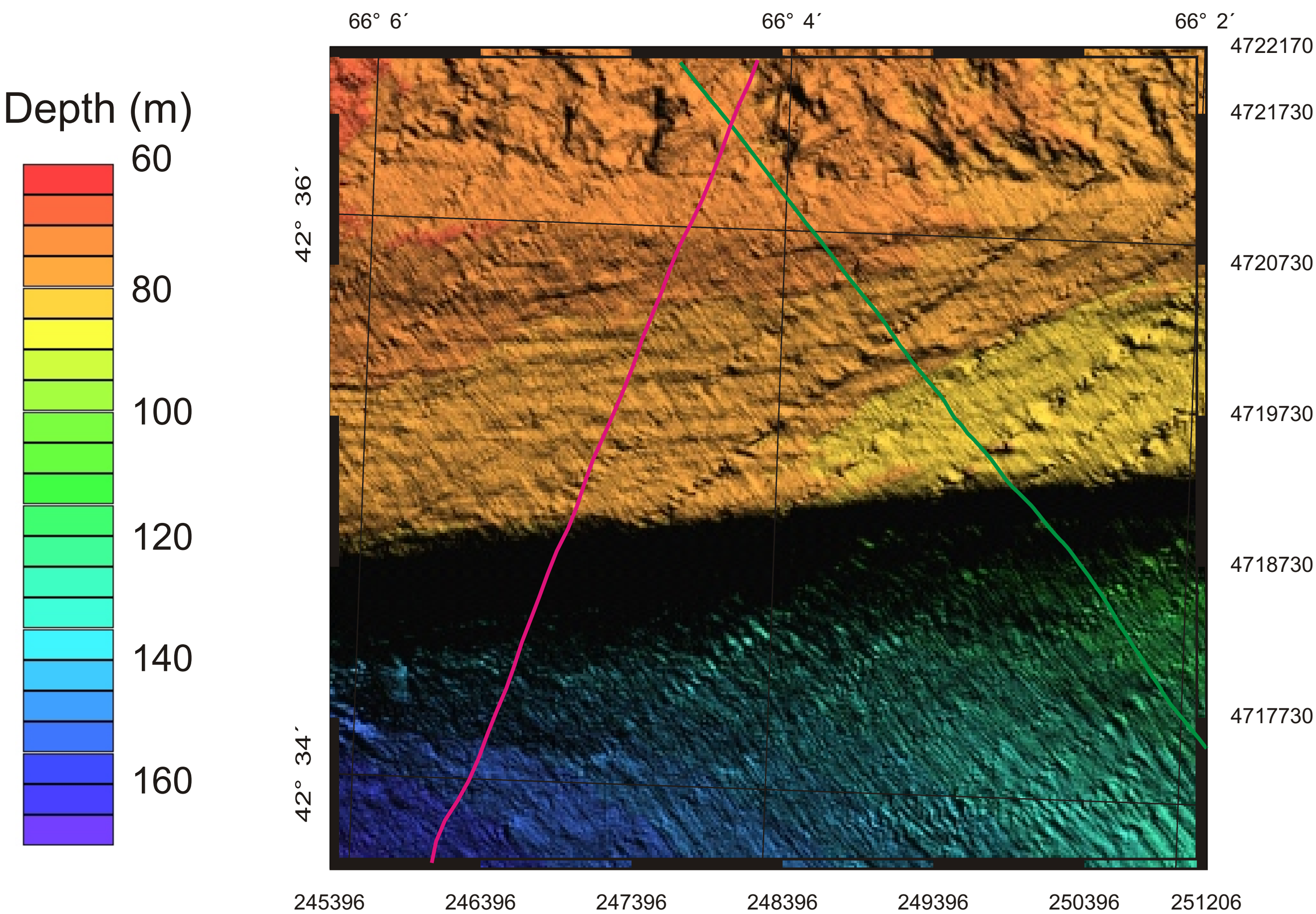


Figure 14.6. Multibeam image from Browns Bank across the steep southern flank of the bank (modified from Todd et al. 1999).

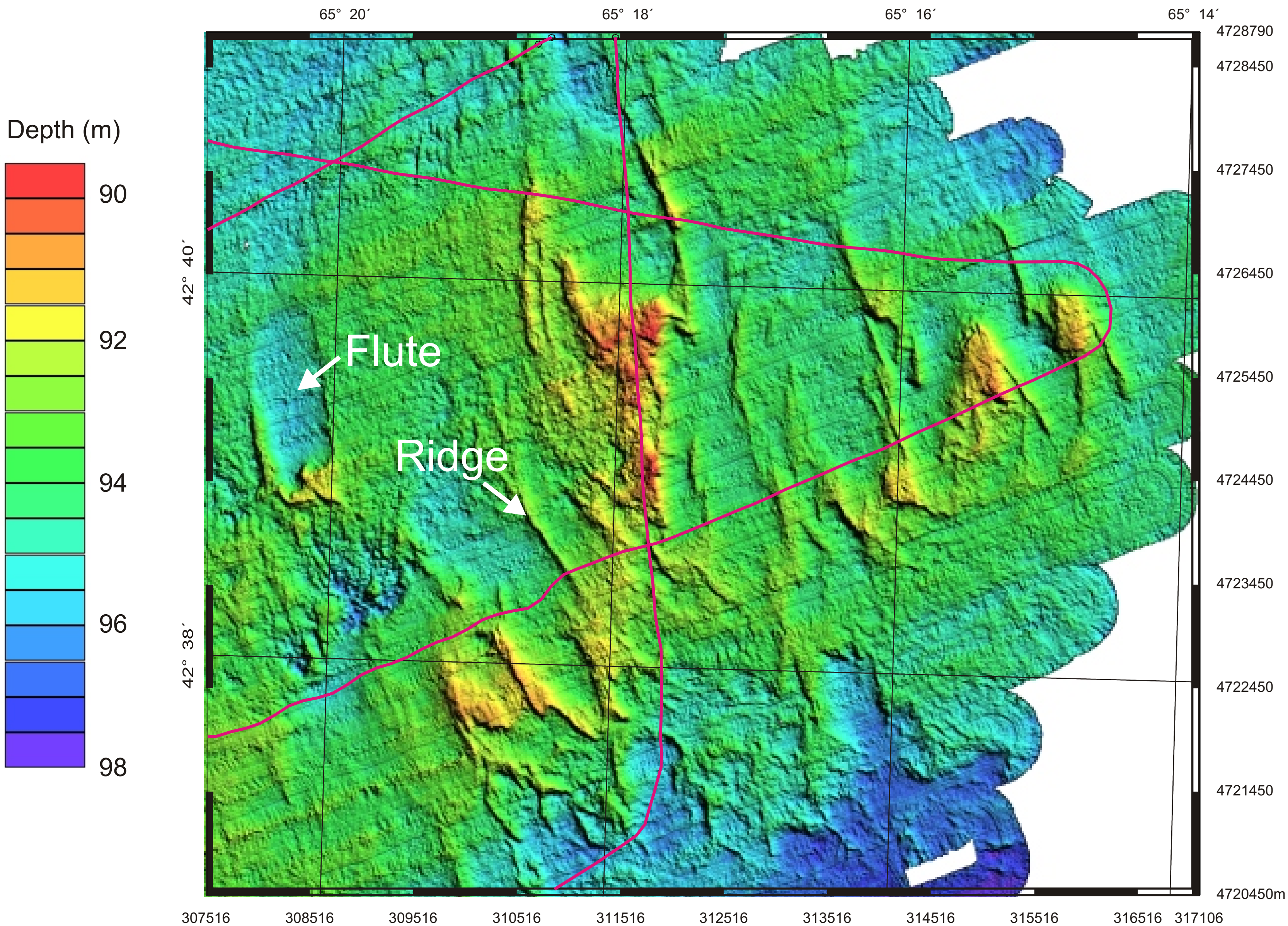


Figure 14.7. Multibeam image from Browns Bank showing lineations interpreted as glacial fluting (modified from Todd et al. 1999).

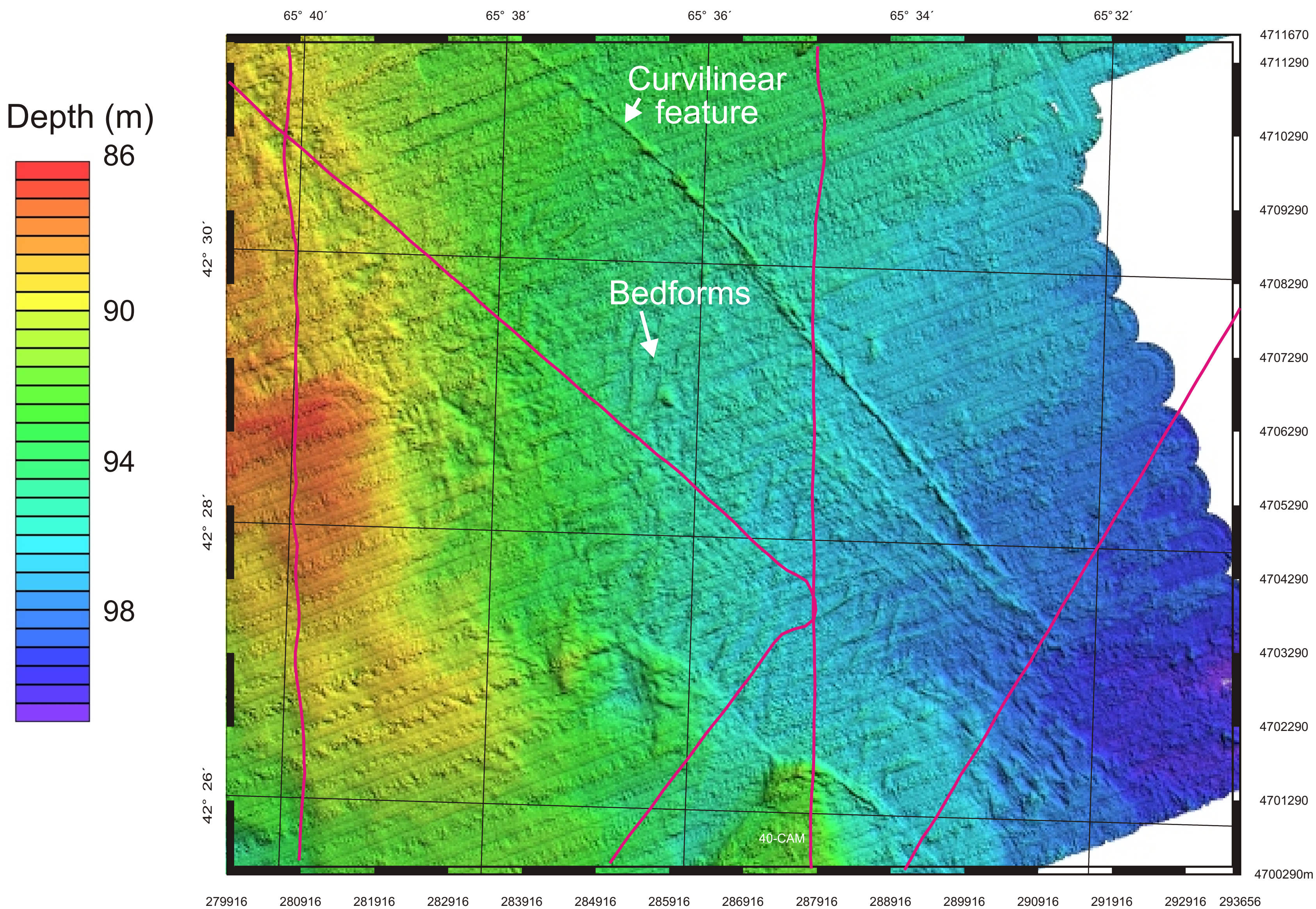
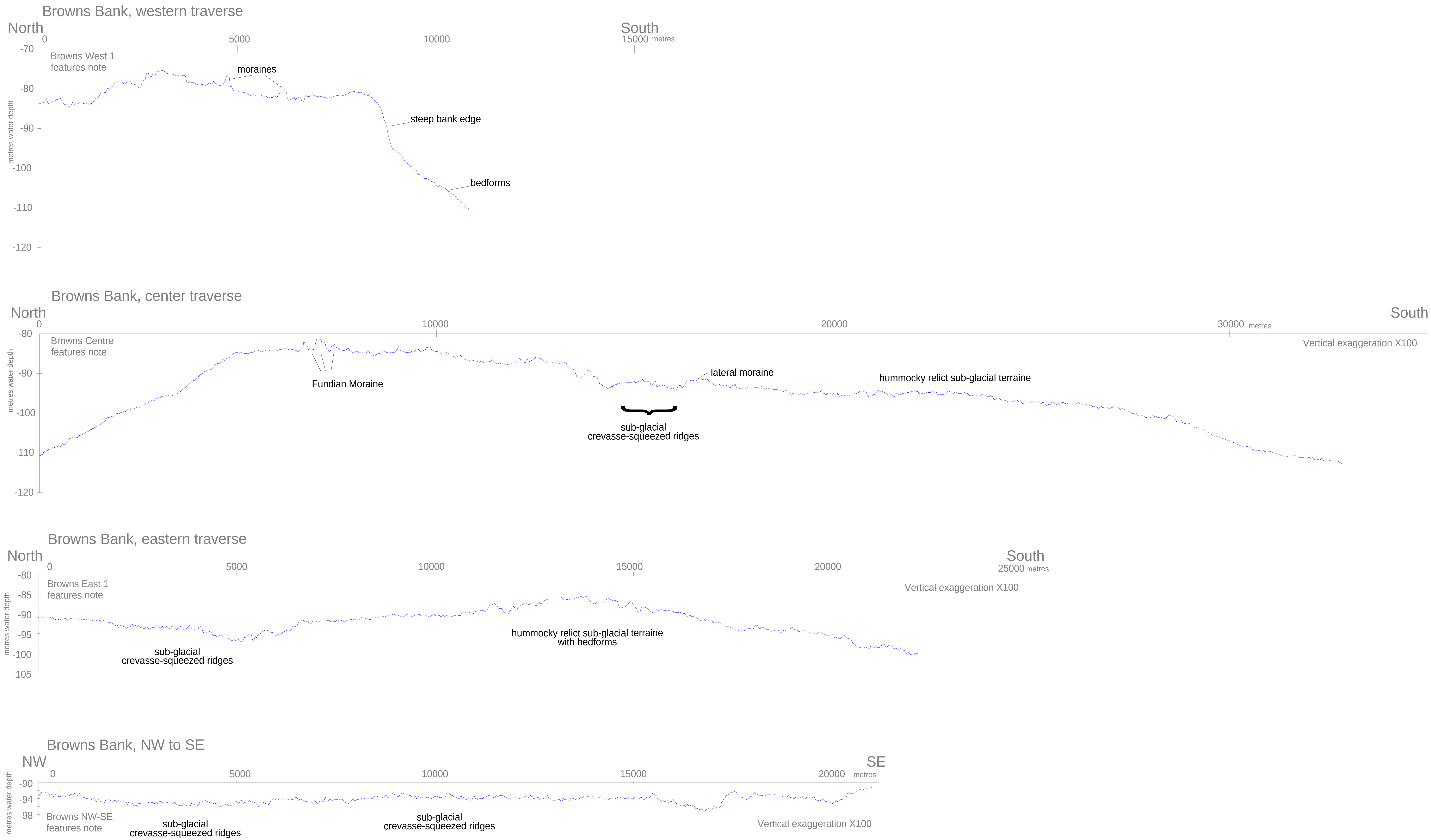


Figure 14.8. Multibeam image from Browns Bank showing the linear ridge interpreted as a lateral moraine and the (subtle) sand bedforms (modified from Todd et al. 200??).



Browns Bank, western traverse
North
South
0
5000
10000
15000 metres
-70
-80
-90
-100
-110
-120
metres water depth
Browns West 1
features note
moraines
steep bank edge
bedforms
Browns Bank, center traverse
North
South
0
10000
20000
30000 metres
-80
-90
-100
-110
-120
metres water depth
Browns Centre
features note
Vertical exaggeration X100
Fundian Moraine
lateral moraine
hummocky relict sub-glacial terraine
sub-glacial
crevasse-squeezed ridges
Browns Bank, eastern traverse
North
South
0
5000
10000
15000
20000
25000 metres
-80
-85
-90
-95
-100
-105
metres water depth
Browns East 1
features note
Vertical exaggeration X100
hummocky relict sub-glacial terraine
with bedforms
sub-glacial
crevasse-squeezed ridges
Browns Bank, NW to SE
NW
SE
0
5000
10000
15000
20000 metres
-90
-94
-98
metres water depth
Browns NW-SE
features note
sub-glacial
crevasse-squeezed ridges
sub-glacial
crevasse-squeezed ridges
Vertical exaggeration X100

Figure 14.9

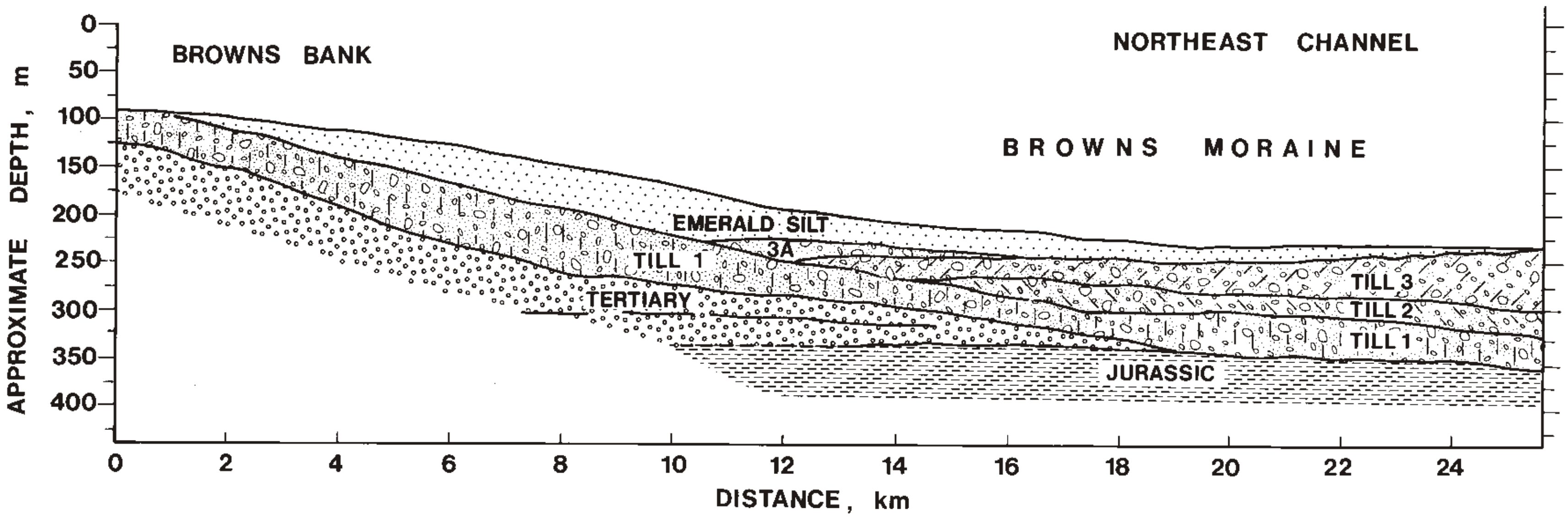


Figure 14.10. Stacked till on the flank of Browns Bank and in Northeast Channel.

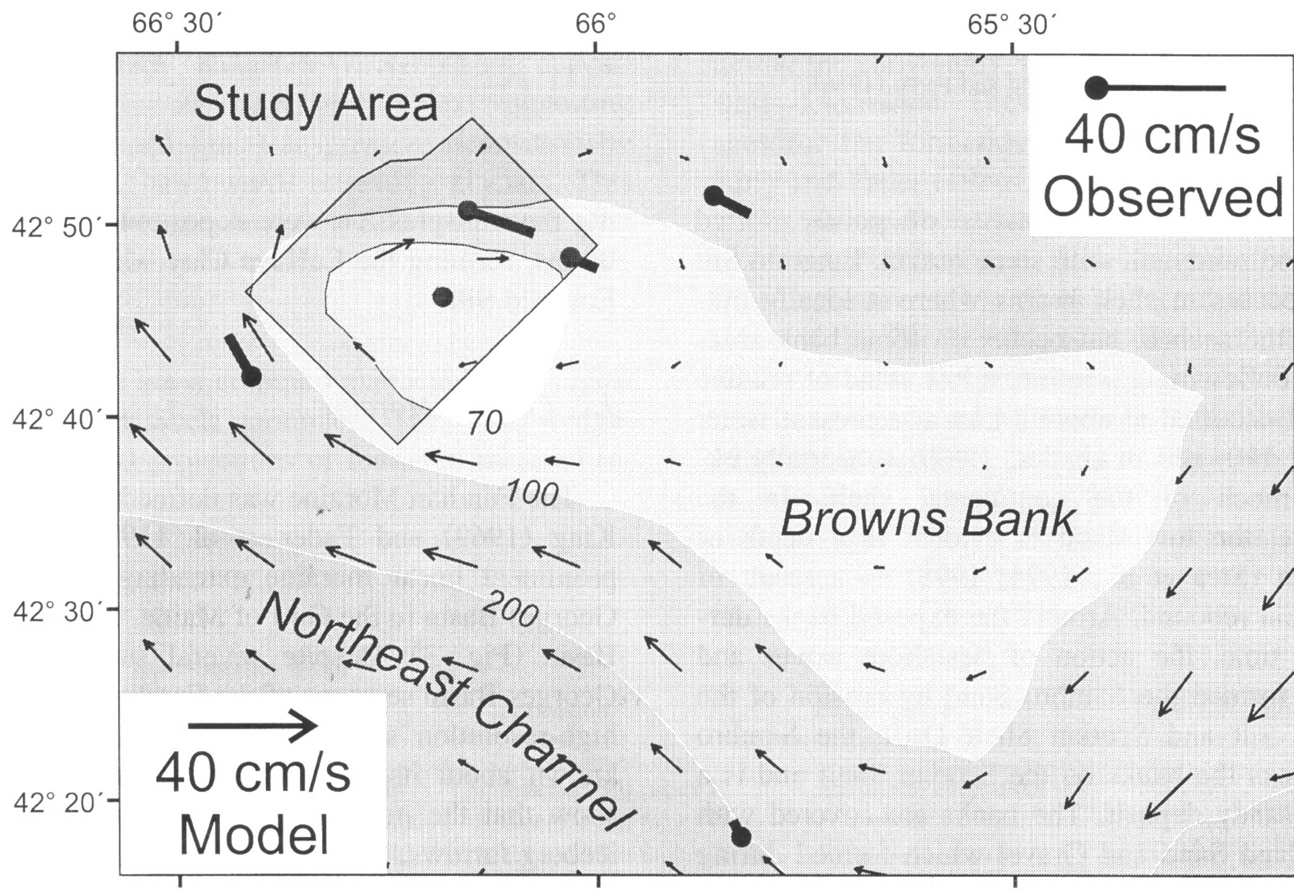


Fig. 2. Anticyclonic gyre of mean winter currents at a depth of 30 m over Browns Bank. Arrows represent direction and velocity of finite element-modeled currents. Black dots are moored current meter positions; associated bars represent direction and velocity of observed currents. The study area is outlined by the stippled box on northwestern Browns Bank. Isobaths are in meters. Figure adapted from Hannah et al. (in preparation).

Figure 15.1. Browns Bank-Northeast Channel circulation gyre (from Todd et al., 1999)

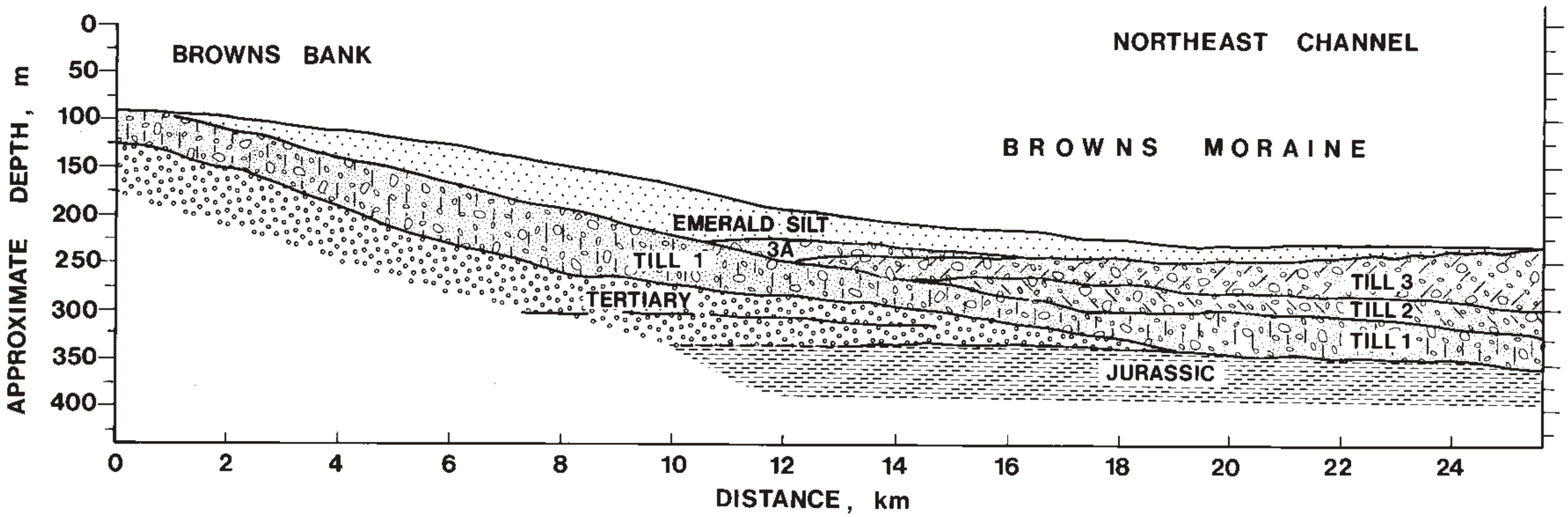


Figure 15.2. Stacked till on the flank of Browns Bank and in Northeast Channel.

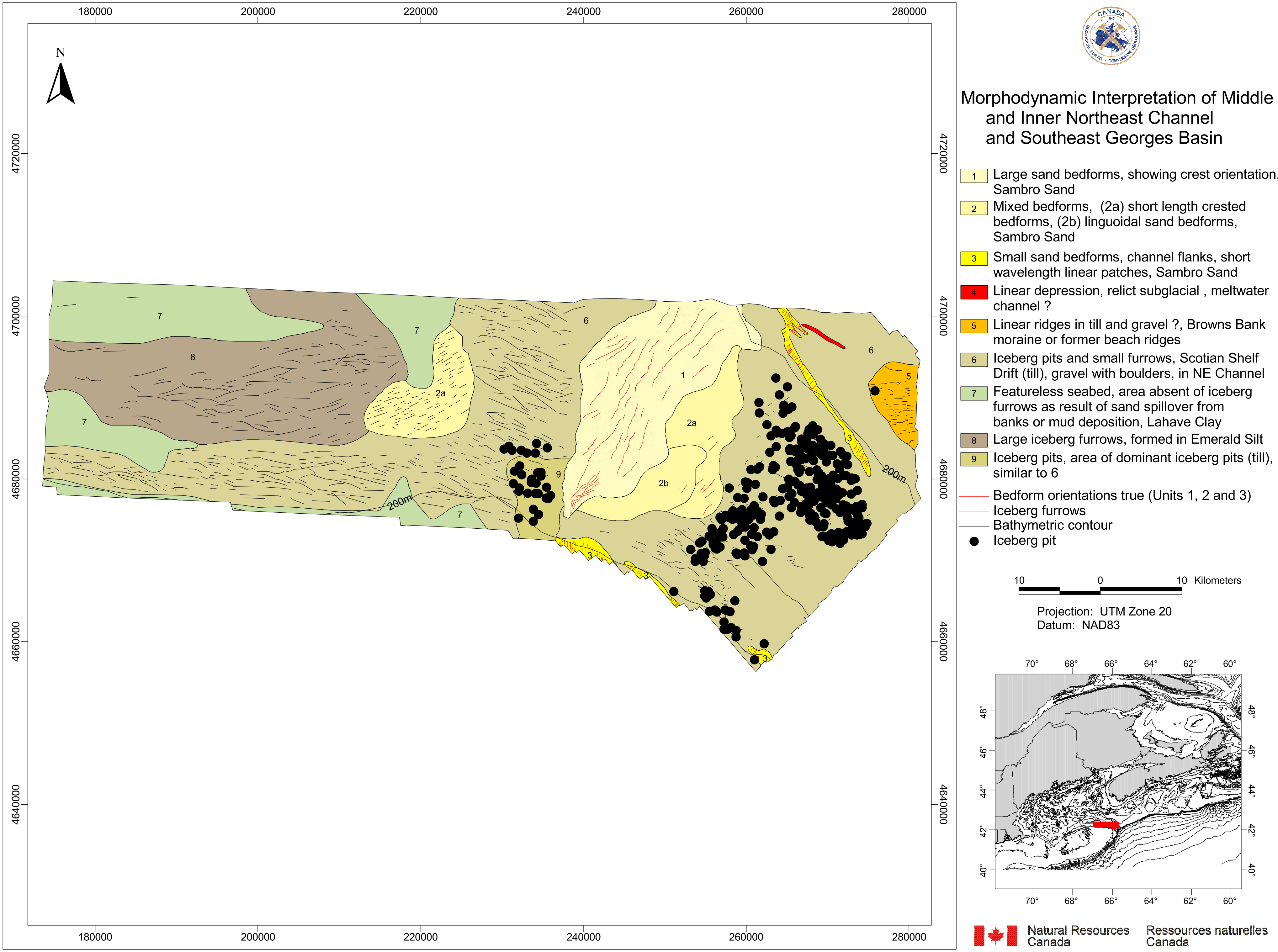
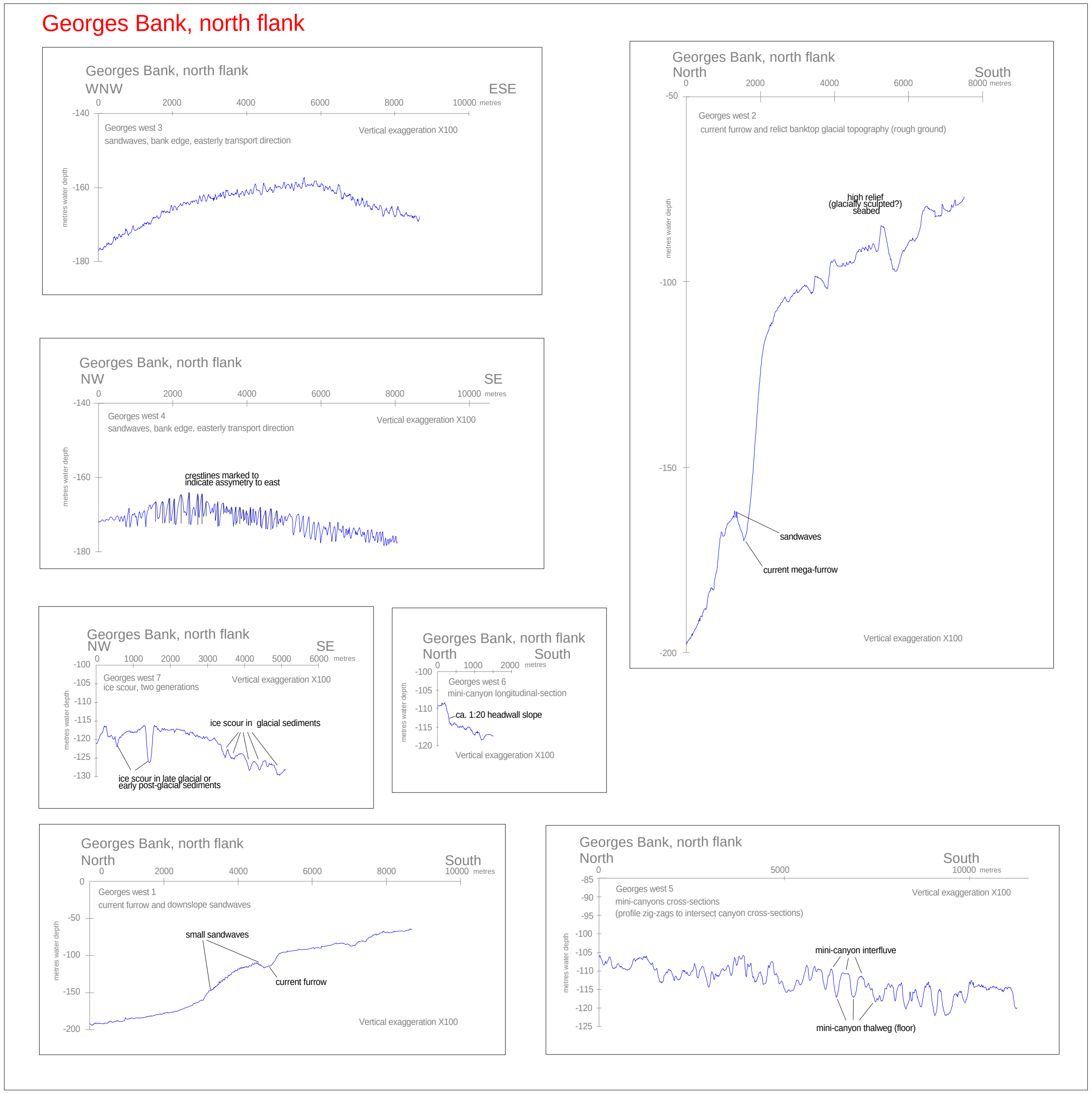
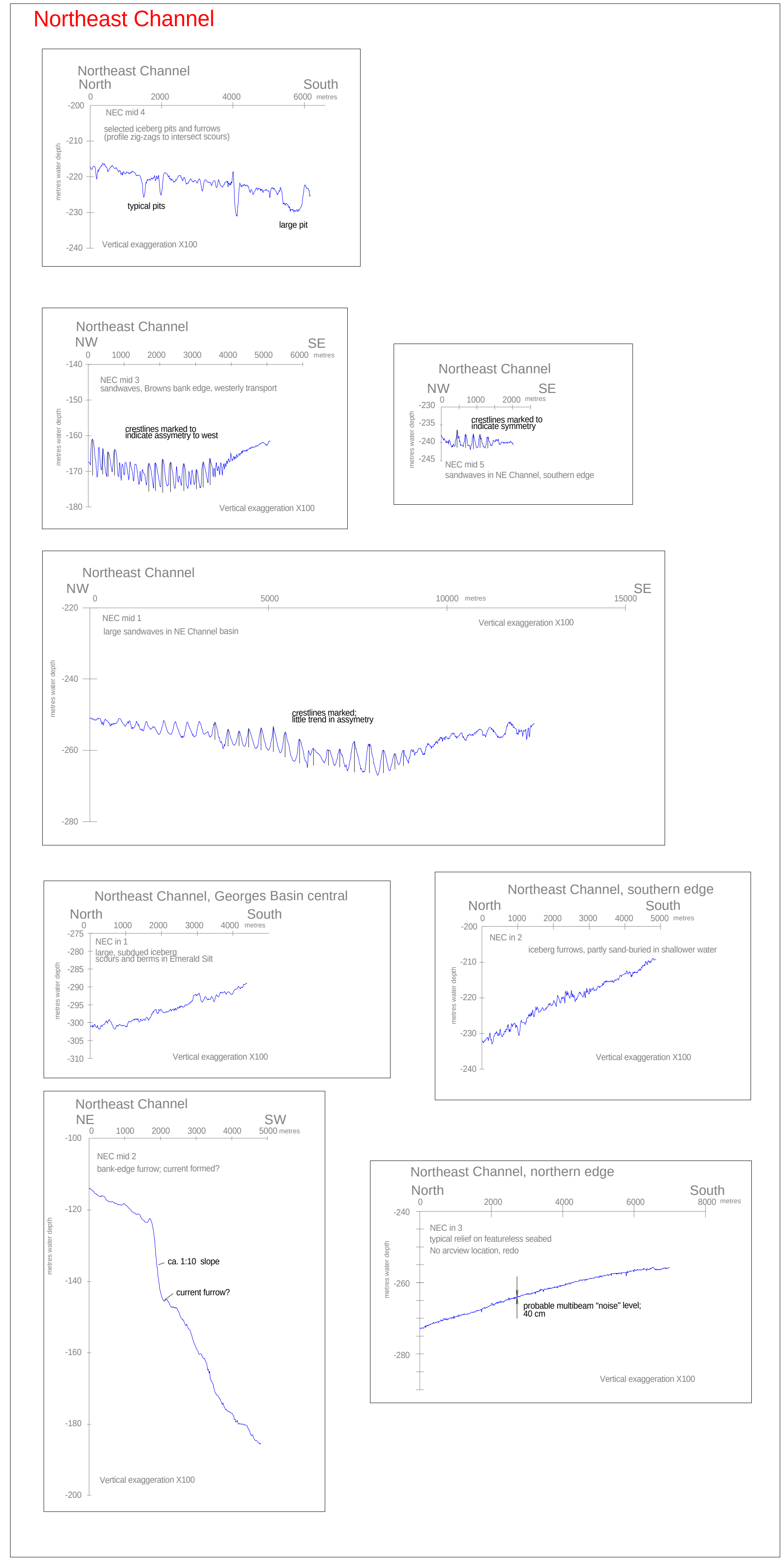
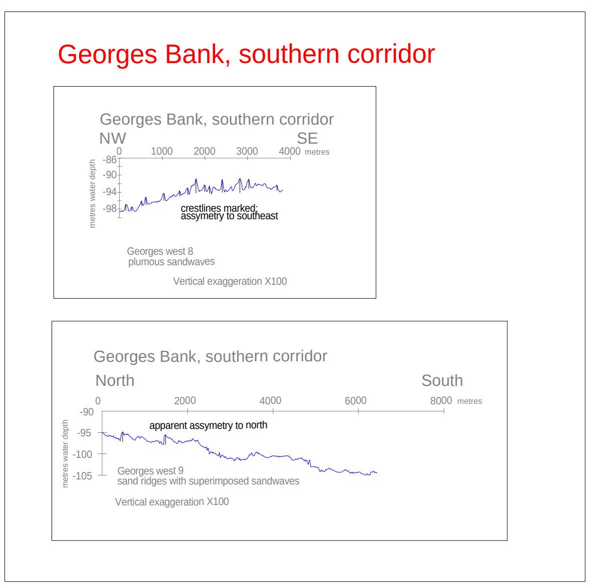

Morphodynamic Interpretation of Middle and Inner Northeast Channel and Southeast Georges Basin
1 Large sand bedforms, showing crest orientation, Sambro Sand
2 Mixed bedforms, (2a) short length crested bedforms, (2b) linguoidal sand bedforms, Sambro Sand
3 Small sand bedforms, channel flanks, short wavelength linear patches, Sambro Sand
4 Linear depression, relict subglacial , meltwater channel ?
5 Linear ridges in till and gravel ?, Browns Bank moraine or former beach ridges
6 Iceberg pits and small furrows, Scotian Shelf Drift (till), gravel with boulders, in NE Channel
7 Featureless seabed, area absent of iceberg furrows as result of sand spillover from banks or mud deposition, Lahave Clay
8 Large iceberg furrows, formed in Emerald Silt
9 Iceberg pits, area of dominant iceberg pits (till), similar to 6
Bedform orientations true (Units 1, 2 and 3)
Iceberg furrows
Bathymetric contour
Iceberg pit
10 0 10 Kilometers
Projection: UTM Zone 20
Datum: NAD83
N
200m
180000
200000
220000
240000
260000
280000
4720000
4700000
4680000
4660000
4640000
70°
68°
66°
64°
62°
60°
48°
46°
44°
42°
40°
Natural Resources Canada
Ressources naturelles Canada

Figure 15.3







ENCLOSURE 14

GEORGES BANK AND NORTHEAST CHANNEL PROFILES FROM MULTIBEAM

Figure 15.4

Photo 27

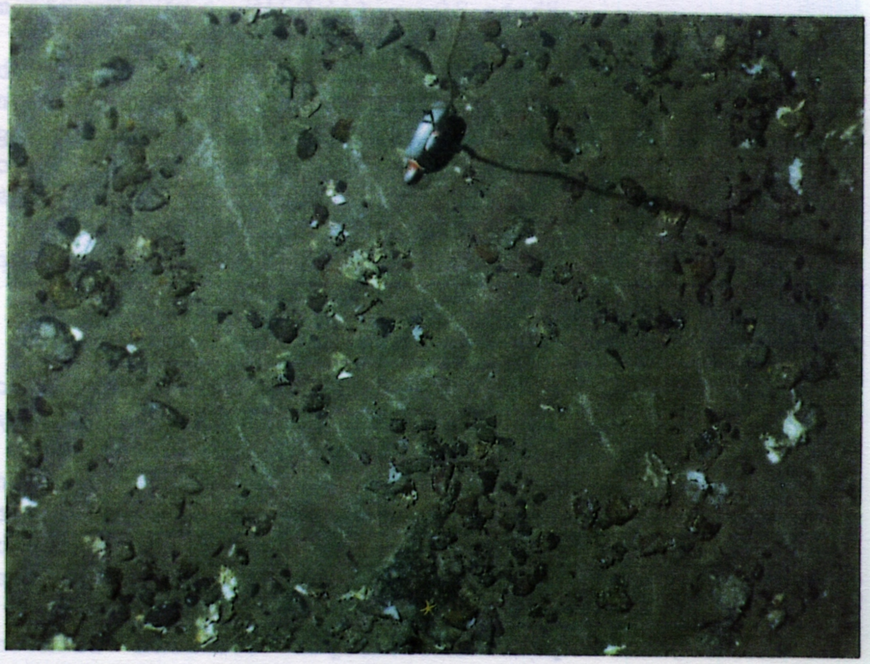


Photo 28

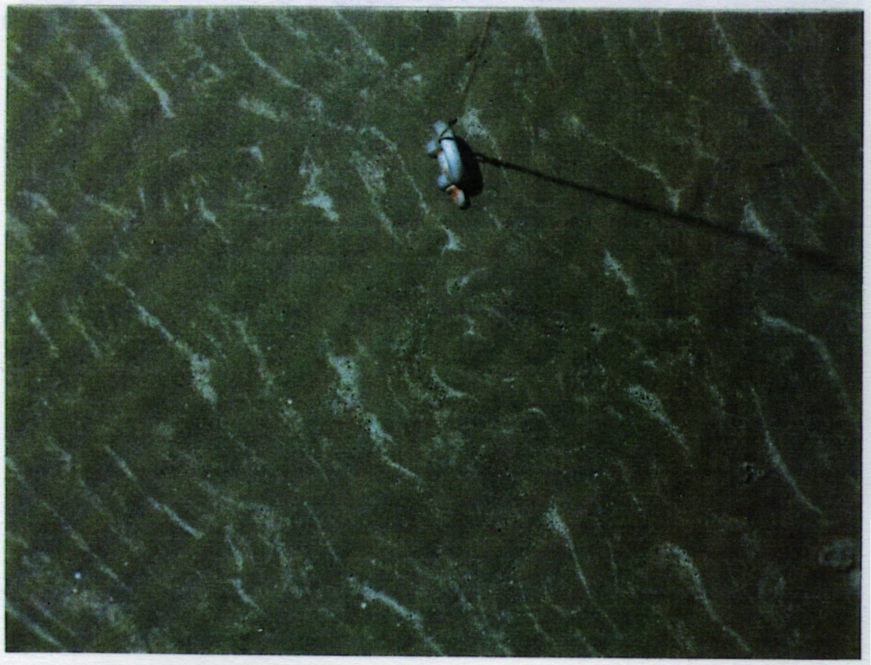


Photo 27 (42°20.1'N, 66°7.2'W, 240-260 m)
Northeast Channel is a deep glacial channel separating Browns and Georges Banks. A gravel lag beneath the thin, clean, coarse Sambro Sand is exposed by the high currents in this area, and the sand itself is rippled. Shell fragments can be seen in the troughs of the ripples and thus enhance the outline of the ripples. Little bioturbation of the surface sediments appears to occur. Sea stars and gastropods can be seen in this photograph, but fauna does not appear to be generally abundant.

Photo 28 (42°20.12'N, 66°7.2'W, 240-260 m)
This photograph shows a similar substrate to that in Photo 27, consisting of a rippled sediment of Sambro Sand. The sand ripples are accentuated by the colour difference between the sand and the shell debris in the troughs. The presence of what looks like fecal casts, seen in a trough (upper left) suggests the presence of infauna, but evidence of animal activity is erased by the currents. Much of the Northeast Channel is a glacial till sediment with a thin veneer of Sambro Sand formed by current erosion. Sand waves are present in adjacent areas.

Figure 15.5. Two seabed photographs of Sambro Sand in Northeast Channel showing that it is periodically active.

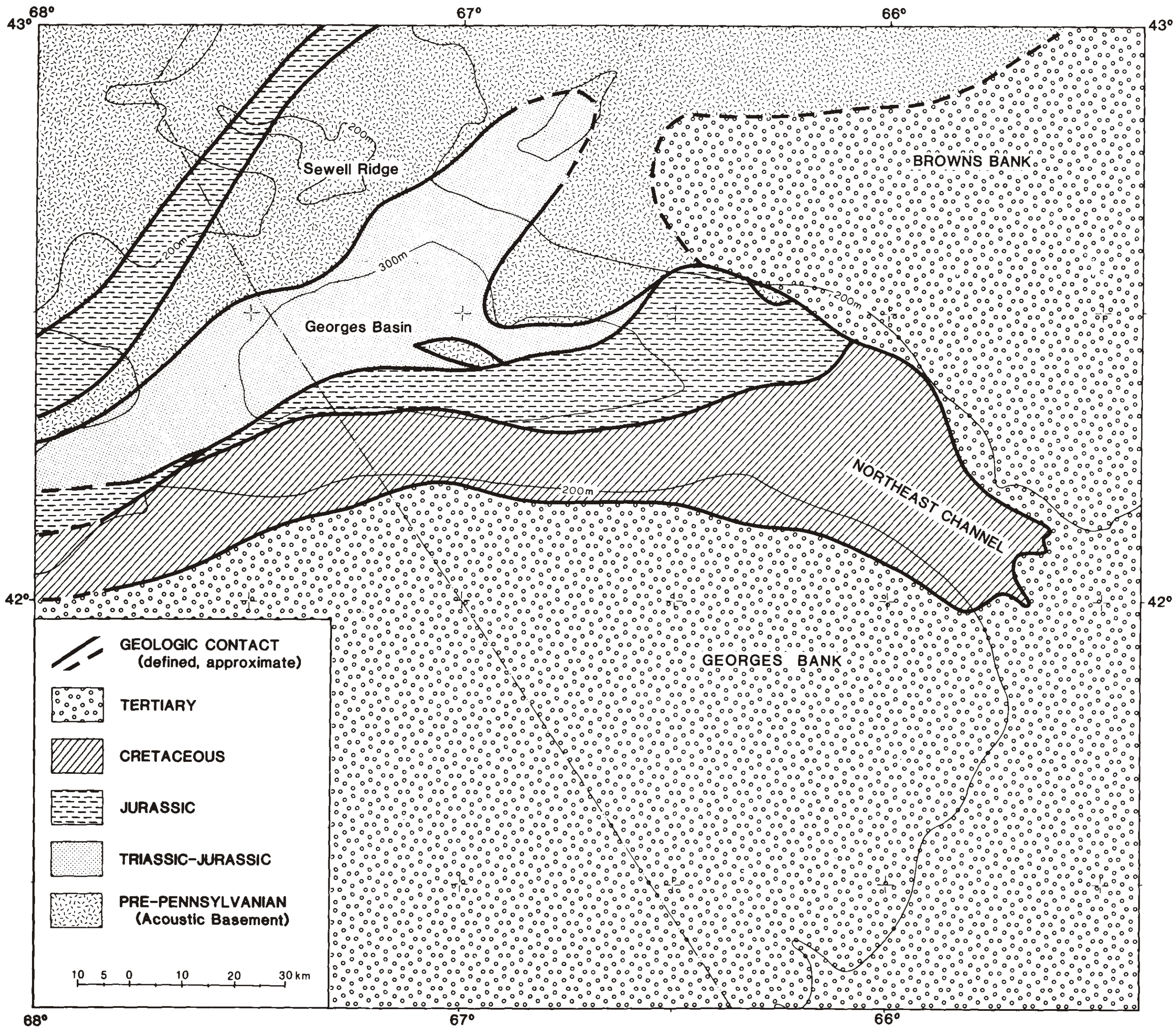


Figure 16.1 Bedrock geology (always in subcrop beneath Quaternary sediments) in the Georges Basin area. The highly variable topography in the northern Browns Bank and Sewell Ridge areas is associated with the hard Paleozoic rocks.

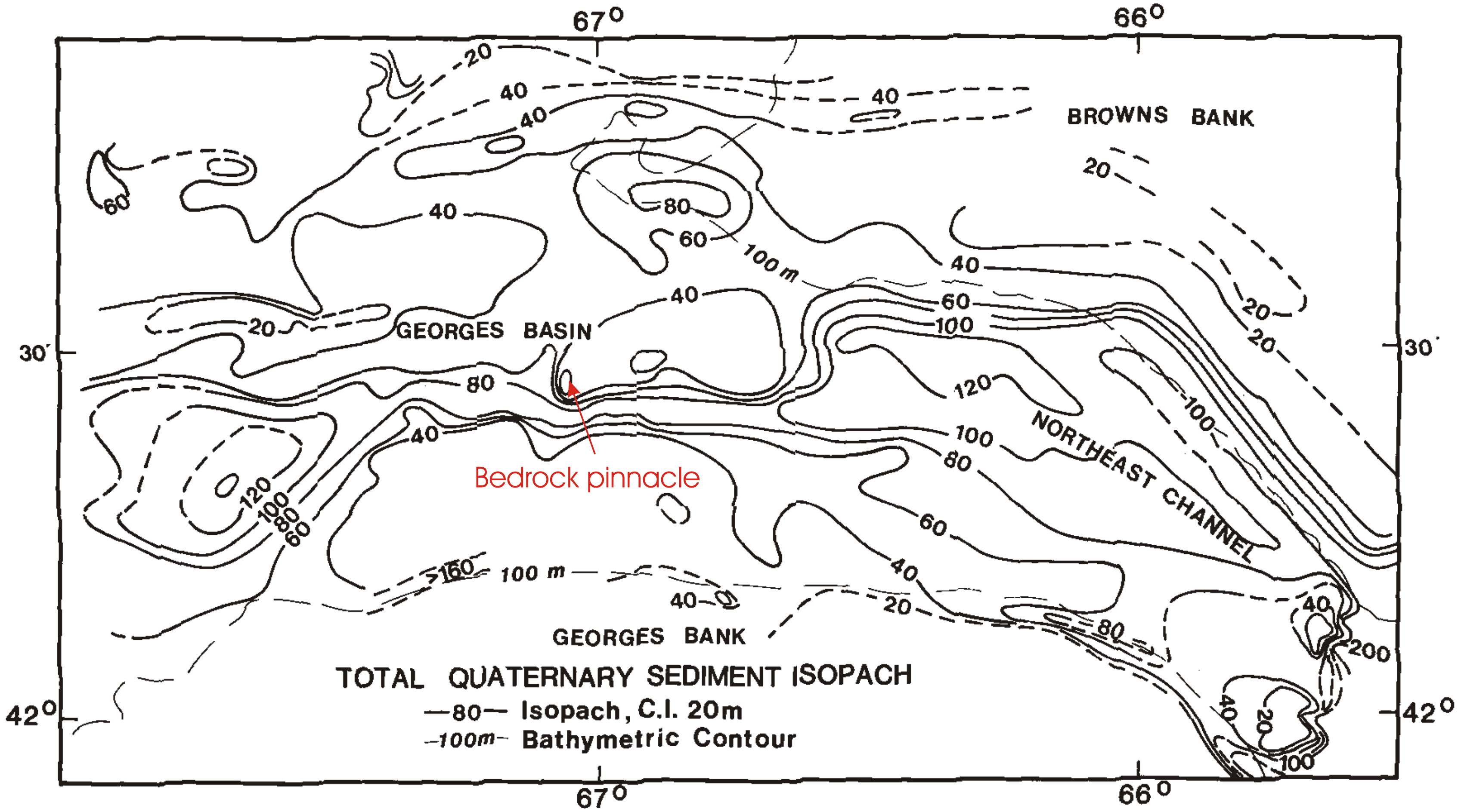


Figure 16.2. Total Quaternary sediment thickness in Georges Basin. The only areas of very thin sediment cover are across a pinnacle of Paleozoic rock near central Georges Basin.

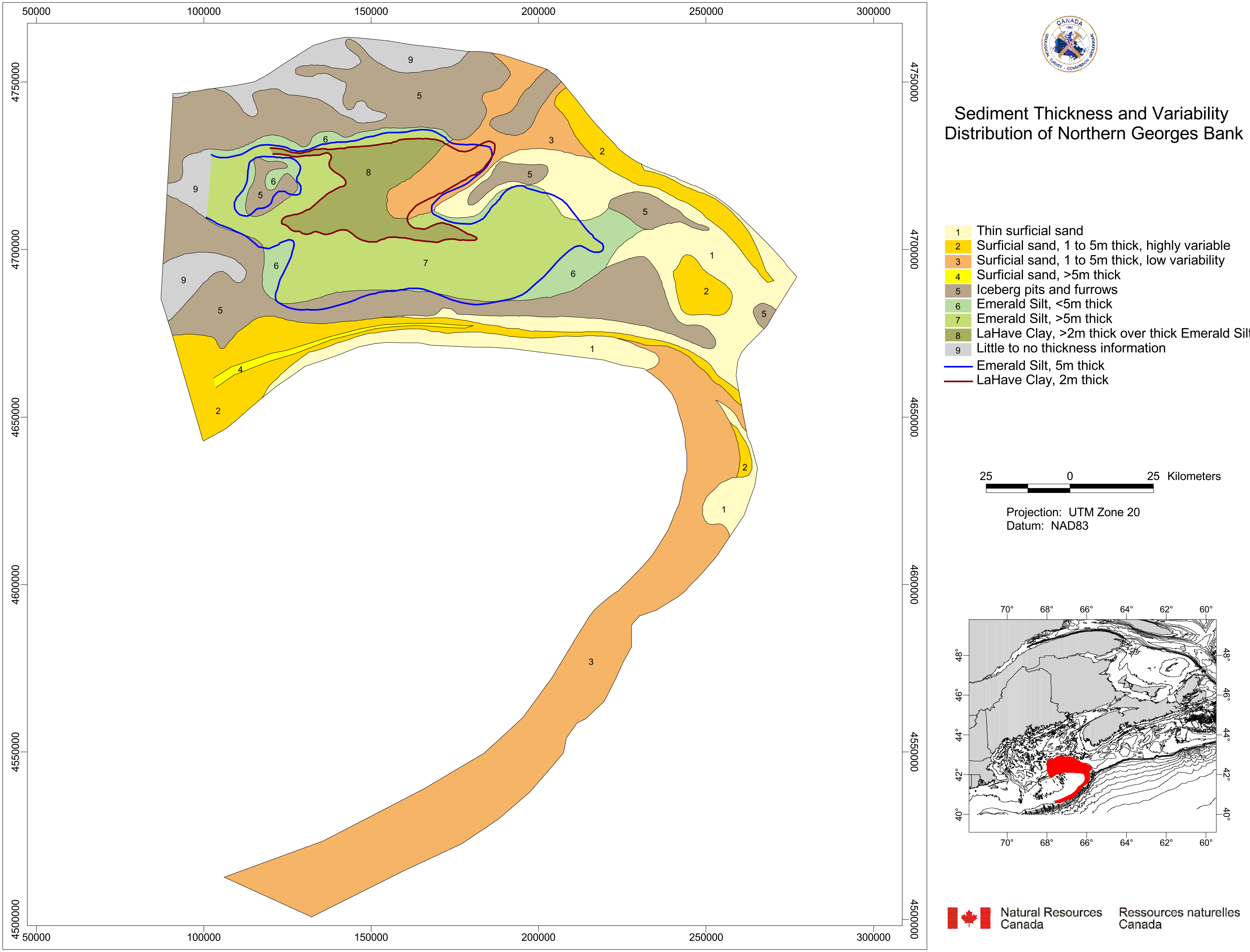

Sediment Thickness and Variability Distribution of Northern Georges Bank
1 Thin surficial sand
2 Surficial sand, 1 to 5m thick, highly variable
3 Surficial sand, 1 to 5m thick, low variability
4 Surficial sand, >5m thick
5 Iceberg pits and furrows
6 Emerald Silt, <5m thick
7 Emerald Silt, >5m thick
8 LaHave Clay, >2m thick over thick Emerald Silt
9 Little to no thickness information
Emerald Silt, 5m thick
LaHave Clay, 2m thick
25 0 25 Kilometers
Projection: UTM Zone 20
Datum: NAD83
50000
100000
150000
200000
250000
300000
4750000
4700000
4650000
4600000
4550000
4500000
70°
68°
66°
64°
62°
60°
48°
46°
44°
42°
40°
Natural Resources Canada
Ressources naturelles Canada

Figure 16.3

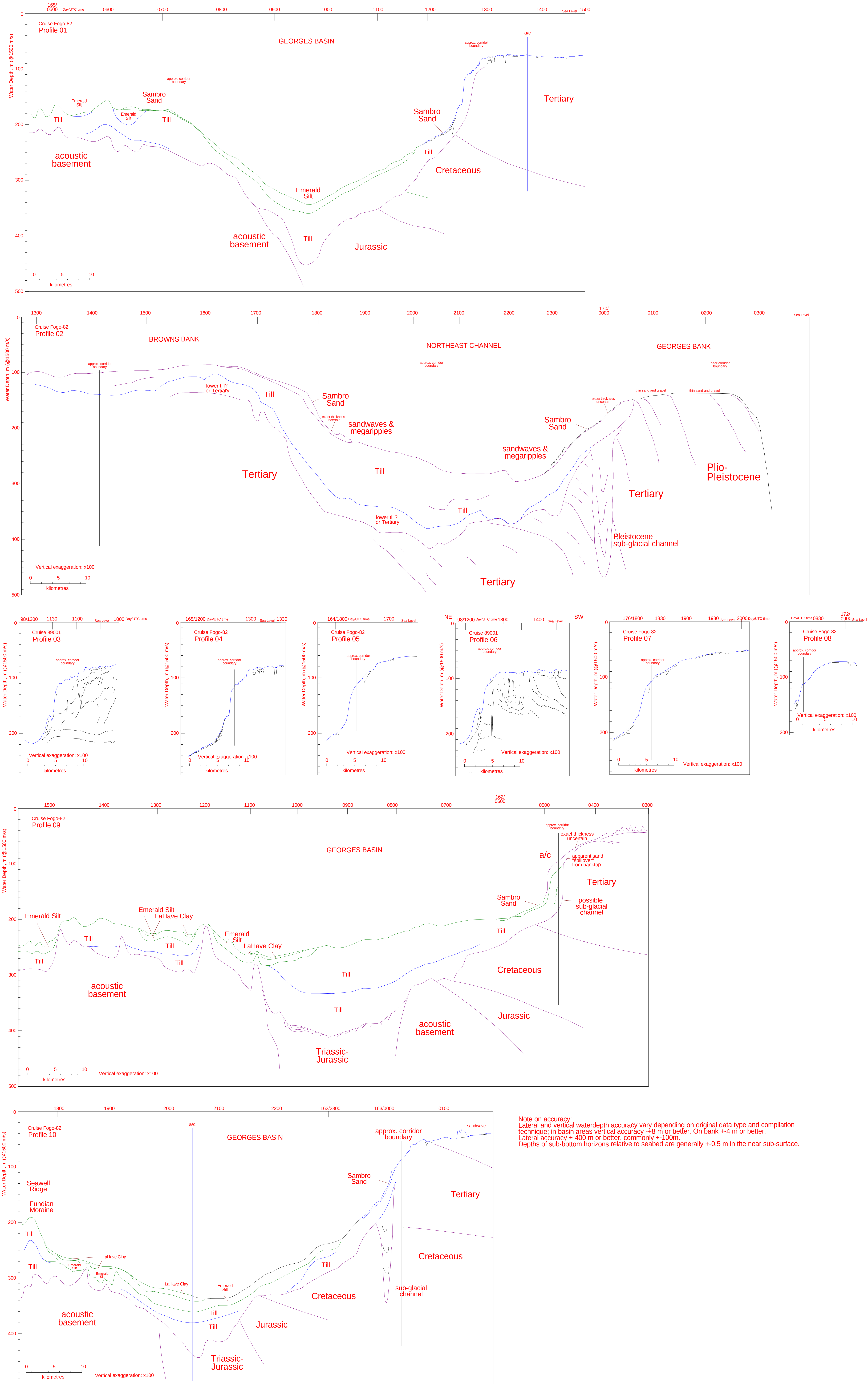

Cruise Fogo-82
Profile 01
GEORGES BASIN
Water Depth, m (@1500 m/s)
165/0500
Day/UTC time
Sea Level
approx. corridor boundary
a/c
Emerald Silt
Sambro Sand
Till
acoustic basement
Tertiary
Cretaceous
Jurassic
kilometres
Cruise Fogo-82
Profile 02
BROWNS BANK
NORTHEAST CHANNEL
GEORGES BANK
lower till? or Tertiary
sandwaves & megaripples
exact thickness uncertain
thin sand and gravel
near corridor boundary
Plio-Pleistocene
Pleistocene sub-glacial channel
lower till? or Tertiary
Vertical exaggeration: x100
Cruise 89001
Profile 03
Cruise Fogo-82
Profile 04
Cruise Fogo-82
Profile 05
NE
SW
Cruise 89001
Profile 06
Cruise Fogo-82
Profile 07
Cruise Fogo-82
Profile 08
Cruise Fogo-82
Profile 09
Emerald Silt
LaHave Clay
apparent sand "spillover" from banktop
possible sub-glacial channel
Triassic-Jurassic
Cruise Fogo-82
Profile 10
Seawell Ridge
Fundian Moraine
sandwave
sub-glacial channel
Note on accuracy:
Lateral and vertical waterdepth accuracy vary depending on original data type and compilation technique; in basin areas vertical accuracy -+8 m or better. On bank +-4 m or better.
Lateral accuracy +-400 m or better, commonly +-100m.
Depths of sub-bottom horizons relative to seabed are generally +-0.5 m in the near sub-surface.

Figure 16.4

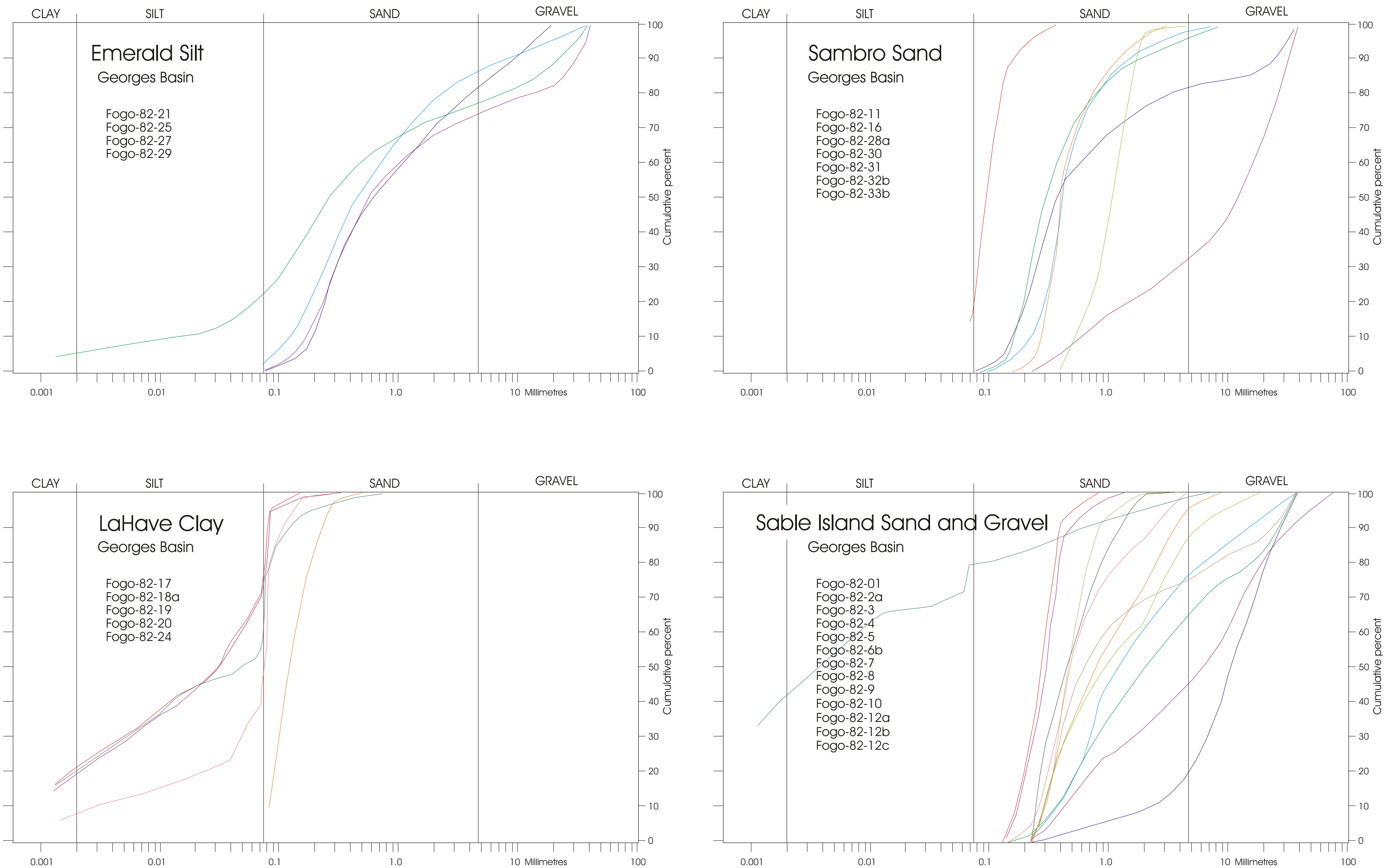


Figure 16.5. Grainsize distribution curves for representative samples from the various stratigraphic units in Georges Basin and Georges Bank.

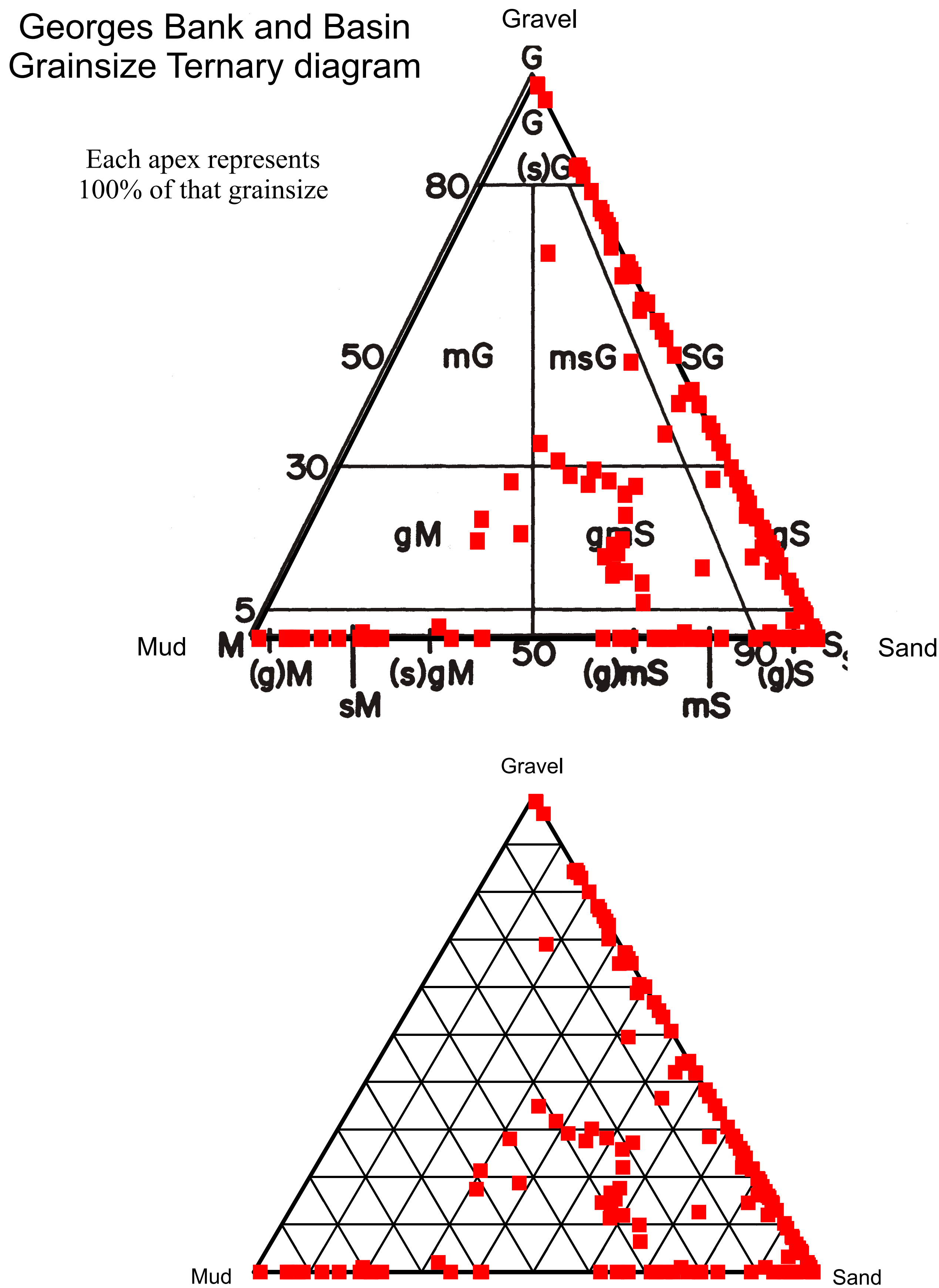


Figure 16.6. Ternary diagram for the grainsize samples shown in the previous figure.

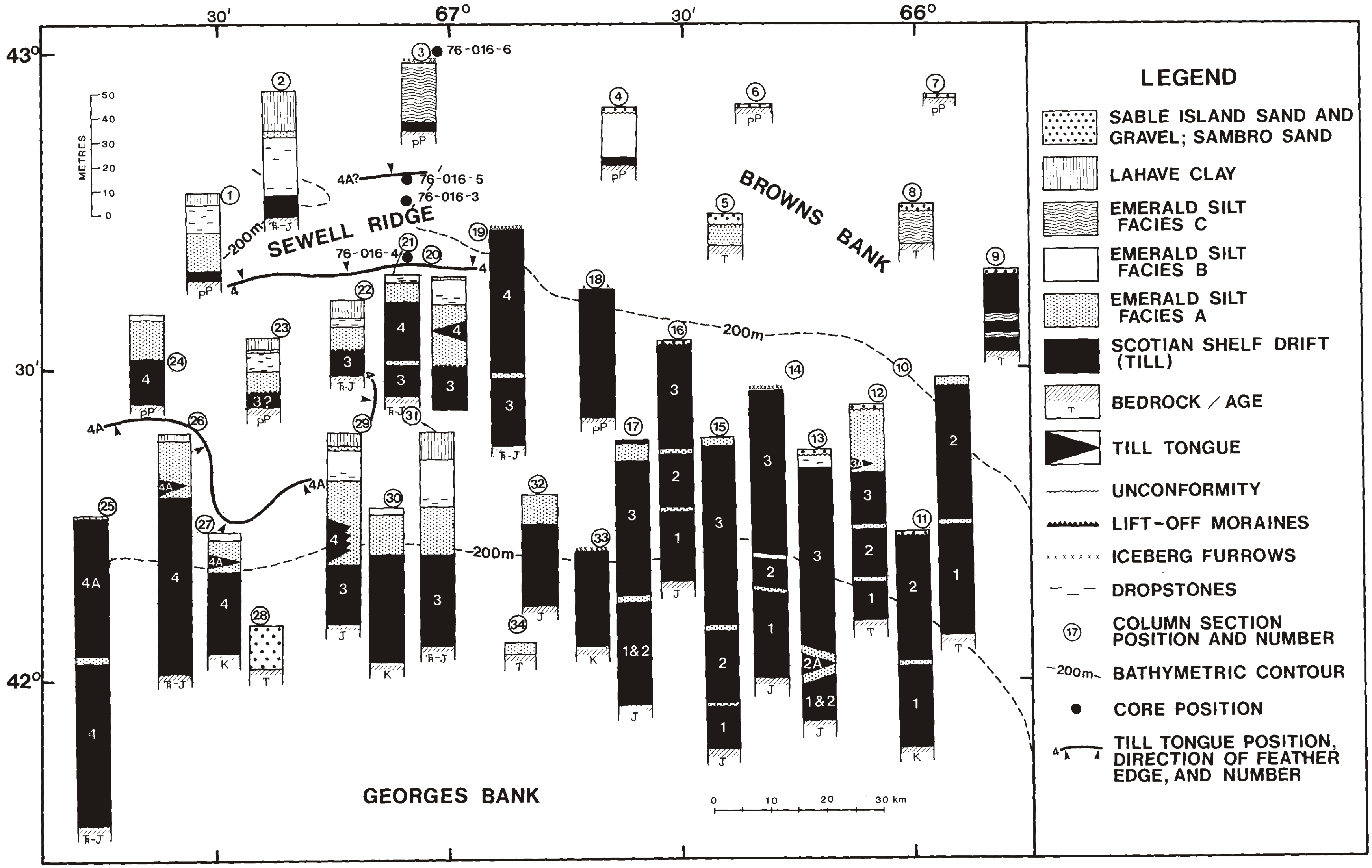


Figure 16.7. Quaternary sediments in Georges Basin. The column sections are derived from seismic profiles and show the presences, thickness, and some features (till tongues and buried ribbed moraines) at various locations.

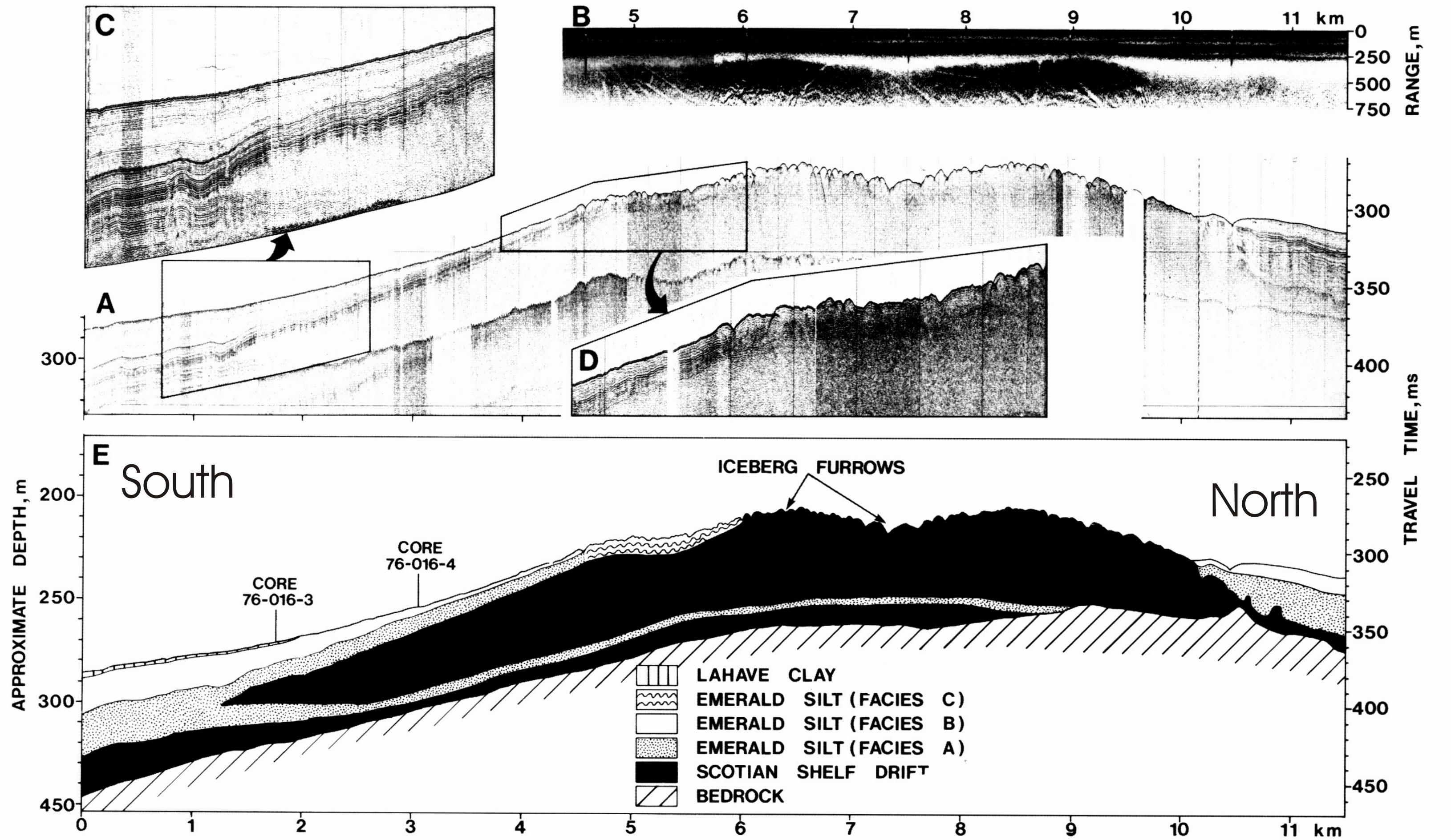


Figure 5. Huntec DTS profile (A), sidescan sonogram (B), enlarged sections of the Huntec DTS profile (C, D), and geological interpretation (E) across the Fundian Moraine, Gulf of Maine. Facies A Emerald Silt, is interbedded with till of the moraine and extends under the moraine for a distance of 8km, where it pinches out against the bedrock surface. Near the top of the moraine, facies A grades to facies C Emerald Silt with an acoustic character of continuous-discontinuous coherent reflections over a distance of 1.5km. The surface of the till of the moraine is covered with iceberg furrows up to 5m in depth. The wedge-shaped body of till interpenetrating facies A Emerald Silt, is referred to as a till tongue. The positions of the piston cores are indicated and the type section for the Gulf of Maine area is located 1.1km south of core 76-016-3. The morphology and position of the bedrock surface was interpreted from an adjacent airgun seismic reflection profile.

Figure 16.8. Seismic section through the Fundian Moraine. The suggested pipeline route lies south of the moraine, in the stratified basinal sediments, in the vicinity of core site 76-0163, thus avoiding the gravel (and boulders) and iceberg furrows (from King and Fader, 1986).

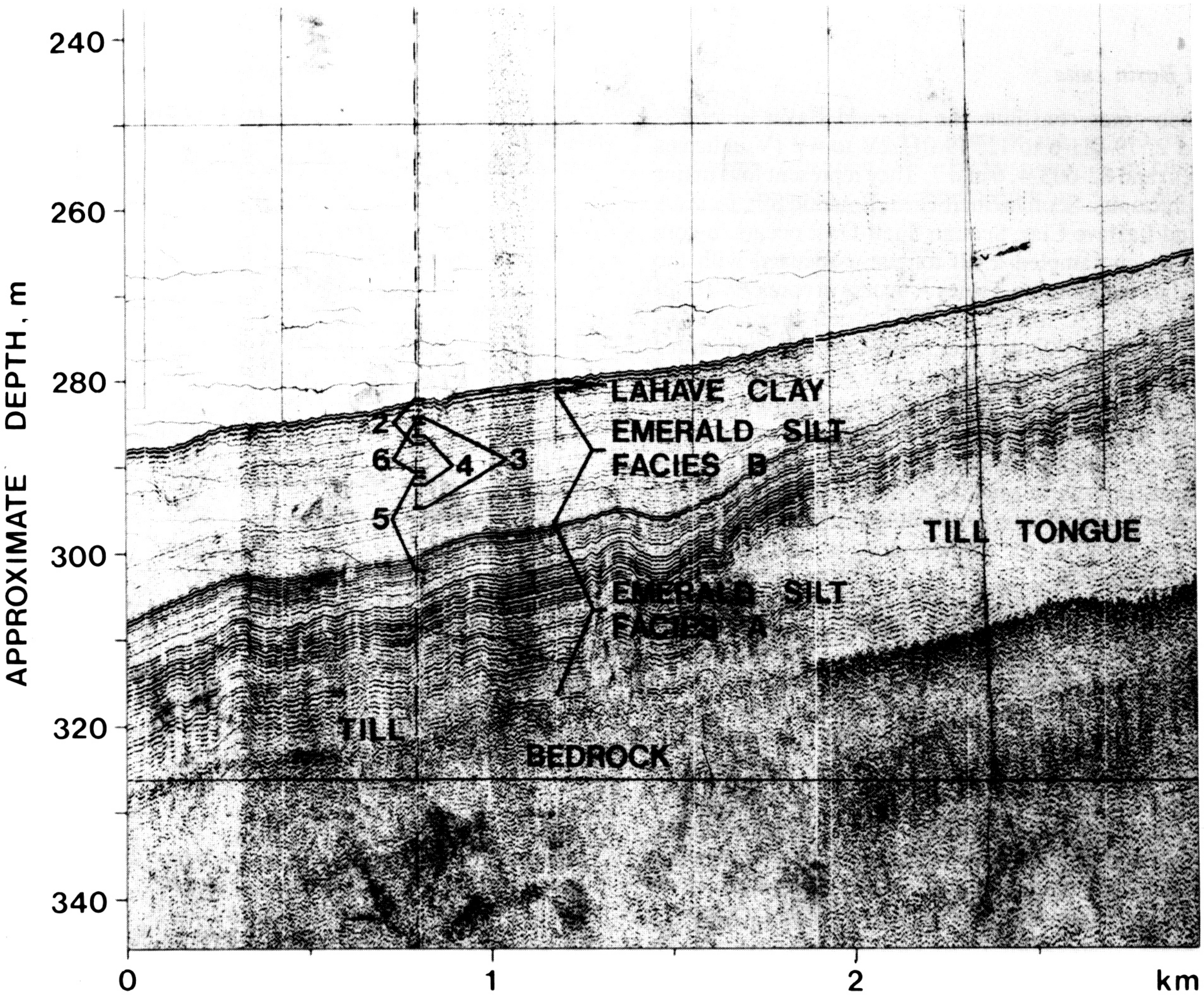


Figure 23. Huntec DTS profile of the type section in the Gulf of Maine. The sections sampled by the cores are bracketed. Emerald Silt facies A consists of medium-high intensity continuous coherent reflections. Emerald Silt facies B consists of medium intensity continuous coherent reflections with occasional dropstones. In this area LaHave Clay is coarser and has an acoustic character similar to facies B Emerald Silt. The till consists of incoherent reflections and the till tongue is interbedded with facies A Emerald Silt.

Figure 16.9 Typical till tongue on the basinward side of the end moraine complex (here, Fundian Moraine), showing relationships between till (probably largely debris flow material here) and the stratified glacimarine Emerald Silt and overlying LaHave Clay.

Figure 16.10. Seabed photograph of the gravel lag developed on the Scotian Shelf Drift (till) on the Fundian Moraine.

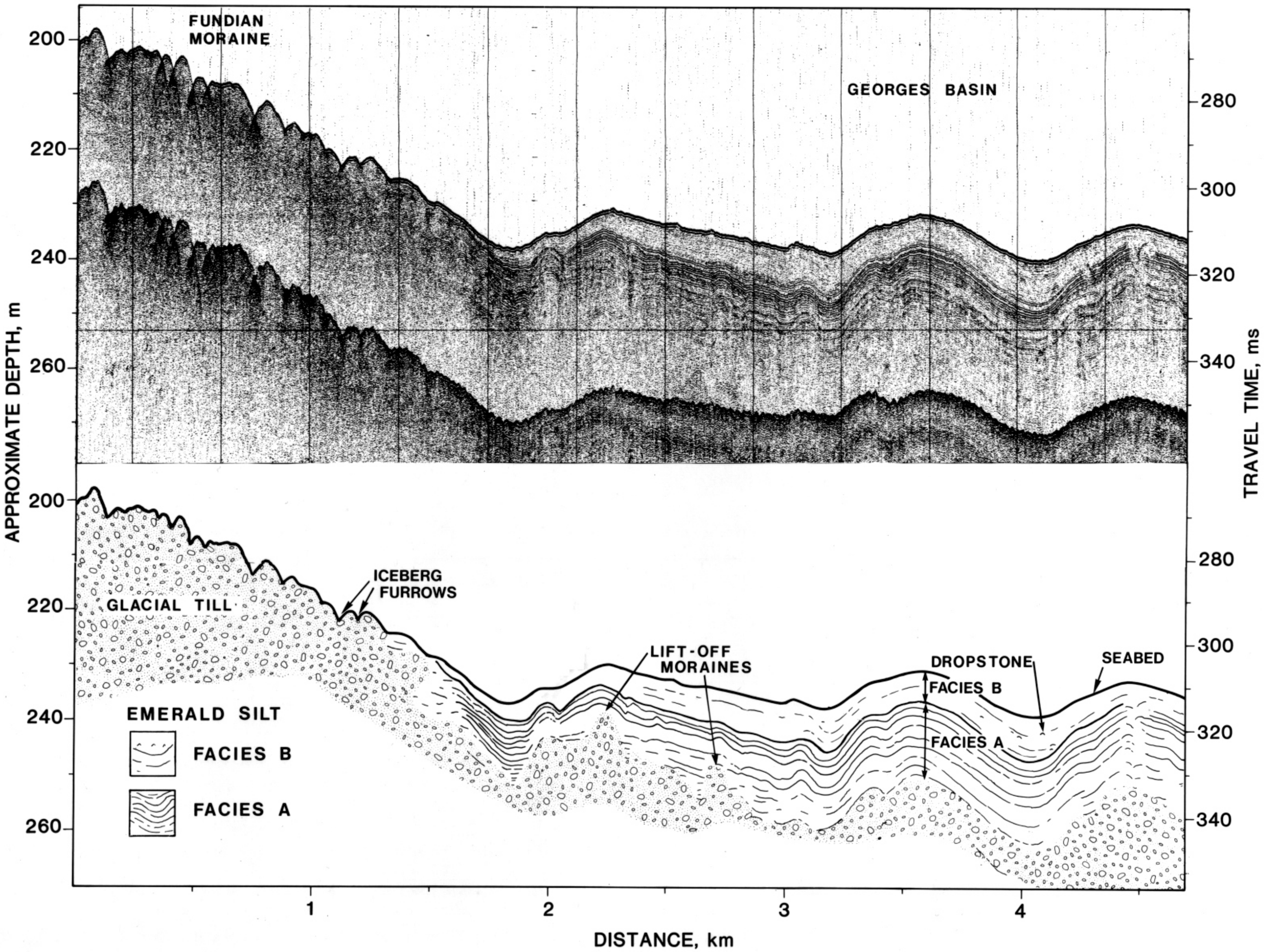


Figure 16.11. More detailed presentation of the southern flank of the Fundian moraine. Pipeline placement over the stratified sediments avoids the relief and gravels of the moraine.

Figure 16.12. Seabed photograph of the Emerald Silt in Georges Basin.

Photo 25 (42°25.2'N, 67°4.5'W, 354 m)
In Georges Basin, Gulf of Maine, the fine grained sediment of LaHave Clay hosts a large number of stalked tunicates and tube-building and burrowing taxa. Some small brittle stars are also present. The openings of two large tubes, possibly those of polychaetes, project from the sediment. The LaHave Clay contains a significant sand-sized component. The presence of the stalked tunicates indicates current activity which also suggests a small coarse component in the sediment to which they can attach. The seabed surface is not extensively pitted, perhaps indicating a low density of infaunal invertebrates.

Photo 25

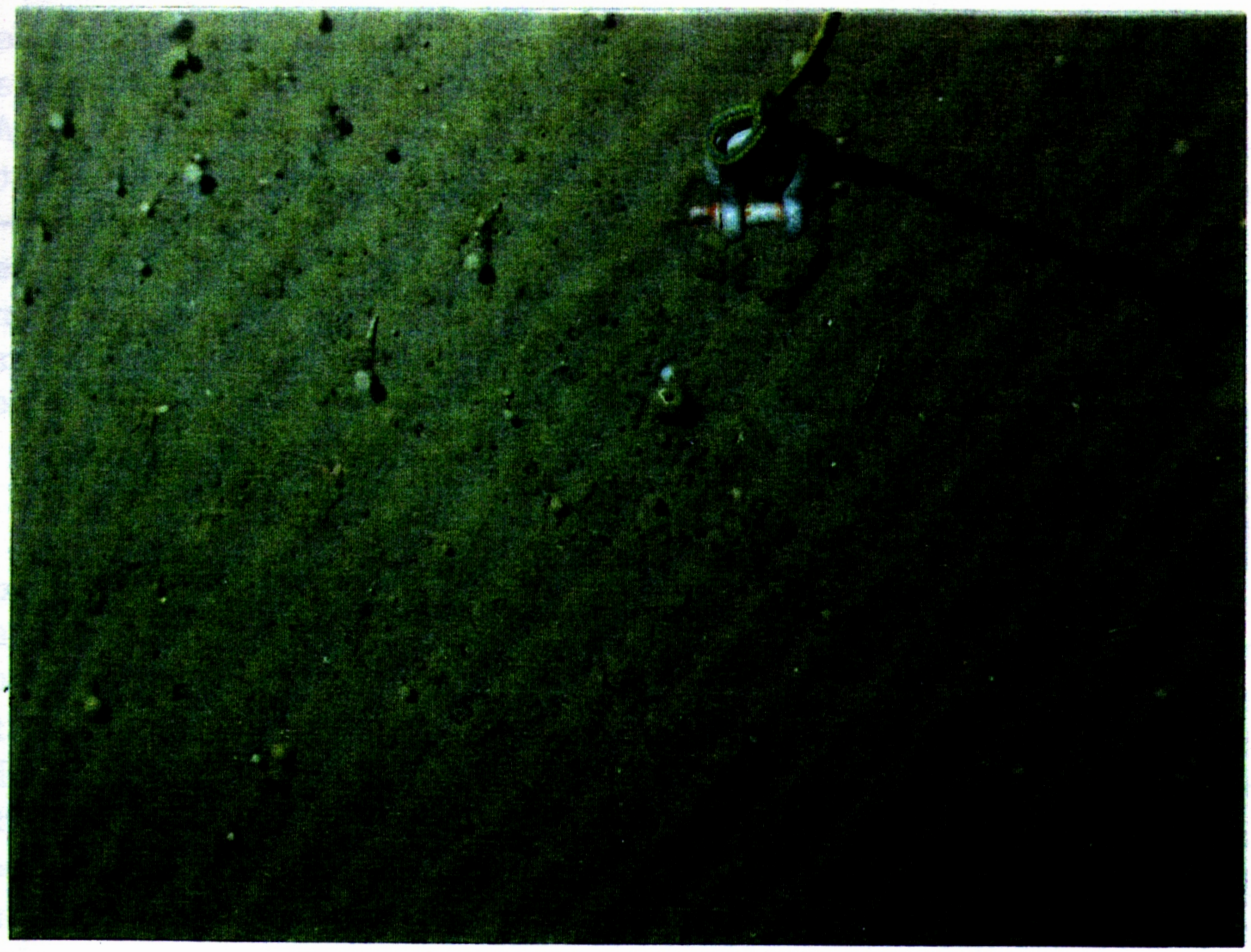


Figure 16.13 Seabed photograph from Georges Basin in a relatively sandy facies of LaHave Clay, with sediment and faunal descriptions.

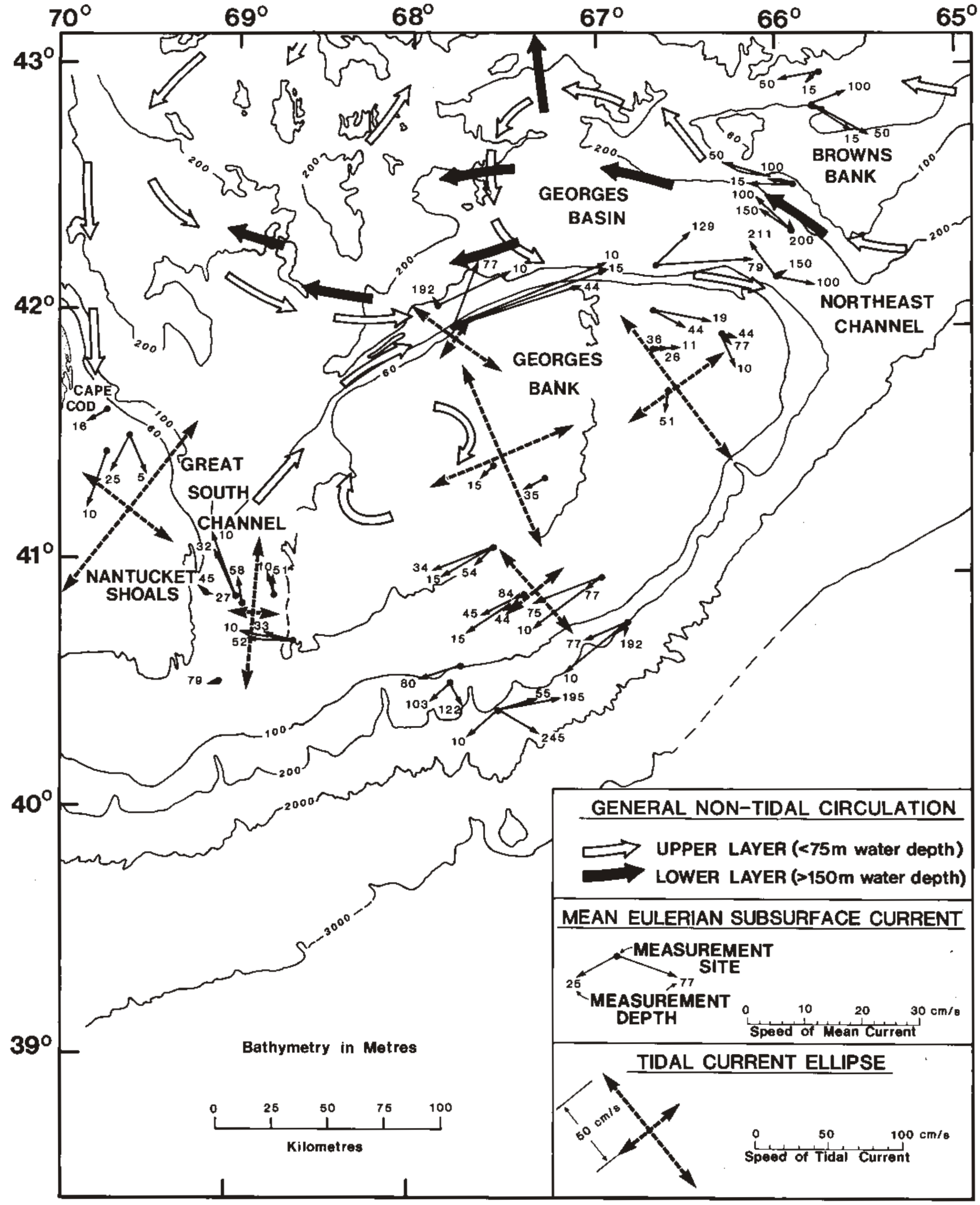


Figure 16.14 Oceanographic elements of Georges Bank and Basin. (compiled largely by John Loder, DFO)

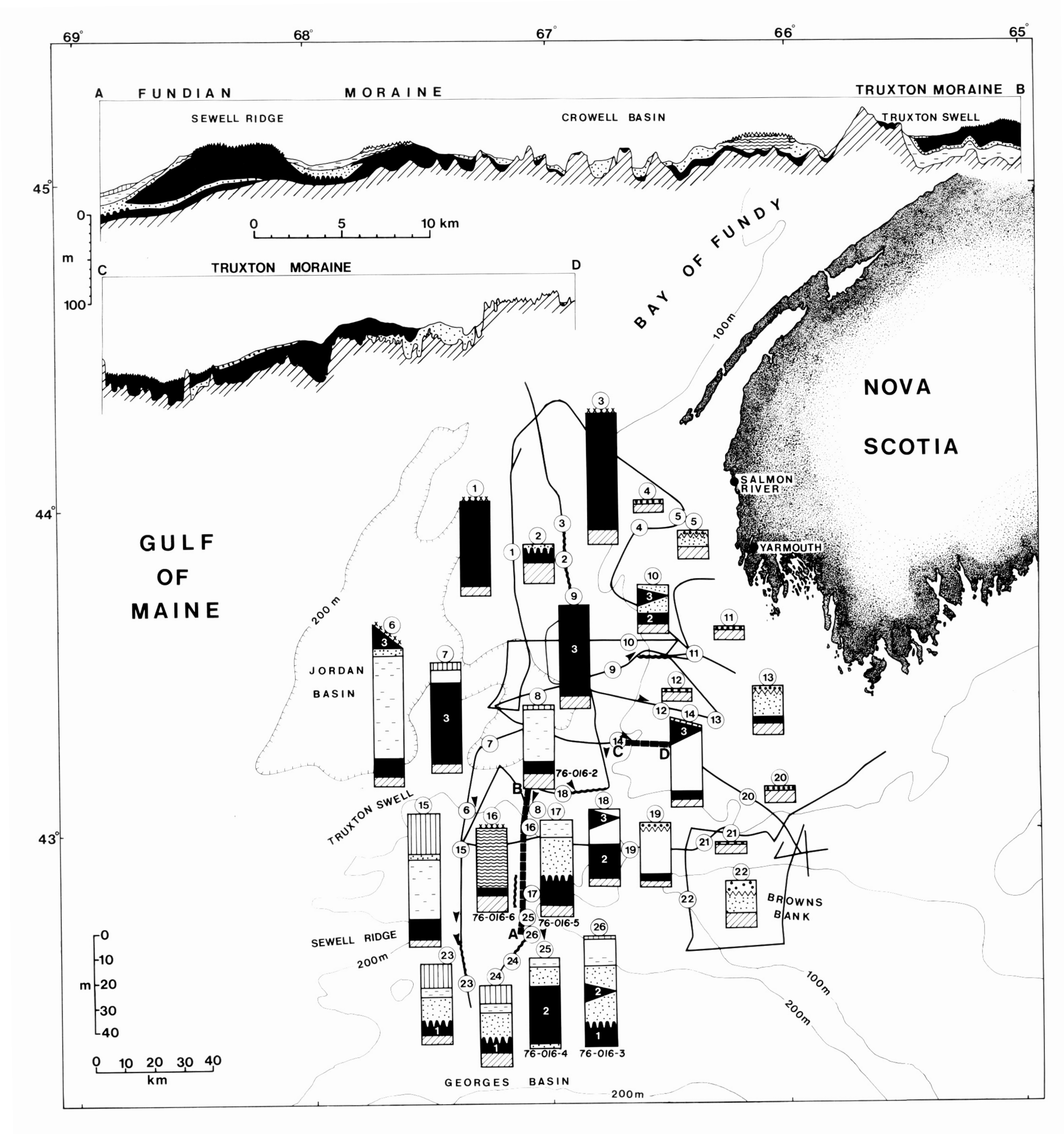


Figure 17.1. Quaternary sediments in the Gulf of Maine. The column sections are derived from seismic profiles and show the presences, thickness, and some features (till tongues and buried ribbed moraines) at various locations, commonly where short cores also exist.

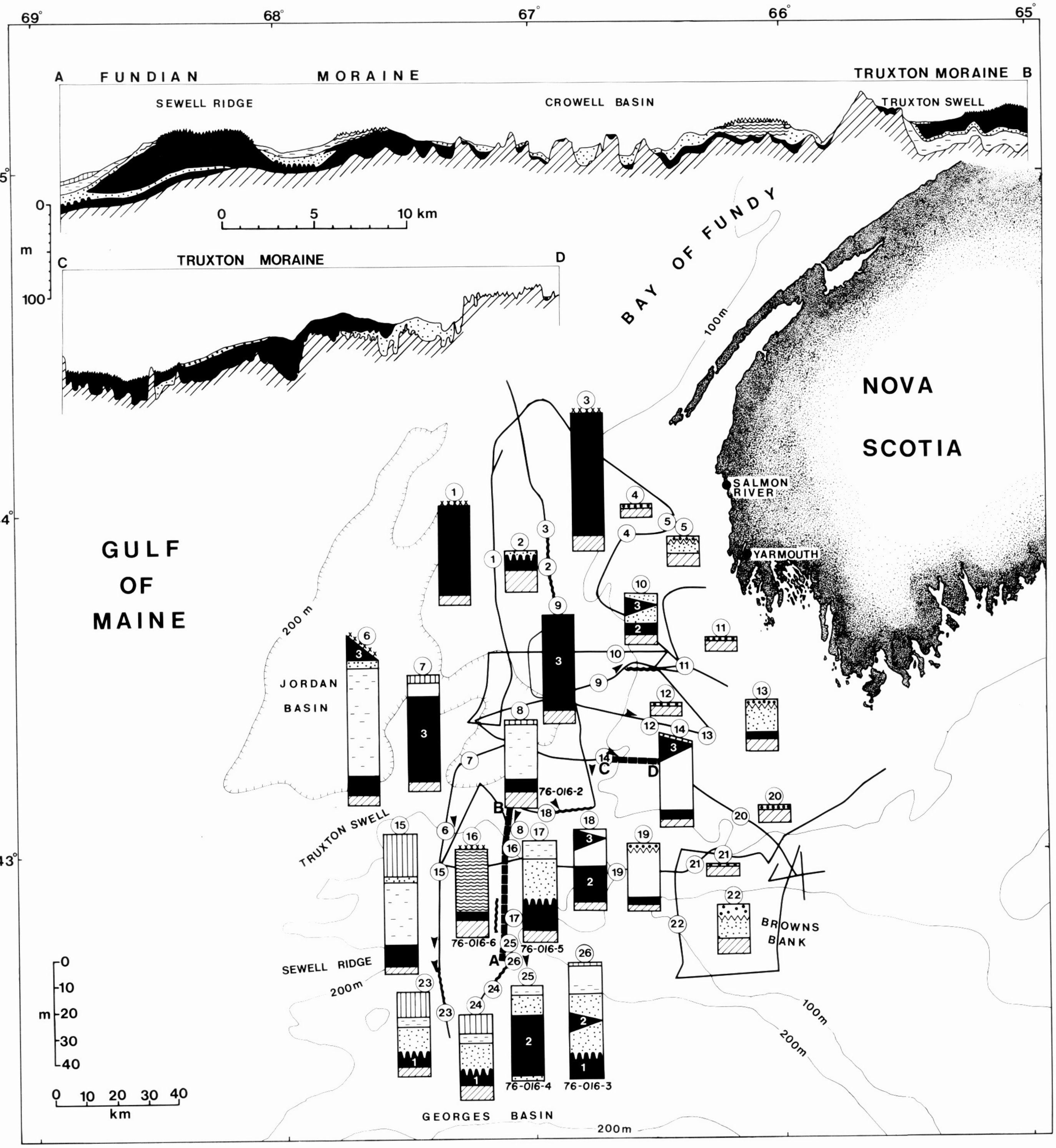


Figure 18.1. Quaternary sediments in the Gulf of Maine. The column sections are derived from seismic profiles and show the presences, thickness, and some features (till tongues and buried ribbed moraines) at various locations, commonly where short cores also exist.

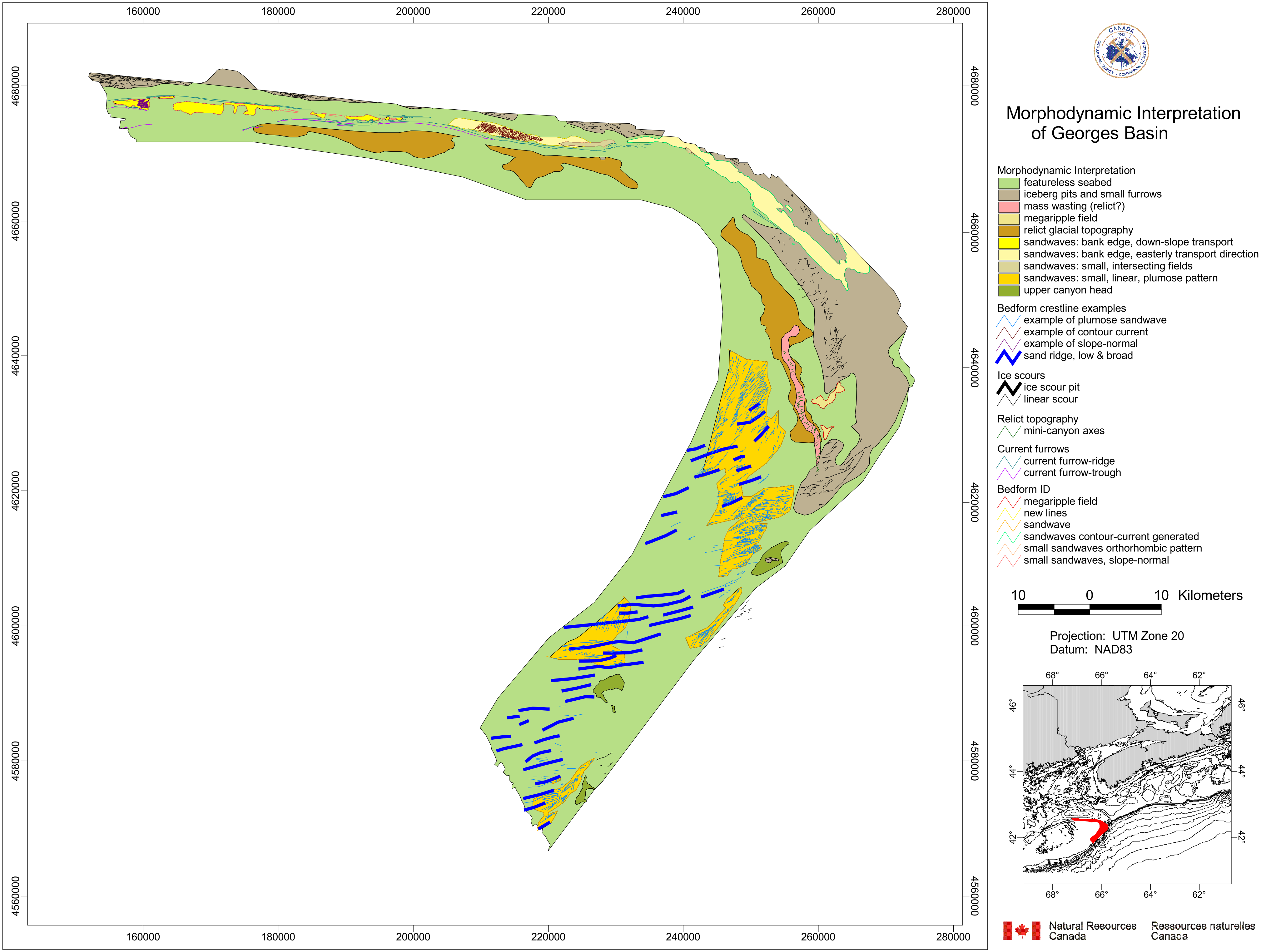
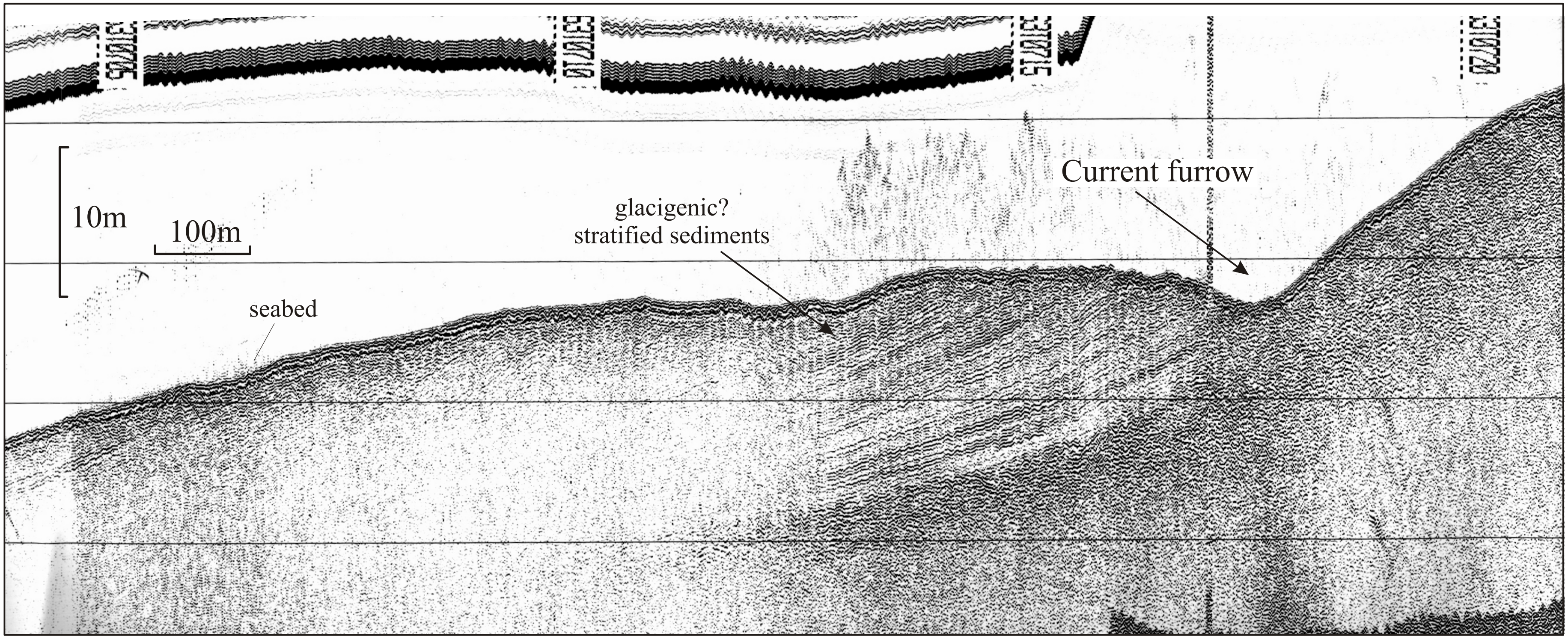

Morphodynamic Interpretation of Georges Basin
Morphodynamic Interpretation
featureless seabed
iceberg pits and small furrows
mass wasting (relict?)
megaripple field
relict glacial topography
sandwaves: bank edge, down-slope transport
sandwaves: bank edge, easterly transport direction
sandwaves: small, intersecting fields
sandwaves: small, linear, plumose pattern
upper canyon head
Bedform crestline examples
example of plumose sandwave
example of contour current
example of slope-normal
sand ridge, low & broad
Ice scours
ice scour pit
linear scour
Relict topography
mini-canyon axes
Current furrows
current furrow-ridge
current furrow-trough
Bedform ID
megaripple field
new lines
sandwave
sandwaves contour-current generated
small sandwaves orthorhombic pattern
small sandwaves, slope-normal
10 0 10 Kilometers
Projection: UTM Zone 20
Datum: NAD83
Natural Resources Canada
Ressources naturelles Canada

Figure 19.1



2000-047 Huntec, 263/0710

E. King, 2002

Figure 19.2. Huntec (sub-bottom profiler) image from northern flank of Georges Bank (ca. 70 m water depth) showing the large current scour feature cut into stratified sediments..

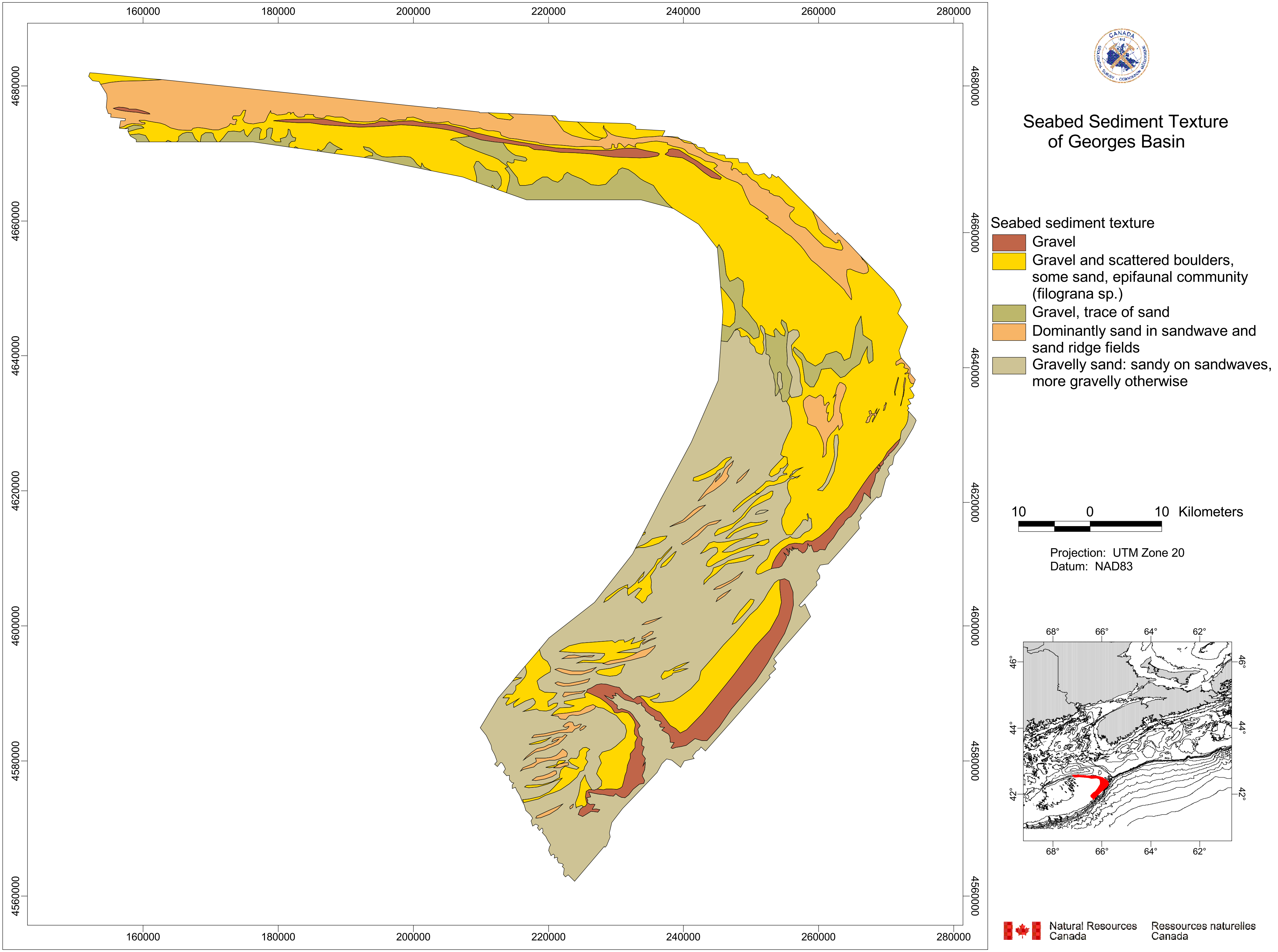

Seabed Sediment Texture of Georges Basin
Seabed sediment texture
Gravel
Gravel and scattered boulders, some sand, epifaunal community (filograna sp.)
Gravel, trace of sand
Dominantly sand in sandwave and sand ridge fields
Gravelly sand: sandy on sandwaves, more gravelly otherwise
10 0 10 Kilometers
Projection: UTM Zone 20
Datum: NAD83
160000
180000
200000
220000
240000
260000
280000
4680000
4660000
4640000
4620000
4600000
4580000
4560000
68°
66°
64°
62°
46°
44°
42°
Natural Resources Canada
Ressources naturelles Canada

Figure 19.3

Photo 77

Photo 79

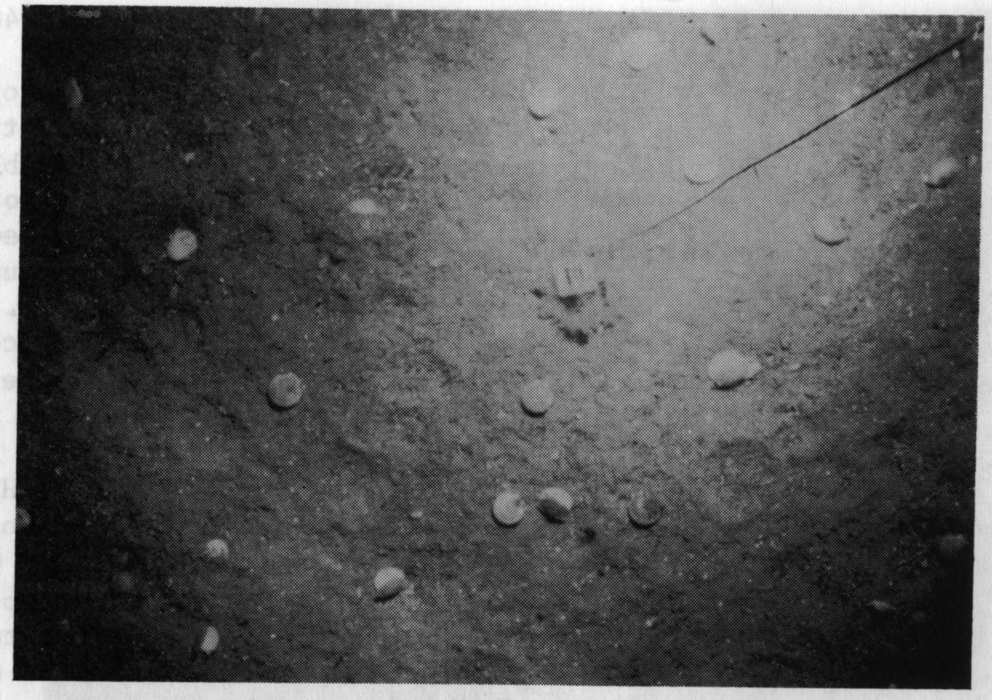


Photo 78

Photo 80

Banks – Georges Bank
The series of photographs (73–80) was taken in and around the Hunky Dory proposed well site of Texaco Canada Resources Ltd.

Photo 77 (41°51.88'N, 66°5.78'W, 93 m)
South of the area shown in Photo 78, the sand of the Sable Island Sand and Gravel formation is rippled by currents, resulting in sorting of the grain sizes. The coarser gravel and shell fragments are found in troughs of the ripples, whereas the finer grained material is found on the ripple crests. Biogenic material or traces are not evident in this photograph.

Photo 78 (41°51.88'N, 66°5.78'W, 94 m)
The Sable Island Sand and Gravel sediment in this area of northeastern Georges Bank consists mainly of poorly sorted coarse to fine sand, with small pebbles and some shell debris, including some small sea scallop shells. The pebbles and fine gravel are aligned parallel with the current direction. No epifauna is visible, and traces of invertebrate activity do not seem to have persisted on this substrate, probably because of the nature of the sediment and currents which sweep the bottom, from bottom left to top right of the picture (see also Photo 77).

Photo 79 (41°46.12'N, 65°57.07'W, 105 m)
In this photo from the eastern edge of Georges Bank, Gulf of Maine, a high density of scallops is evident on the sand and fine gravel sediments of the Sable Island Sand and Gravel formation. "Sitz" marks, which cover much of the surface of the seabed, indicate where the suspension feeding scallops have rested. The activities of various infaunal animals have resulted in a considerable bioturbation.

Photo 80 (41°46.12'N, 65°58.88'W, 104 m)
The relatively fine sediments in this area are Sable Island Sand and Gravel with a mixture of sand and fine gravel. The benthic community includes scallops and a rich, diverse infauna. A colonial hydroid or bryozoan grows on a shell at bottom left, and the scallop at bottom right also supports a hydroid growth. The tube building polychaete fauna is represented by at least two major families: the onuphids and the terebellids. The tubes of the former are heavily encrusted with small gravel clasts and shell debris. The terebellid tubes, on the other hand, are coated with fine sand particles. Feeding modes of these taxa include suspension feeders, subsurface and surface deposit feeders and carnivores.

Figure 19.4. Seabed photographs from Georges Bank with sediment and fauna descriptions.

Photo 73

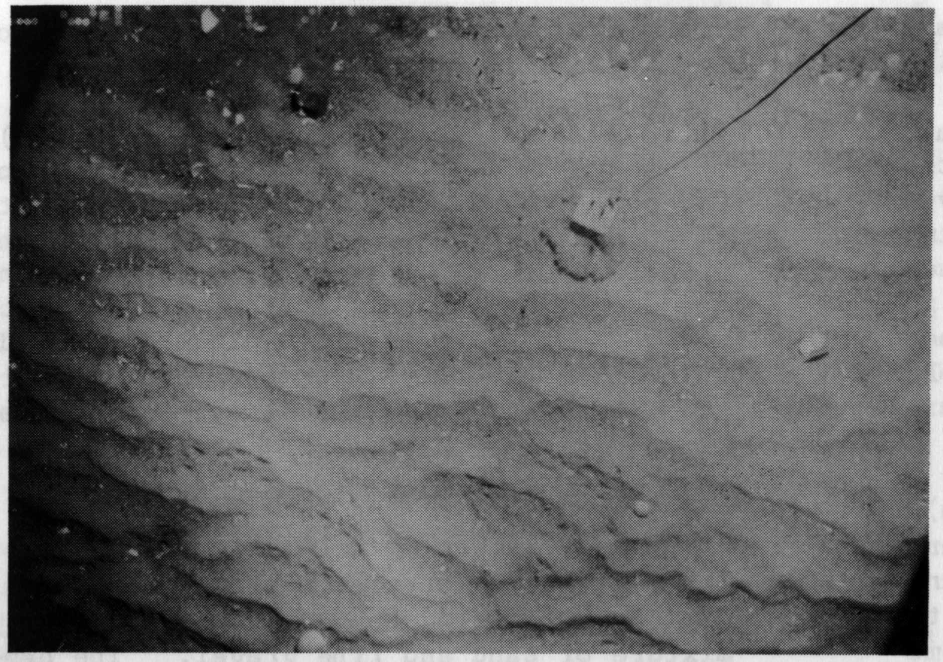


Photo 75

Photo 74

Photo 76

Banks - Georges Bank

The series of photographs (73-80) was taken in and around the proposed Hunky Dory well site of Texaco Canada Resources Ltd.

Photo 73 (41°45.72'N, 65°57.48'W, 107 m)
The coarse to fine-grained sand of the Sable Island Sand and Gravel formation is mixed with shell debris and is heavily rippled by the current. Shells are visible at upper right. Traces of feeding activity by fish, lower left, and tracks left by a sea urchin, lower right, are visible. Depressions (lower left) appear to have been made by scallop (Placopecten magellanicus) movements.

Photo 74 (41°45.72'N, 65°57.48'W, 107 m)
In the same area (see Photo 73) on eastern Georges Bank, an edge of a rippled seabed can be seen. The coarser, poorly-sorted gravelly sediments of the Sable Island Sand and Gravel formation adjacent to the rippled sand seem to support a higher density of sea scallop (Placopecten magellanicus) but other fauna are not in evidence. The dynamic nature of this habitat prevents colonisation by attached forms and suggests that benthic fauna would be generally represented by deposit-feeding infauna.

Photo 75 (41°48.75'N, 65°55.80'W, 105 m)
The pebble-cobble gravel clasts of Sable Island Sand and Gravel formation, gravel facies, are dominant in this area, and the micro-roughness of the seabed is increased. The presence of motile epifauna such as sea stars, probably Asterias sp., as well as some attached forms, such as fleshy sponges, hydroids and bryozoans, indicates a slightly more stable environment than that seen in Photos 73 and 74. This habitat also supports sea scallop (Placopecten magellanicus). This variability within a small area indicates how habitat features (seabed sediments) control the patchy distribution observed for benthic fauna. The finer substrate supports a variety of infauna.

Photo 76 (41°48.75'N, 65°55.80'W, 105 m)
The poorly sorted gravelly sediment of the Sable Island Sand and Gravel formation at this site on the northern edge of Georges Bank hosts a variety of epibenthic organisms as well as infauna. The larger gravel clasts are sparsely colonised by bryozoans, hydroids and tunicates. Sea scallop are also present, and an unidentified fish skims over the surface. This pattern of faunal distribution contrasts sharply with Photo 79, where little colonisation is observed.

Figure 19.5. Seabed photographs from Georges Bank Sable Island Sand and Gravel with sediment and fauna descriptions.

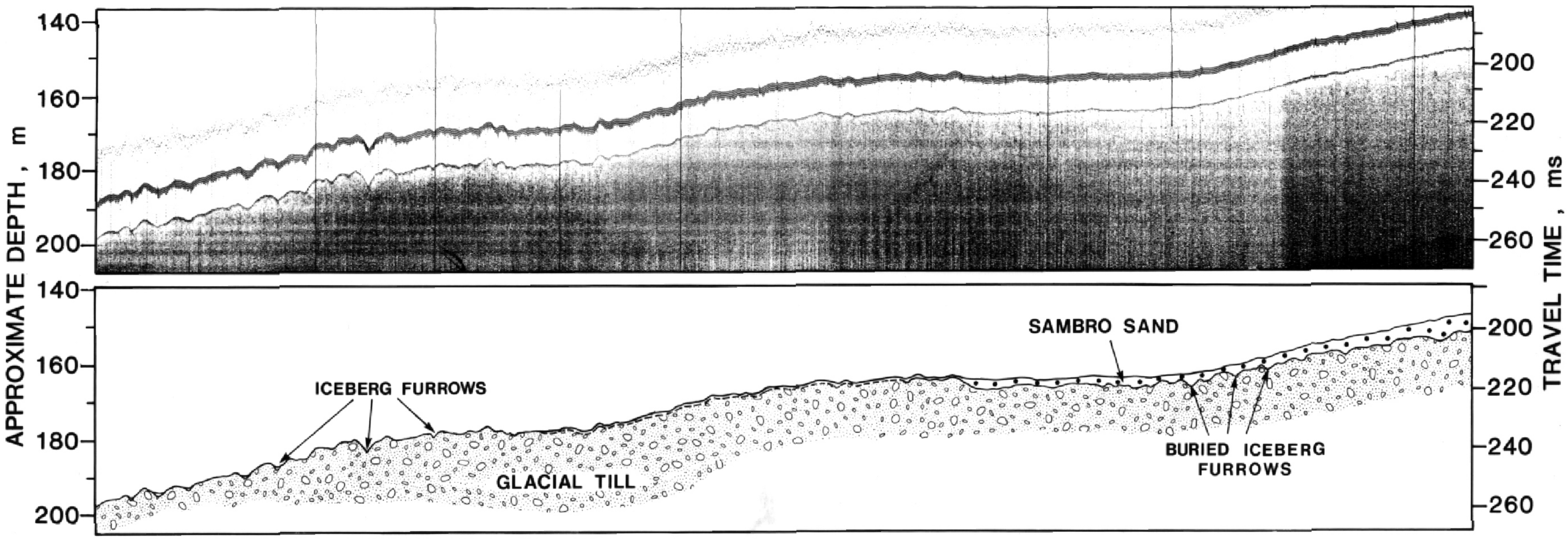


Figure 19.6. High resolution (boomer) profiler data, with interpretation, on the northern Geroges Bank flank showing the relationship of Sambro Sand covering till. The optimum pipeline route here is positioned deeper than the bedforms (shown in next illustration) and shallower than the exposed iceberg furrows (right side of profile).

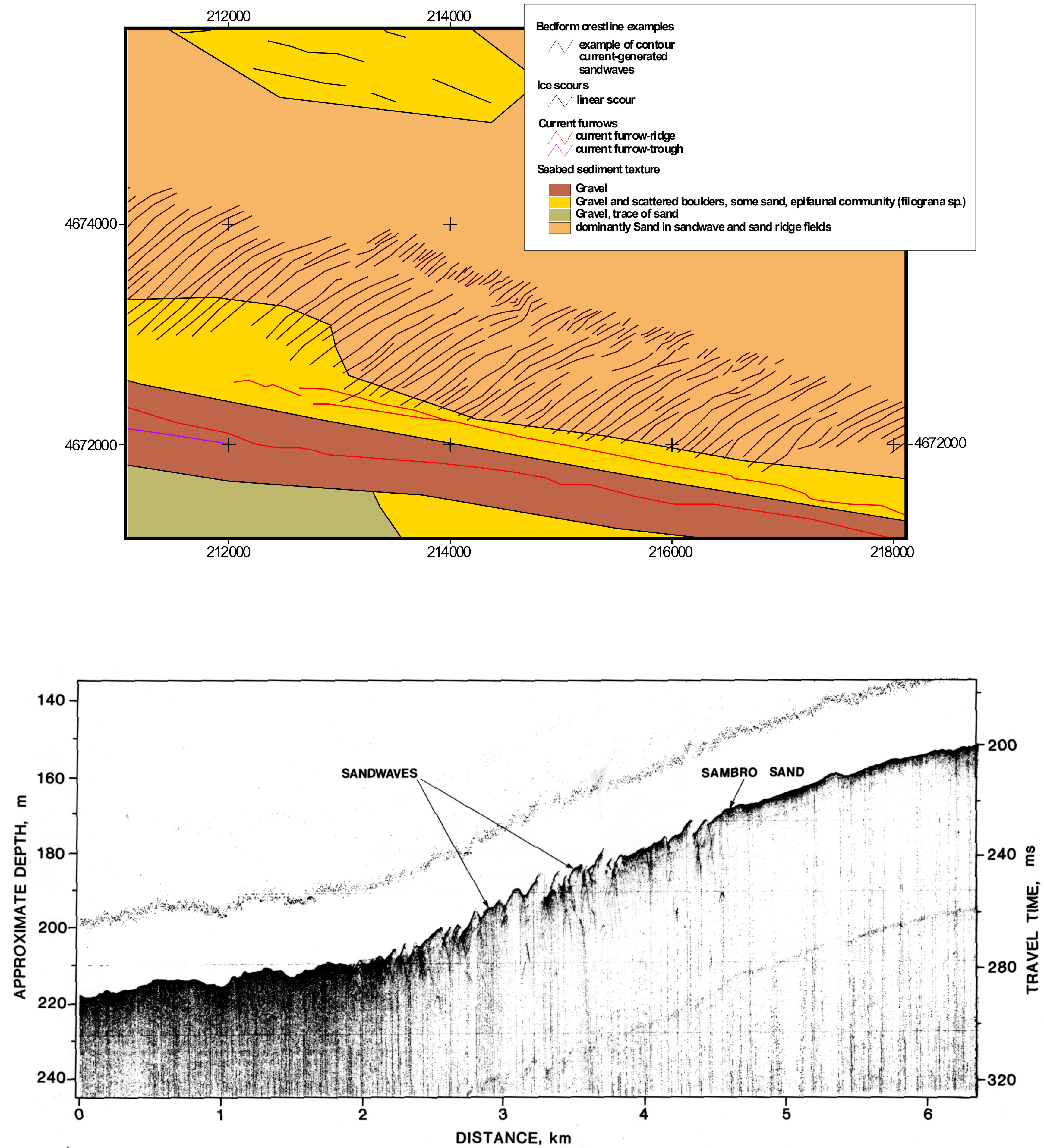


Figure 19.7. Sandwaves in Sambro Sand on the north flank of Georges Bank. Huntec boomer profile (lower panel) and crestline tracings (from mulitbeam) in the same general vicinity (upper panel). A pipeline routing north (below) these is suggested. Generally there is enough sand cover over the till below this, to mask much of the furrowed surface. See previous illustration.

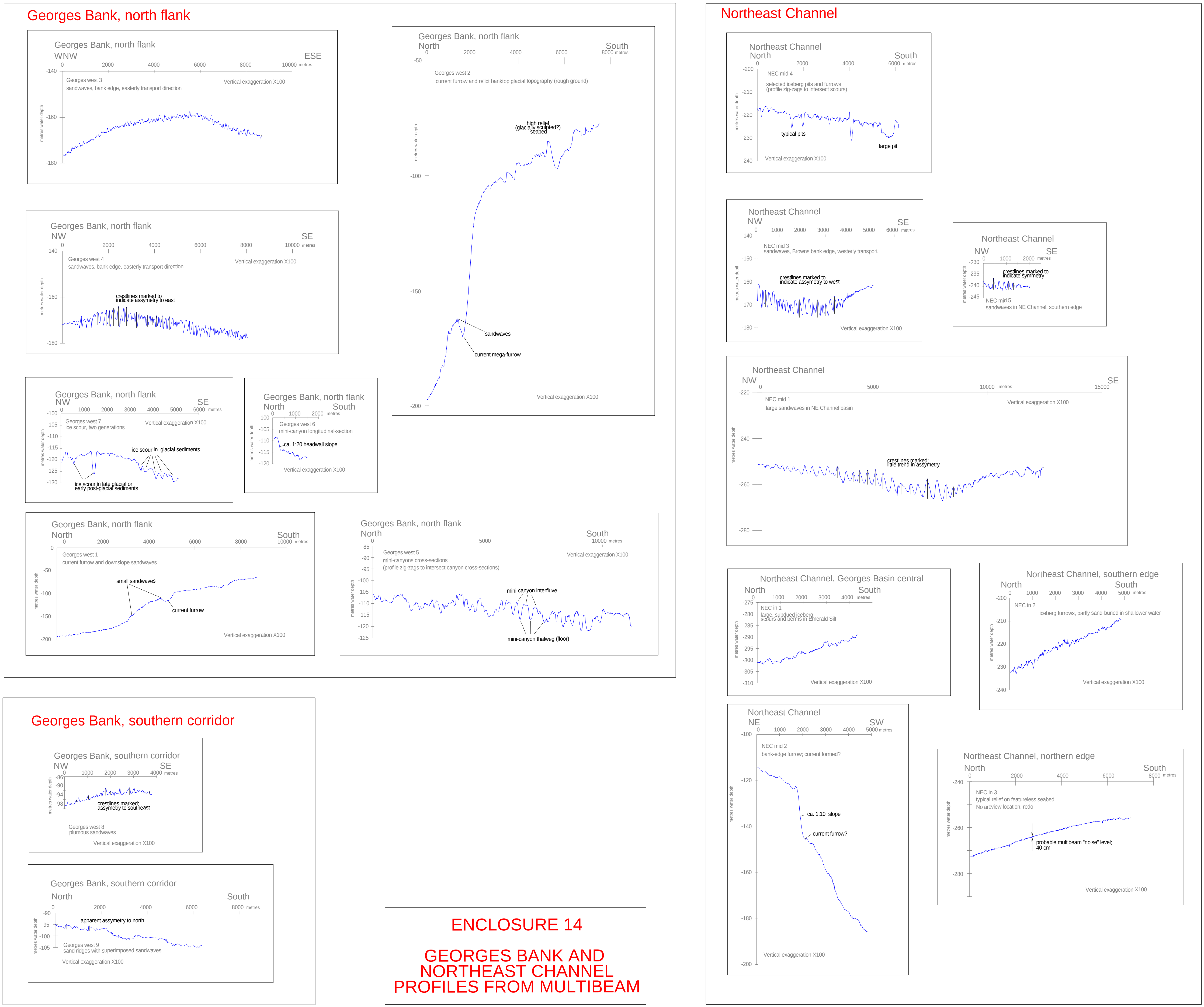

Georges Bank, north flank
Georges Bank, north flank
WNW
ESE
Georges west 3
sandwaves, bank edge, easterly transport direction
Vertical exaggeration X100
Georges Bank, north flank
NW
SE
Georges west 4
sandwaves, bank edge, easterly transport direction
crestlines marked to indicate assymetry to east
Georges Bank, north flank
NW
SE
Georges west 7
ice scour, two generations
ice scour in glacial sediments
ice scour in late glacial or early post-glacial sediments
Georges Bank, north flank
North
South
Georges west 6
mini-canyon longitudinal-section
ca. 1:20 headwall slope
Georges Bank, north flank
North
South
Georges west 2
current furrow and relict banktop glacial topography (rough ground)
high relief (glacially sculpted?) seabed
sandwaves
current mega-furrow
Georges Bank, north flank
North
South
Georges west 1
current furrow and downslope sandwaves
small sandwaves
current furrow
Georges Bank, north flank
North
South
Georges west 5
mini-canyons cross-sections
(profile zig-zags to intersect canyon cross-sections)
mini-canyon interfluve
mini-canyon thalweg (floor)
metres water depth
metres
Georges Bank, southern corridor
Georges Bank, southern corridor
NW
SE
crestlines marked; assymetry to southeast
Georges west 8
plumous sandwaves
Georges Bank, southern corridor
North
South
apparent assymetry to north
Georges west 9
sand ridges with superimposed sandwaves
Northeast Channel
Northeast Channel
North
South
NEC mid 4
selected iceberg pits and furrows
(profile zig-zags to intersect scours)
typical pits
large pit
Northeast Channel
NW
SE
NEC mid 3
sandwaves, Browns bank edge, westerly transport
crestlines marked to indicate assymetry to west
Northeast Channel
NW
SE
crestlines marked to indicate symmetry
NEC mid 5
sandwaves in NE Channel, southern edge
Northeast Channel
NW
SE
NEC mid 1
large sandwaves in NE Channel basin
crestlines marked; little trend in assymetry
Northeast Channel, Georges Basin central
North
South
NEC in 1
large, subdued iceberg scours and berms in Emerald Silt
Northeast Channel, southern edge
North
South
NEC in 2
iceberg furrows, partly sand-buried in shallower water
Northeast Channel
NE
SW
NEC mid 2
bank-edge furrow; current formed?
ca. 1:10 slope
current furrow?
Northeast Channel, northern edge
North
South
NEC in 3
typical relief on featureless seabed
No arcview location, redo
probable multibeam "noise" level; 40 cm
ENCLOSURE 14
GEORGES BANK AND NORTHEAST CHANNEL PROFILES FROM MULTIBEAM

Figure 19.8

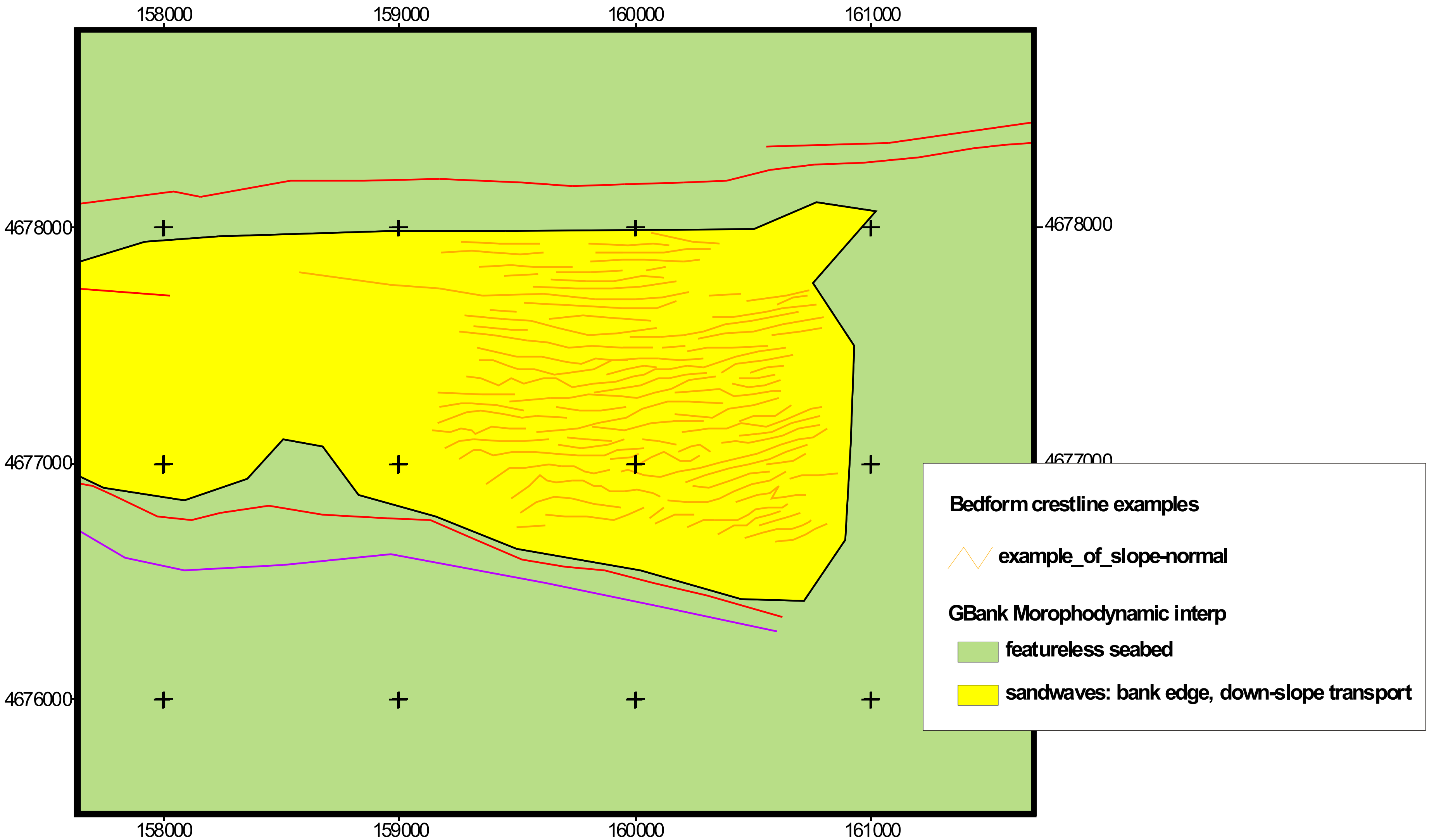


Figure 19.9. Sandwaves on Georges Bank northern flank indicating sediment transport down-slope.

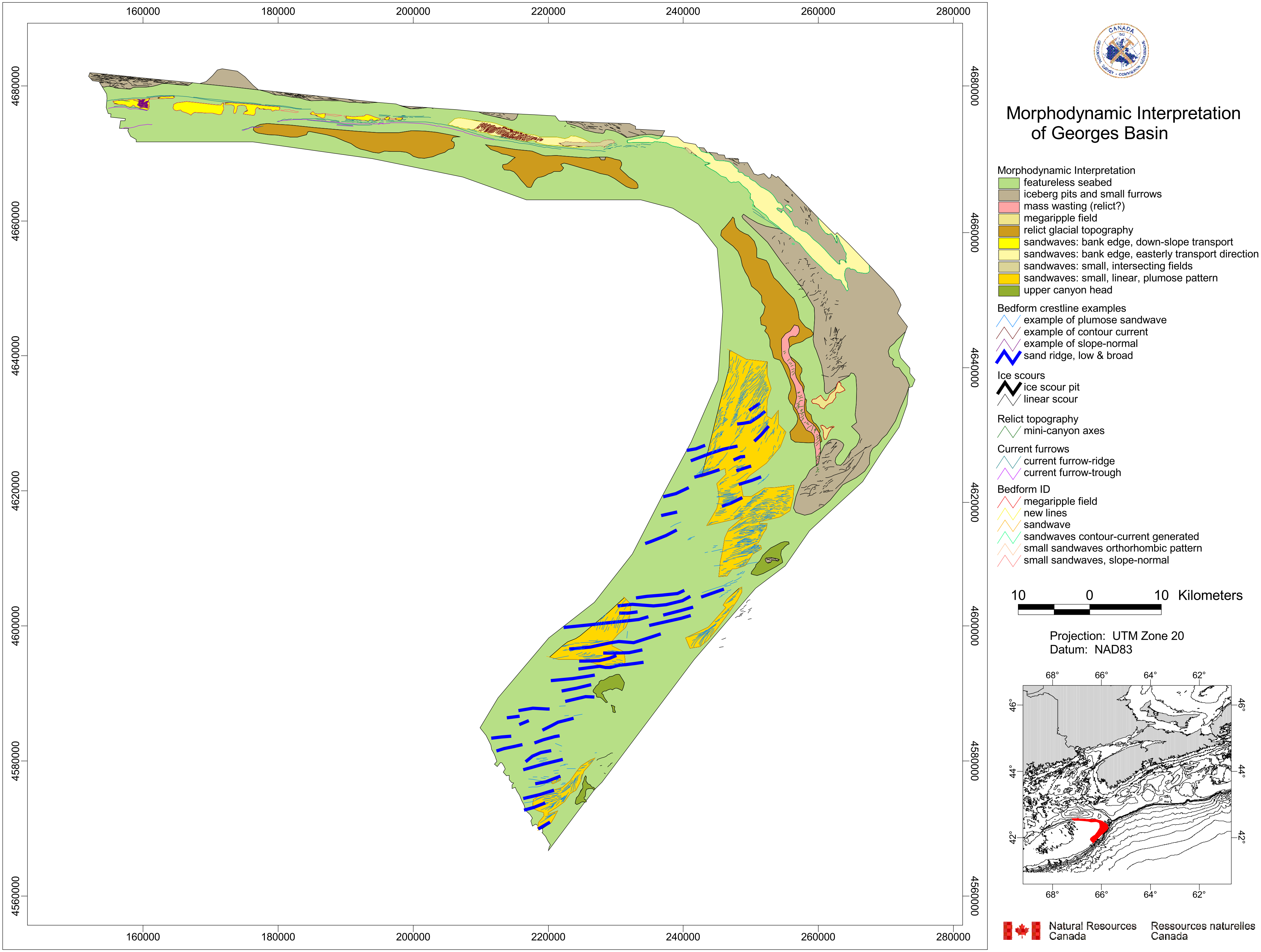

Morphodynamic Interpretation of Georges Basin
Morphodynamic Interpretation
featureless seabed
iceberg pits and small furrows
mass wasting (relict?)
megaripple field
relict glacial topography
sandwaves: bank edge, down-slope transport
sandwaves: bank edge, easterly transport direction
sandwaves: small, intersecting fields
sandwaves: small, linear, plumose pattern
upper canyon head
Bedform crestline examples
example of plumose sandwave
example of contour current
example of slope-normal
sand ridge, low & broad
Ice scours
ice scour pit
linear scour
Relict topography
mini-canyon axes
Current furrows
current furrow-ridge
current furrow-trough
Bedform ID
megaripple field
new lines
sandwave
sandwaves contour-current generated
small sandwaves orthorhombic pattern
small sandwaves, slope-normal
10 0 10 Kilometers
Projection: UTM Zone 20
Datum: NAD83
Natural Resources Canada
Ressources naturelles Canada
160000
180000
200000
220000
240000
260000
280000
4680000
4660000
4640000
4620000
4600000
4580000
4560000
68°
66°
64°
62°
46°
44°
42°

Figure 20.1

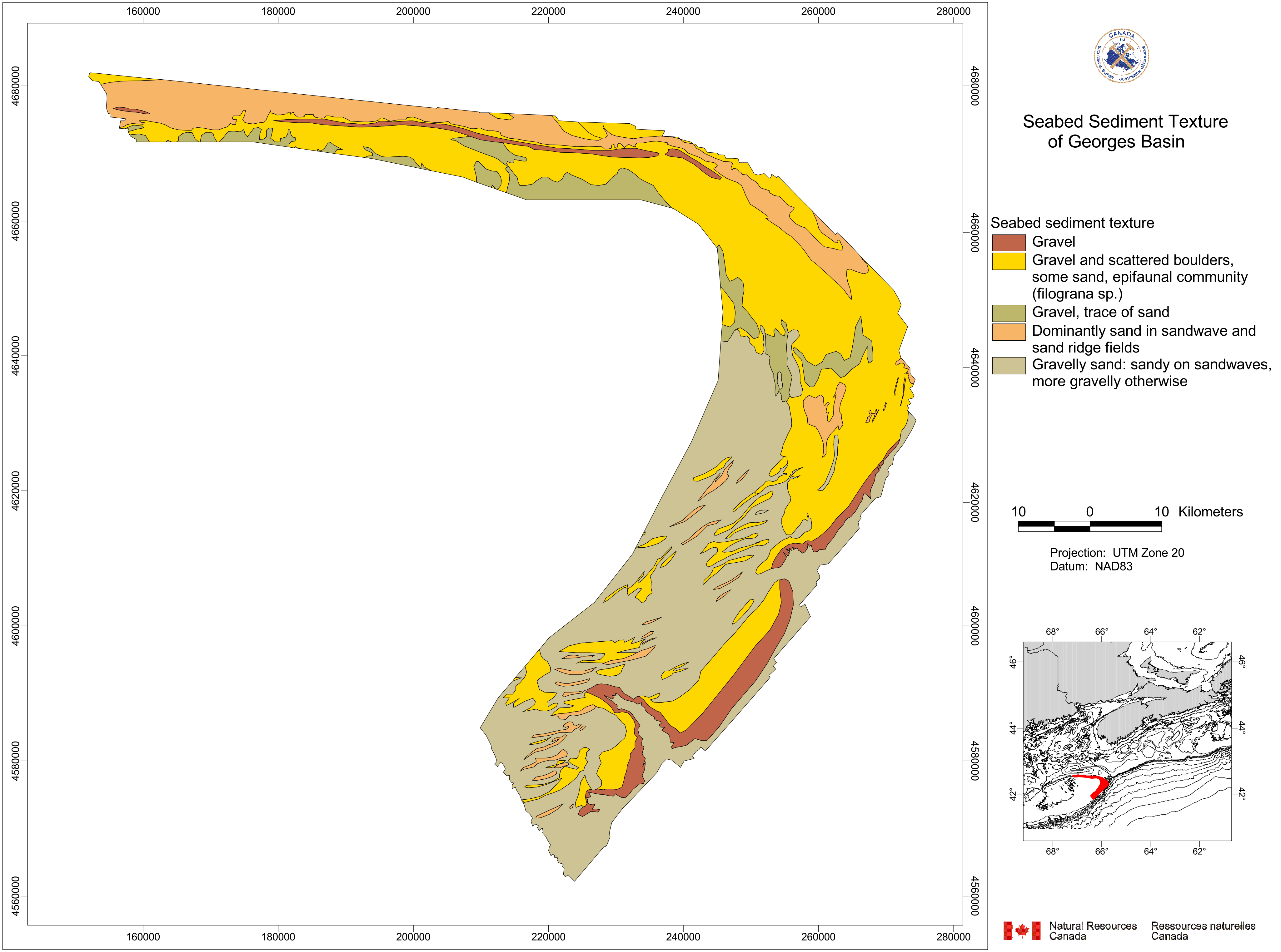

Seabed Sediment Texture of Georges Basin
Seabed sediment texture
Gravel
Gravel and scattered boulders, some sand, epifaunal community (filograna sp.)
Gravel, trace of sand
Dominantly sand in sandwave and sand ridge fields
Gravelly sand: sandy on sandwaves, more gravelly otherwise
10 0 10 Kilometers
Projection: UTM Zone 20
Datum: NAD83
Natural Resources Canada
Ressources naturelles Canada
160000
180000
200000
220000
240000
260000
280000
4680000
4660000
4640000
4620000
4600000
4580000
4560000
68°
66°
64°
62°
46°
44°
42°

Figure 20.2

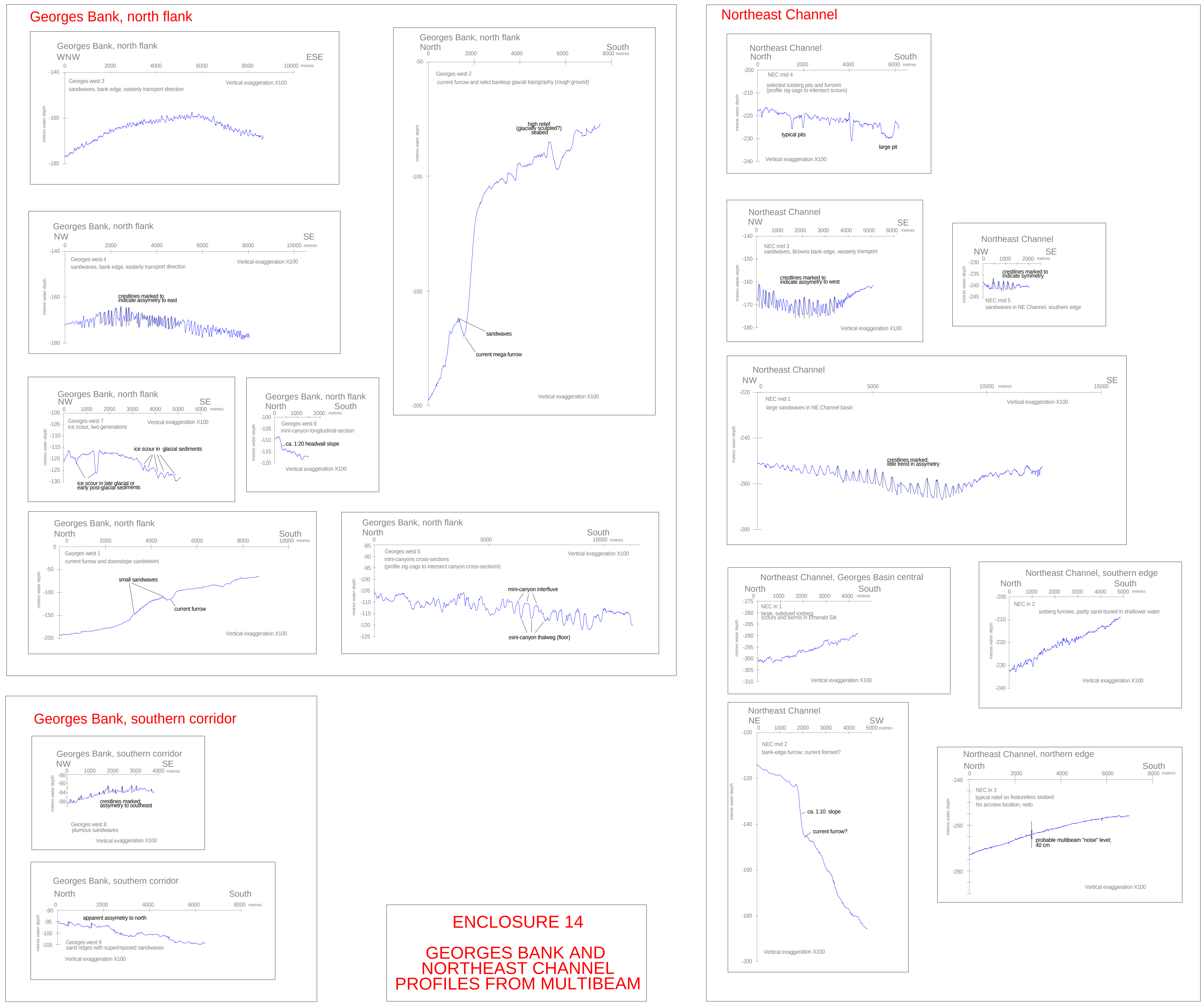

Georges Bank, north flank
Georges Bank, north flank
WNW
ESE
Georges west 3
sandwaves, bank edge, easterly transport direction
Vertical exaggeration X100
Georges Bank, north flank
North
South
Georges west 2
current furrow and relict banktop glacial topography (rough ground)
high relief (glacially sculpted?) seabed
sandwaves
current mega-furrow
Vertical exaggeration X100
Georges Bank, north flank
NW
SE
Georges west 4
sandwaves, bank edge, easterly transport direction
crestlines marked to indicate assymetry to east
Vertical exaggeration X100
Georges Bank, north flank
NW
SE
Georges west 7
ice scour, two generations
ice scour in glacial sediments
ice scour in late glacial or early post-glacial sediments
Vertical exaggeration X100
Georges Bank, north flank
North
South
Georges west 6
mini-canyon longitudinal-section
ca. 1:20 headwall slope
Vertical exaggeration X100
Georges Bank, north flank
North
South
Georges west 1
current furrow and downslope sandwaves
small sandwaves
current furrow
Vertical exaggeration X100
Georges Bank, north flank
North
South
Georges west 5
mini-canyons cross-sections
(profile zig-zags to intersect canyon cross-sections)
mini-canyon interfluve
mini-canyon thalweg (floor)
Vertical exaggeration X100
Georges Bank, southern corridor
Georges Bank, southern corridor
NW
SE
crestlines marked; assymetry to southeast
Georges west 8
plumous sandwaves
Vertical exaggeration X100
Georges Bank, southern corridor
North
South
apparent assymetry to north
Georges west 9
sand ridges with superimposed sandwaves
Vertical exaggeration X100
Northeast Channel
Northeast Channel
North
South
NEC mid 4
selected iceberg pits and furrows
(profile zig-zags to intersect scours)
typical pits
large pit
Vertical exaggeration X100
Northeast Channel
NW
SE
NEC mid 3
sandwaves, Browns bank edge, westerly transport
crestlines marked to indicate assymetry to west
Vertical exaggeration X100
Northeast Channel
NW
SE
crestlines marked to indicate symmetry
NEC mid 5
sandwaves in NE Channel, southern edge
Northeast Channel
NW
SE
NEC mid 1
large sandwaves in NE Channel basin
crestlines marked; little trend in assymetry
Vertical exaggeration X100
Northeast Channel, Georges Basin central
North
South
NEC in 1
large, subdued iceberg scours and berms in Emerald Silt
Vertical exaggeration X100
Northeast Channel, southern edge
North
South
NEC in 2
iceberg furrows, partly sand-buried in shallower water
Vertical exaggeration X100
Northeast Channel
NE
SW
NEC mid 2
bank-edge furrow, current formed?
ca. 1:10 slope
current furrow?
Vertical exaggeration X100
Northeast Channel, northern edge
North
South
NEC in 3
typical relief on featureless seabed
No arcview location, redo
probable multibeam "noise" level; 40 cm
Vertical exaggeration X100
ENCLOSURE 14
GEORGES BANK AND NORTHEAST CHANNEL PROFILES FROM MULTIBEAM

Figure 20.3

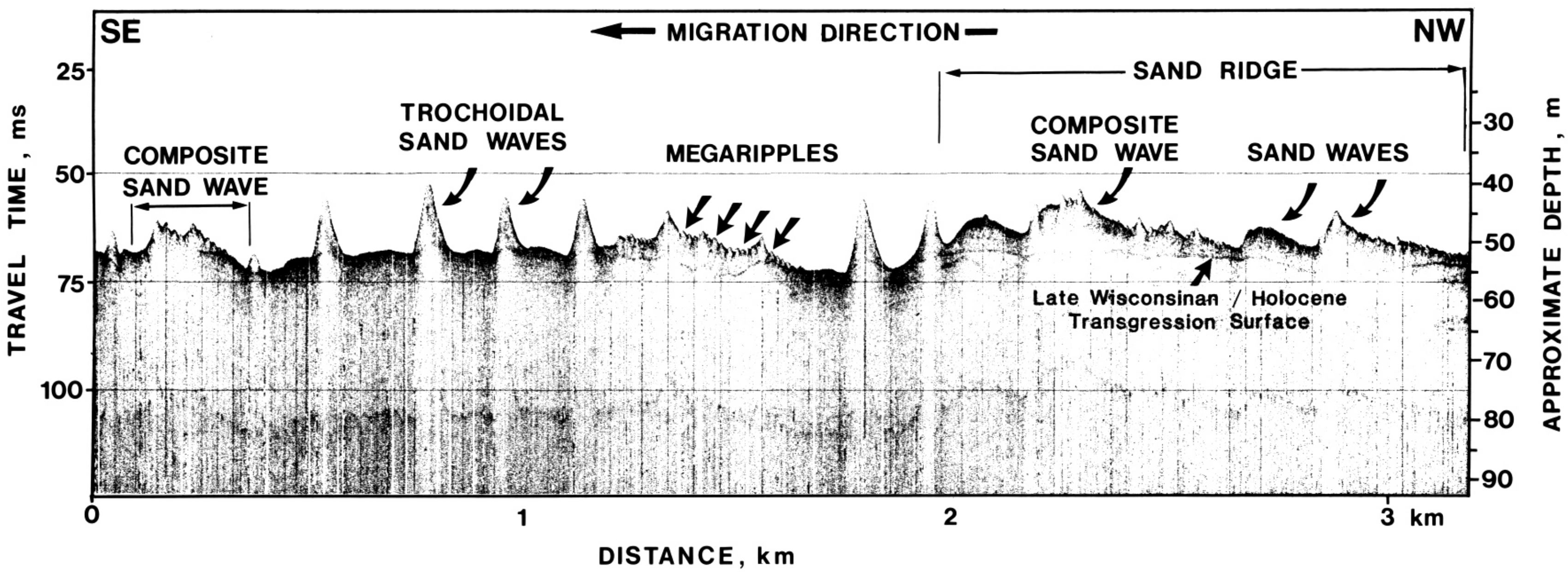
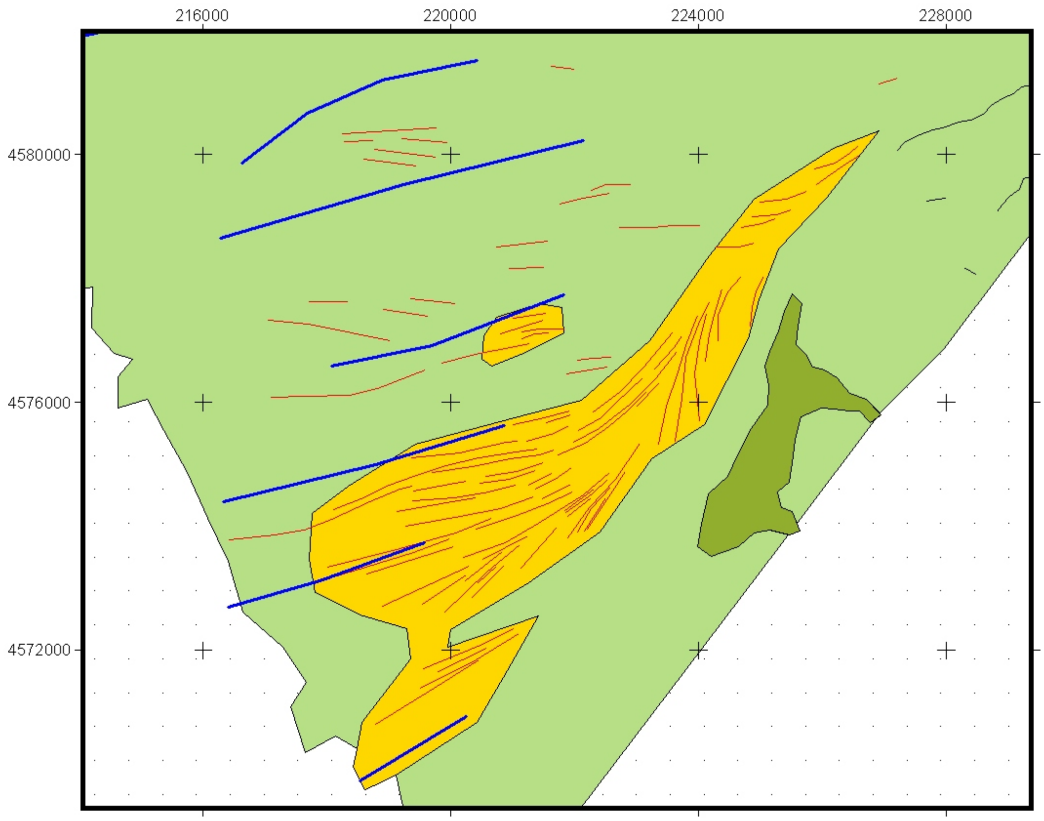
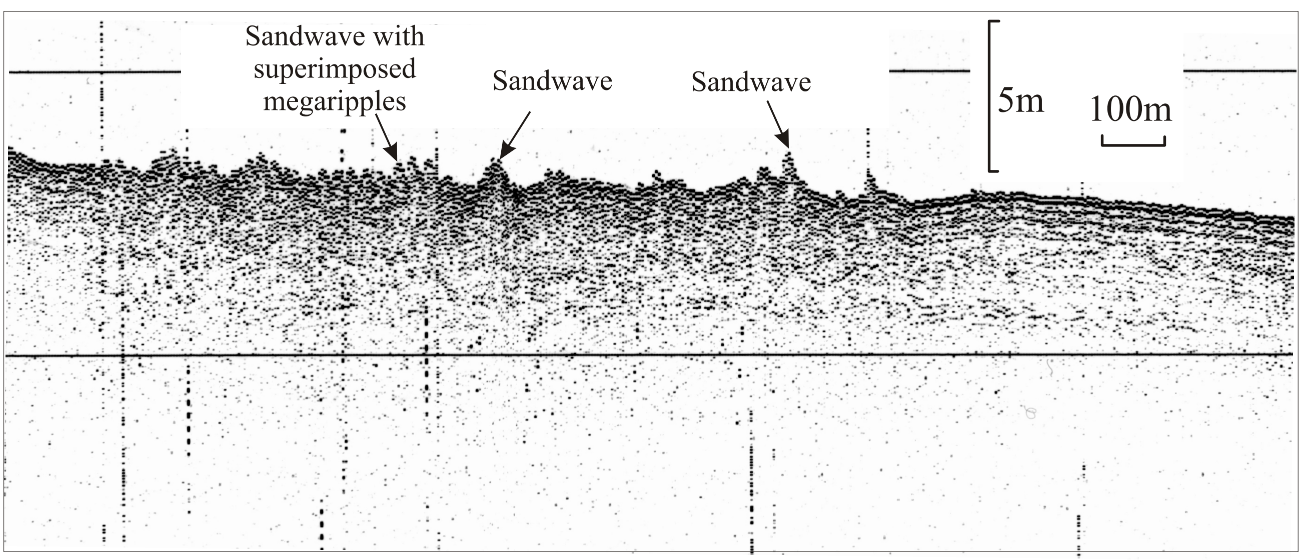


Figure 20.4. Large, active sandwaves superimposed on low amplitude sand ridges in the shoals of Georges Bank (outside corridor). Superimposed megaripples actively modify the sandwaves.

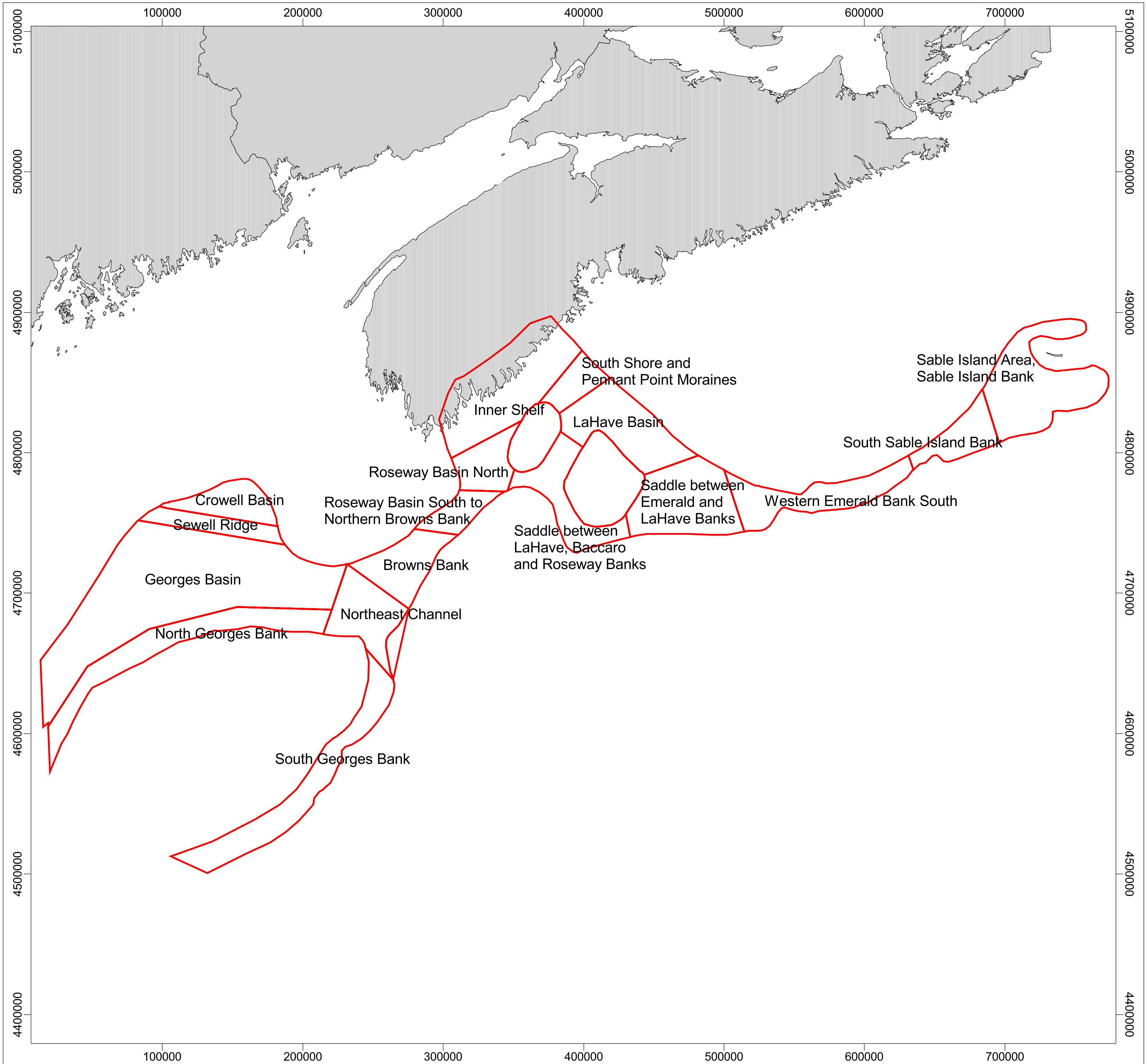




99-Hamilton Banker Huntec, 282/1620

E. King, 2002

Figure 20.5. Huntec (sub-bottom profiler) image from the Georges Bank southern route alternative showing the morphology of "plumous-pattern" sandwaves with superimposed megaripples.

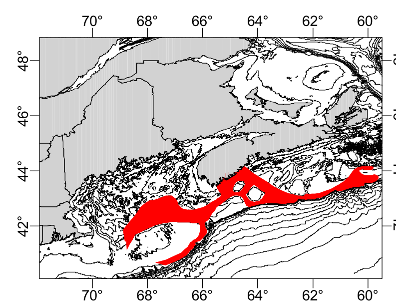


Geographic Subdivisions of the Pipeline Corridor

Corridor boundary
Land

25 0 25 50 75 100 Kilometers

Projection: UTM Zone 20
Datum: NAD83



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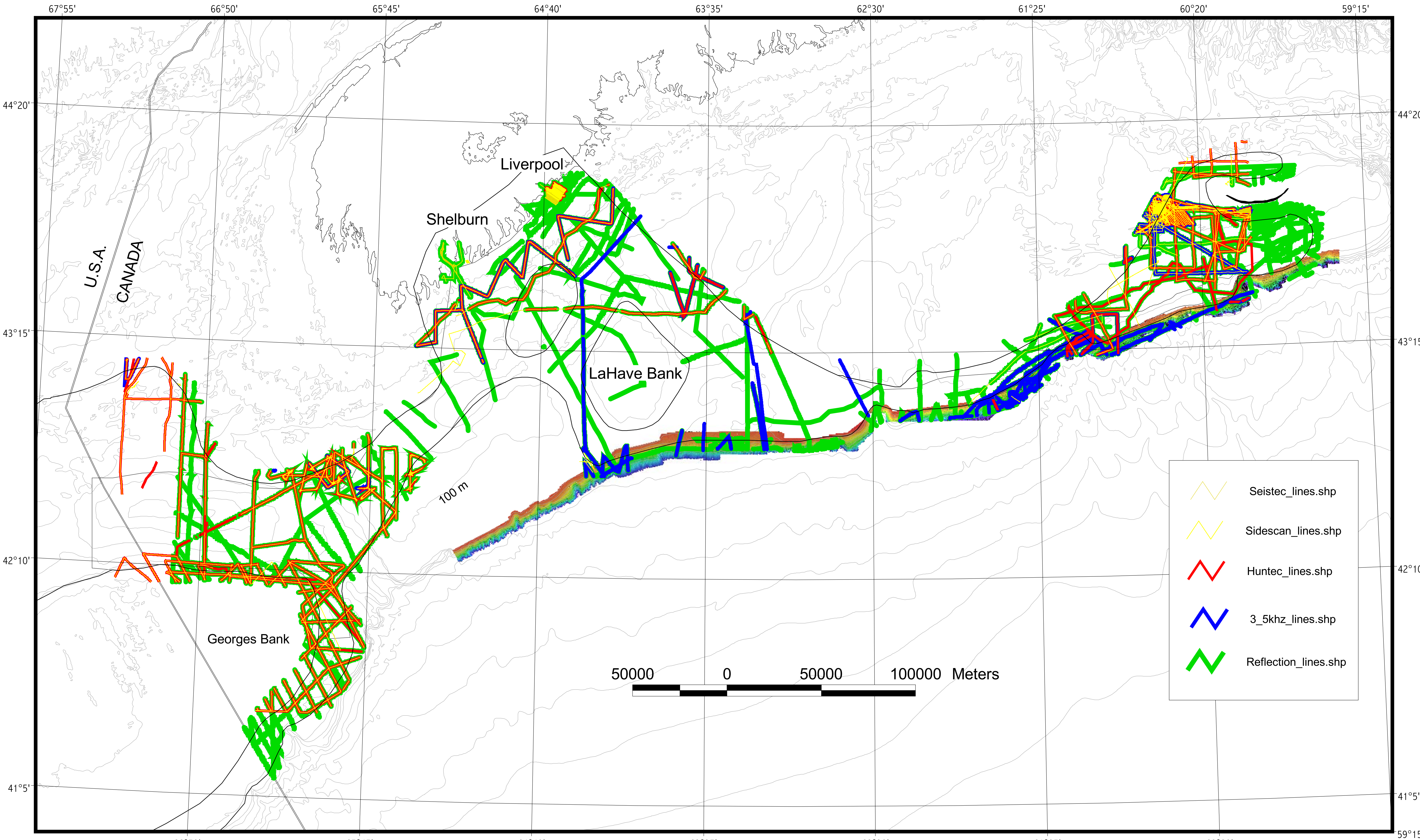
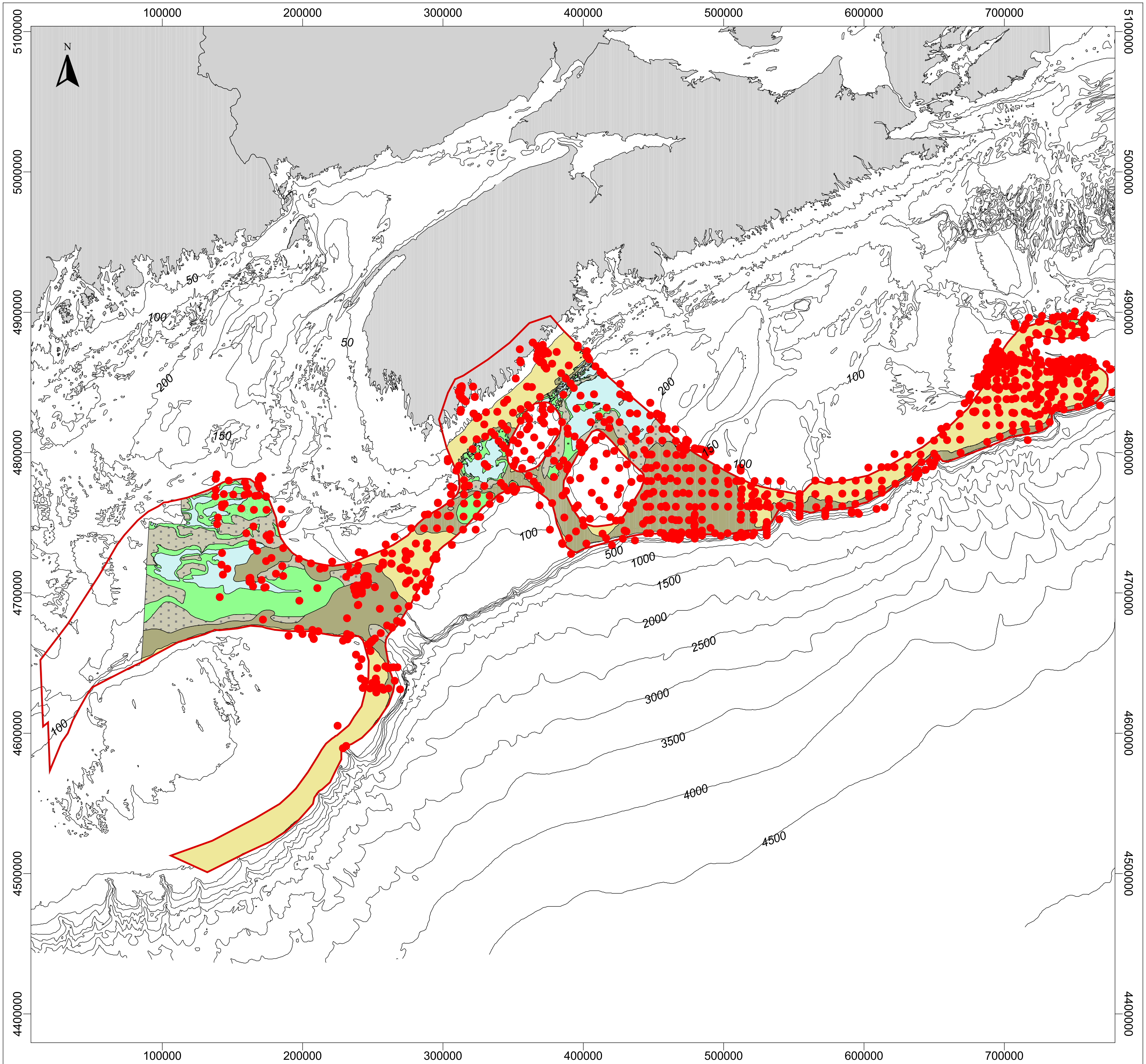
Enclosure 1


67°55'
66°50'
65°45'
64°40'
63°35'
62°30'
61°25'
60°20'
59°15'
44°20'
43°15'
42°10'
41°5'
U.S.A.
CANADA
Liverpool
Shelburn
LaHave Bank
Georges Bank
100 m
50000 0 50000 100000 Meters
Seistec_lines.shp
Sidescan_lines.shp
Huntec_lines.shp
3_5khz_lines.shp
Reflection_lines.shp

Enclosure 2

Surficial Geology of the Pipeline Corridor with Sample Locations



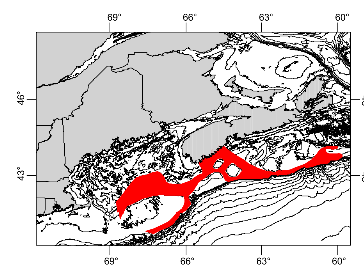
Surficial Geology

- Emerald Silt
- LaHave Clay
- Sable Island Sand and Gravel
- Sambro Sand
- Scotian Shelf Drift

- Corridor boundary
- Sample location
- Bathymetric contour
- Land

25 0 25 50 75 100 Kilometers

Projection: UTM Zone 20
Datum: NAD83



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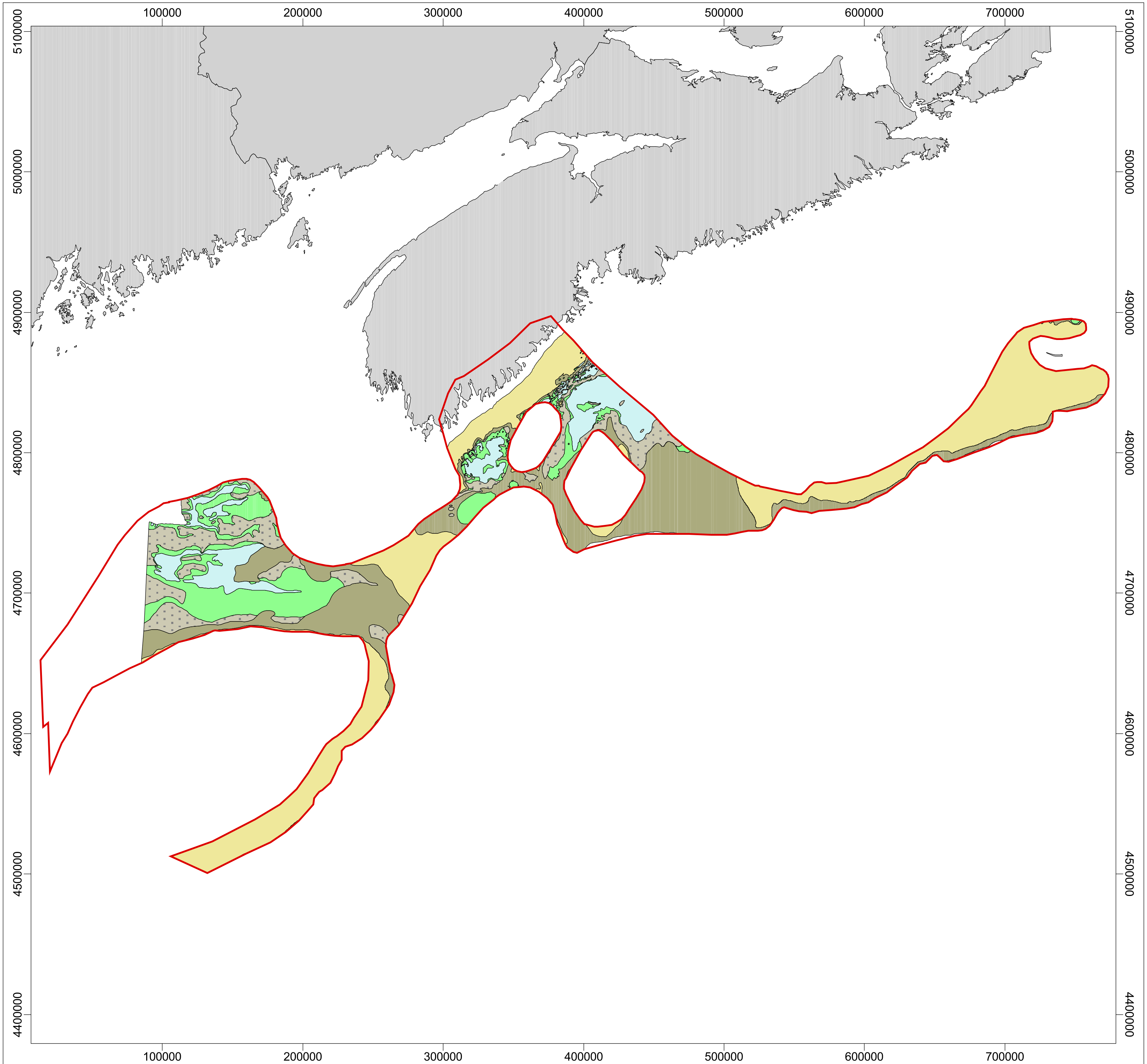
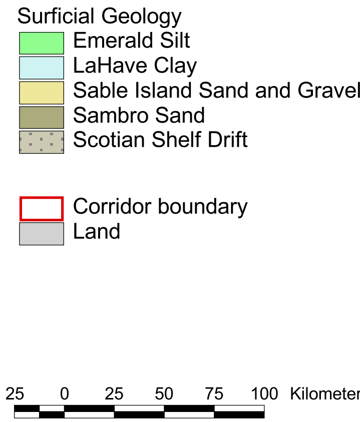
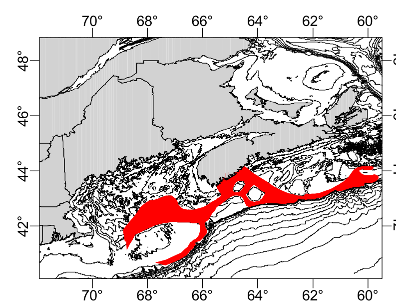
Enclosure 3



Surficial Geology of the Pipeline Corridor



Projection: UTM Zone 20
Datum: NAD83



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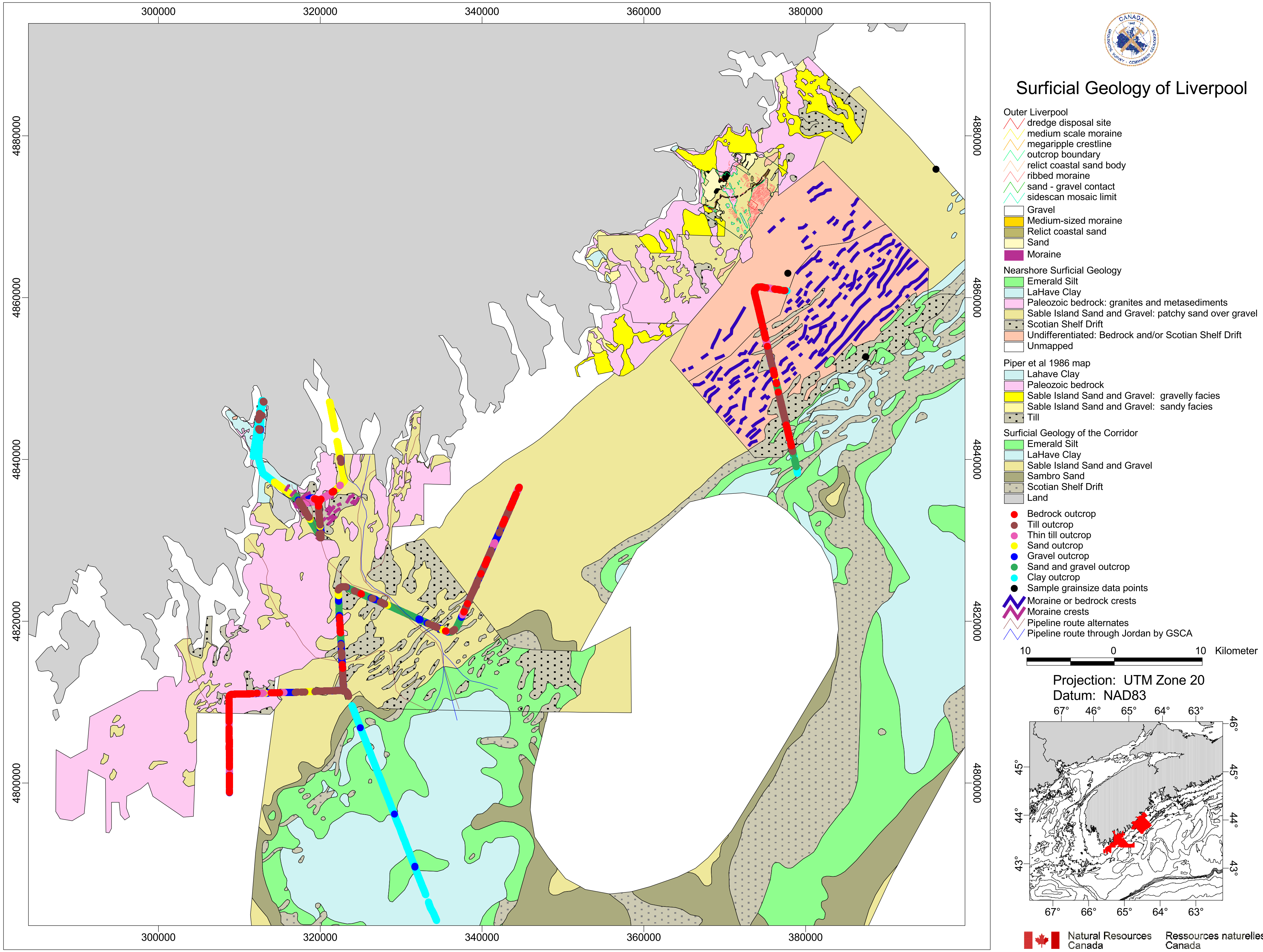
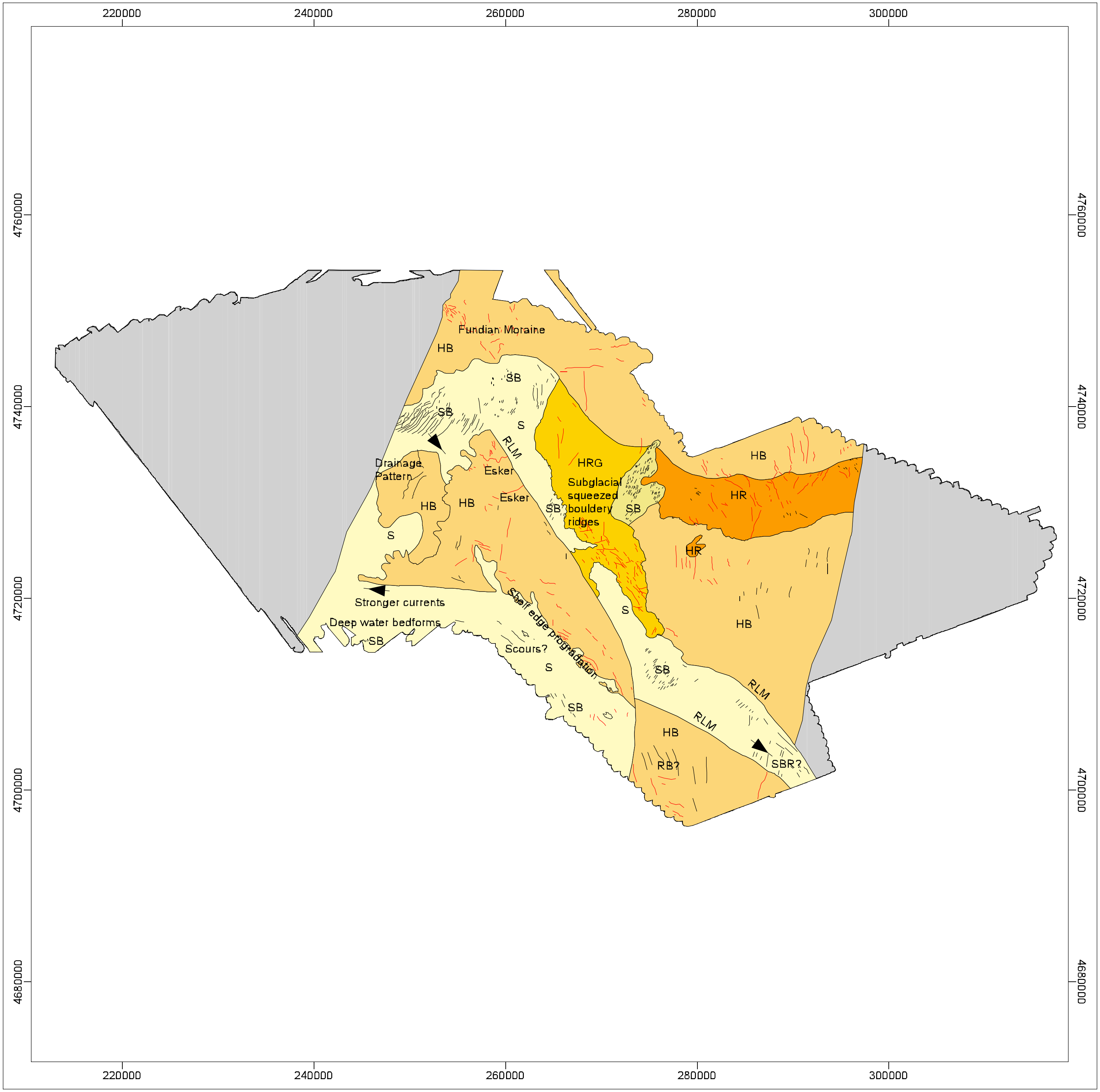
Enclosure 4


Surficial Geology of Liverpool
Outer Liverpool
dredge disposal site
medium scale moraine
megaripple crestline
outcrop boundary
relict coastal sand body
ribbed moraine
sand - gravel contact
sidescan mosaic limit
Gravel
Medium-sized moraine
Relict coastal sand
Sand
Moraine
Nearshore Surficial Geology
Emerald Silt
LaHave Clay
Paleozoic bedrock: granites and metasediments
Sable Island Sand and Gravel: patchy sand over gravel
Scotian Shelf Drift
Undifferentiated: Bedrock and/or Scotian Shelf Drift
Unmapped
Piper et al 1986 map
Lahave Clay
Paleozoic bedrock
Sable Island Sand and Gravel: gravelly facies
Sable Island Sand and Gravel: sandy facies
Till
Surficial Geology of the Corridor
Emerald Silt
LaHave Clay
Sable Island Sand and Gravel
Sambro Sand
Scotian Shelf Drift
Land
Bedrock outcrop
Till outcrop
Thin till outcrop
Sand outcrop
Gravel outcrop
Sand and gravel outcrop
Clay outcrop
Sample grainsize data points
Moraine or bedrock crests
Moraine crests
Pipeline route alternates
Pipeline route through Jordan by GSCA
10 0 10 Kilometer
Projection: UTM Zone 20
Datum: NAD83
300000
320000
340000
360000
380000
4800000
4820000
4840000
4860000
4880000
67° 66° 65° 64° 63°
43° 44° 45° 46°
Natural Resources Canada
Ressources naturelles Canada

Enclosure 5

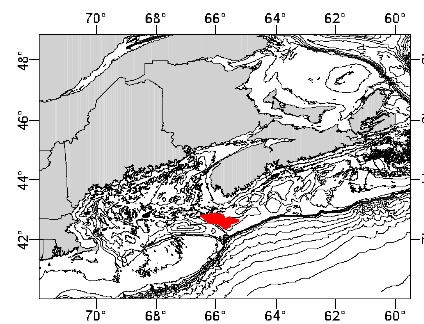
Morphodynamic Interpretation of Central Browns Bank



HB	Hummocky with boulders, likely till with some ridges
HRG	Hummocky with ridges formed in glacial marine sediment with boulders
HR	Hummocky with ridges, till with moraines and flutes
S	Sand
SB	Sand with bedforms, some sand waves relict
	Browns Bank multibeam coverage
	Bedform orientations true
	Ridge orientations true
	Transport pathway
RLM	Regional lateral moraine
RB	Relict bedforms

10 0 10 Kilometers

Projection: UTM Zone 20
Datum: NAD83



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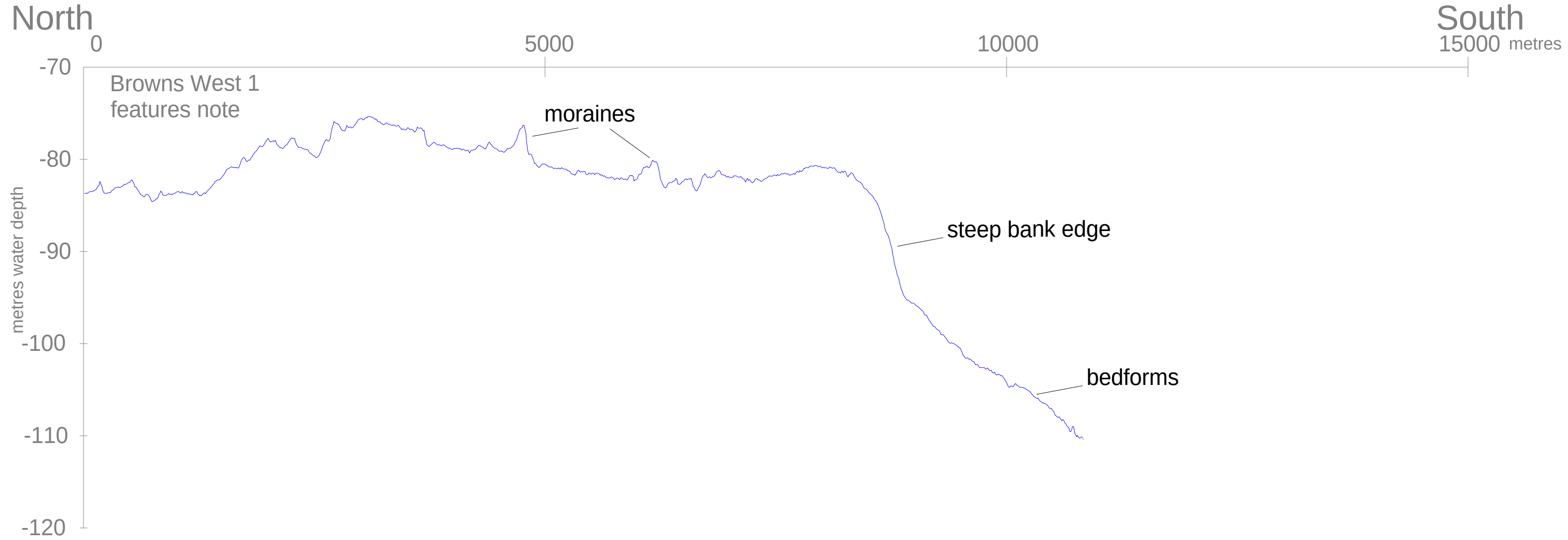
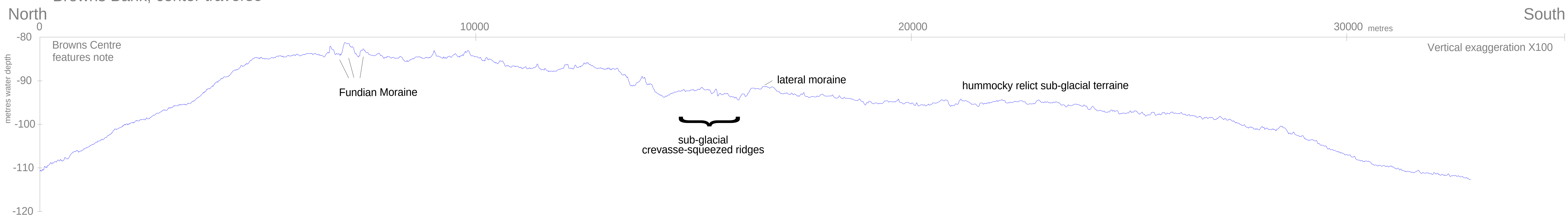
Enclosure 6

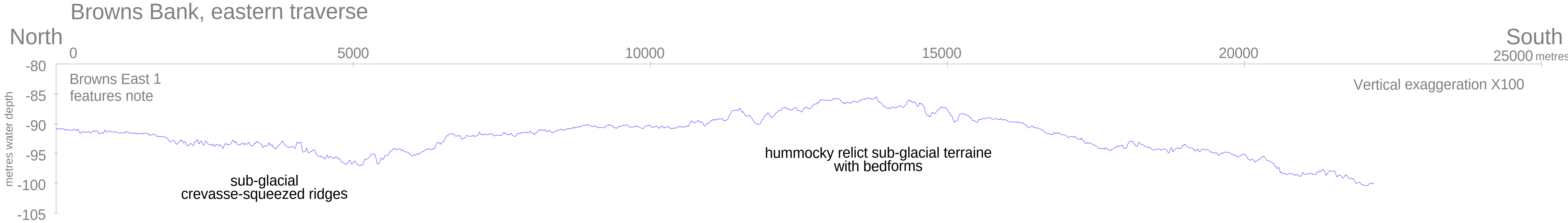
Browns Bank, western traverse



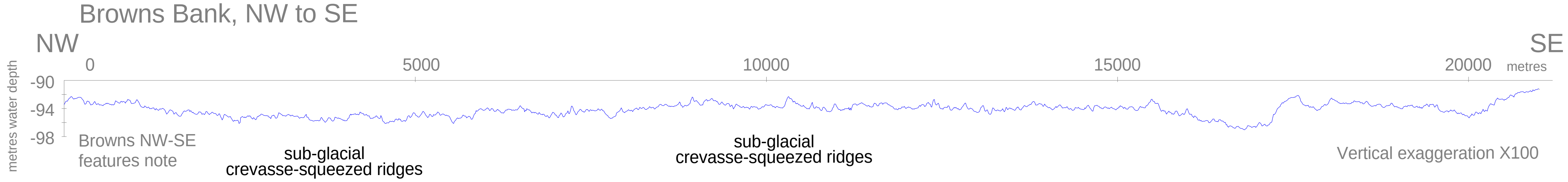
Browns Bank, center traverse



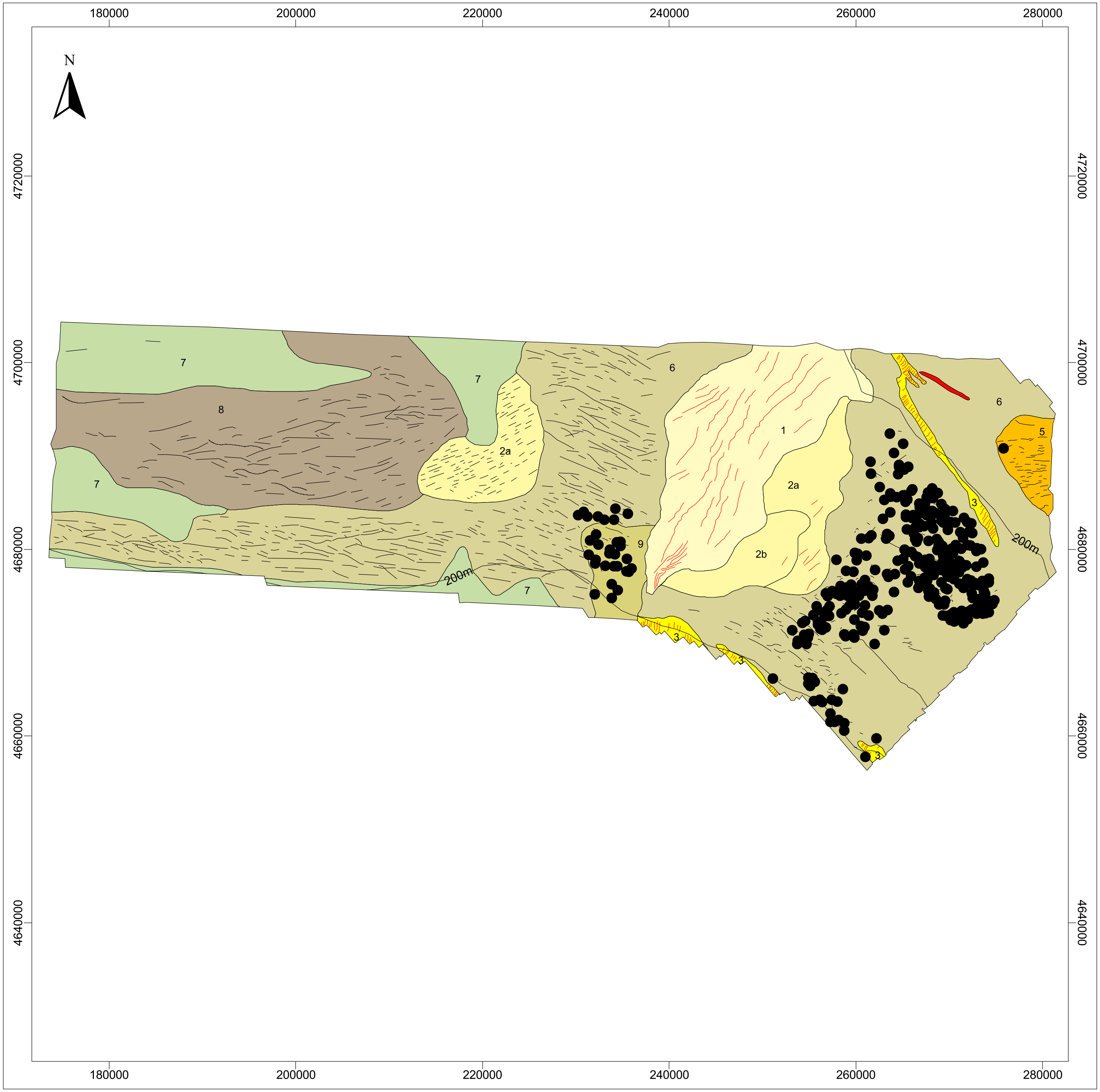
Browns Bank, eastern traverse



Browns Bank, NW to SE



Enclosure 7



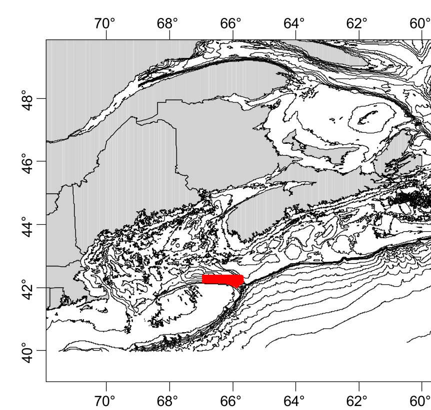
Morphodynamic Interpretation of Middle and Inner Northeast Channel and Southeast Georges Basin

- 1 — Large sand bedforms, showing crest orientation, Sambro Sand
- 2 — Mixed bedforms, (2a) short length crested bedforms, (2b) linguoidal sand bedforms, Sambro Sand
- 3 — Small sand bedforms, channel flanks, short wavelength linear patches, Sambro Sand
- 4 — Linear depression, relict subglacial , meltwater channel ?
- 5 — Linear ridges in till and gravel ?, Browns Bank moraine or former beach ridges
- 6 — Iceberg pits and small furrows, Scotian Shelf Drift (till), gravel with boulders, in NE Channel
- 7 — Featureless seabed, area absent of iceberg furrows as result of sand spillover from banks or mud deposition, Lahave Clay
- 8 — Large iceberg furrows, formed in Emerald Silt
- 9 — Iceberg pits, area of dominant iceberg pits (till), similar to 6

Bedform orientations true (Units 1, 2 and 3)
Iceberg furrows
Bathymetric contour
Iceberg pit

10 0 10 Kilometers

Projection: UTM Zone 20
Datum: NAD83



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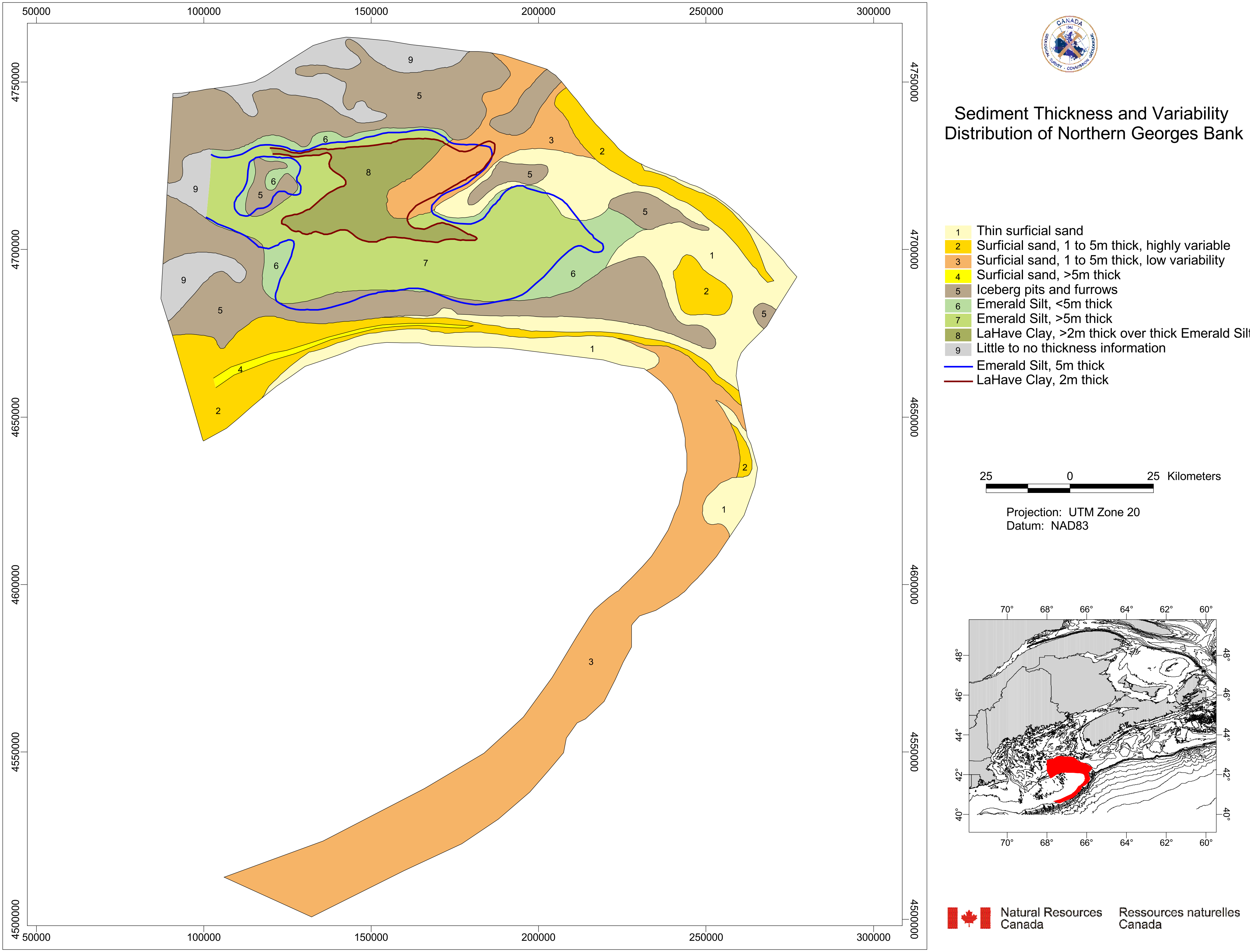
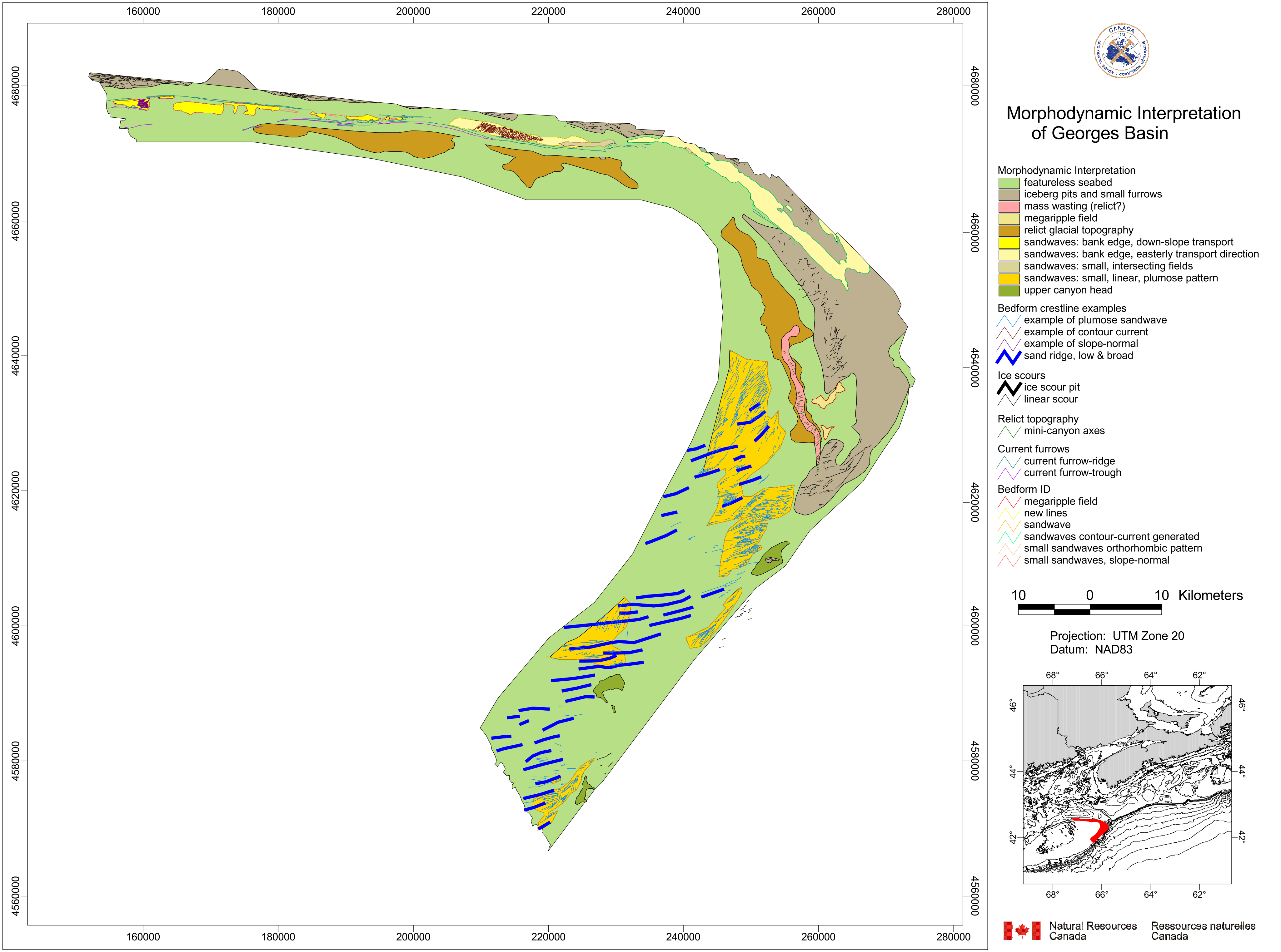
Enclosure 8

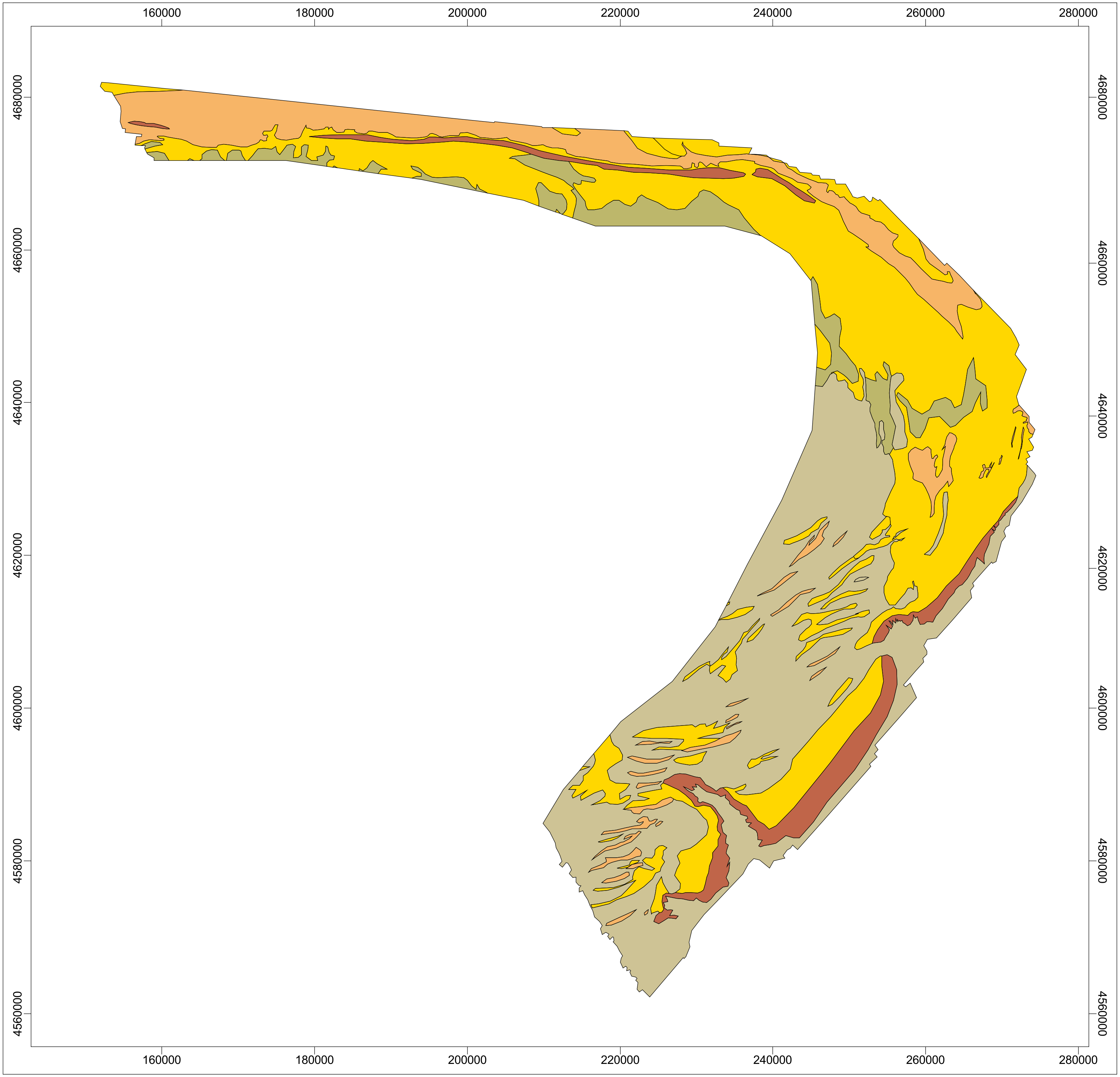

50000
100000
150000
200000
250000
300000
4750000
4700000
4650000
4600000
4550000
4500000
Sediment Thickness and Variability
Distribution of Northern Georges Bank
1 Thin surficial sand
2 Surficial sand, 1 to 5m thick, highly variable
3 Surficial sand, 1 to 5m thick, low variability
4 Surficial sand, >5m thick
5 Iceberg pits and furrows
6 Emerald Silt, <5m thick
7 Emerald Silt, >5m thick
8 LaHave Clay, >2m thick over thick Emerald Silt
9 Little to no thickness information
Emerald Silt, 5m thick
LaHave Clay, 2m thick
25 0 25 Kilometers
Projection: UTM Zone 20
Datum: NAD83
70° 68° 66° 64° 62° 60°
48° 46° 44° 42° 40°
Natural Resources Canada
Ressources naturelles Canada

Enclosure 9



Enclosure 10

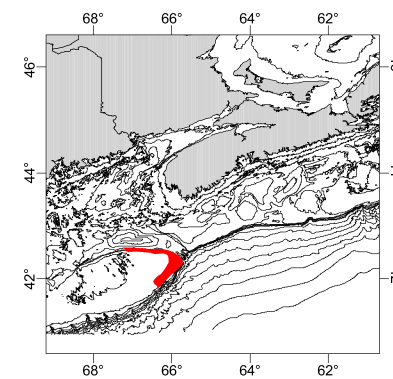
Seabed Sediment Texture of Georges Basin



Seabed sediment texture
- Gravel
- Gravel and scattered boulders, some sand, epifaunal community (filograna sp.)
- Gravel, trace of sand
- Dominantly sand in sandwave and sand ridge fields
- Gravelly sand: sandy on sandwaves, more gravelly otherwise

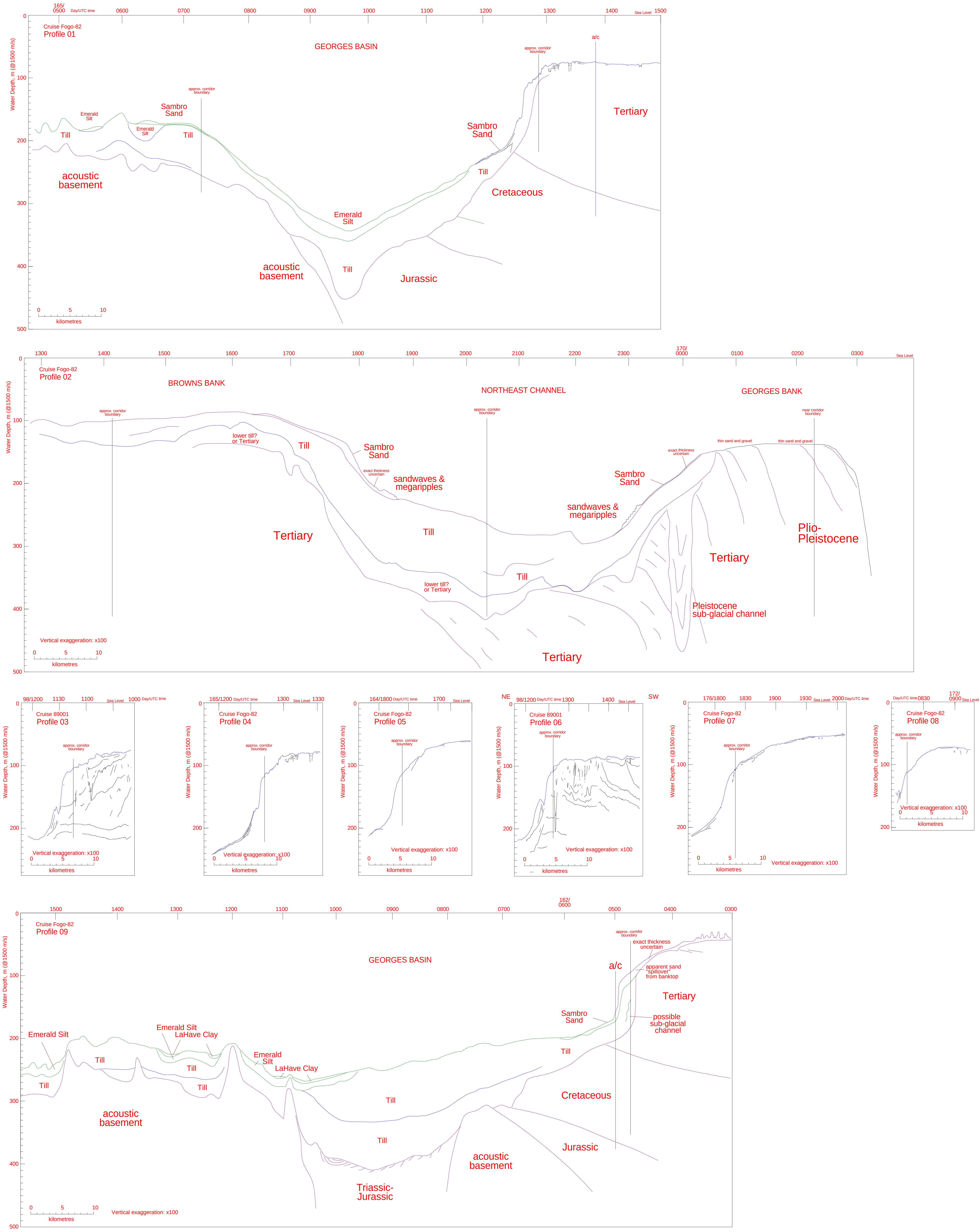
10 0 10 Kilometers

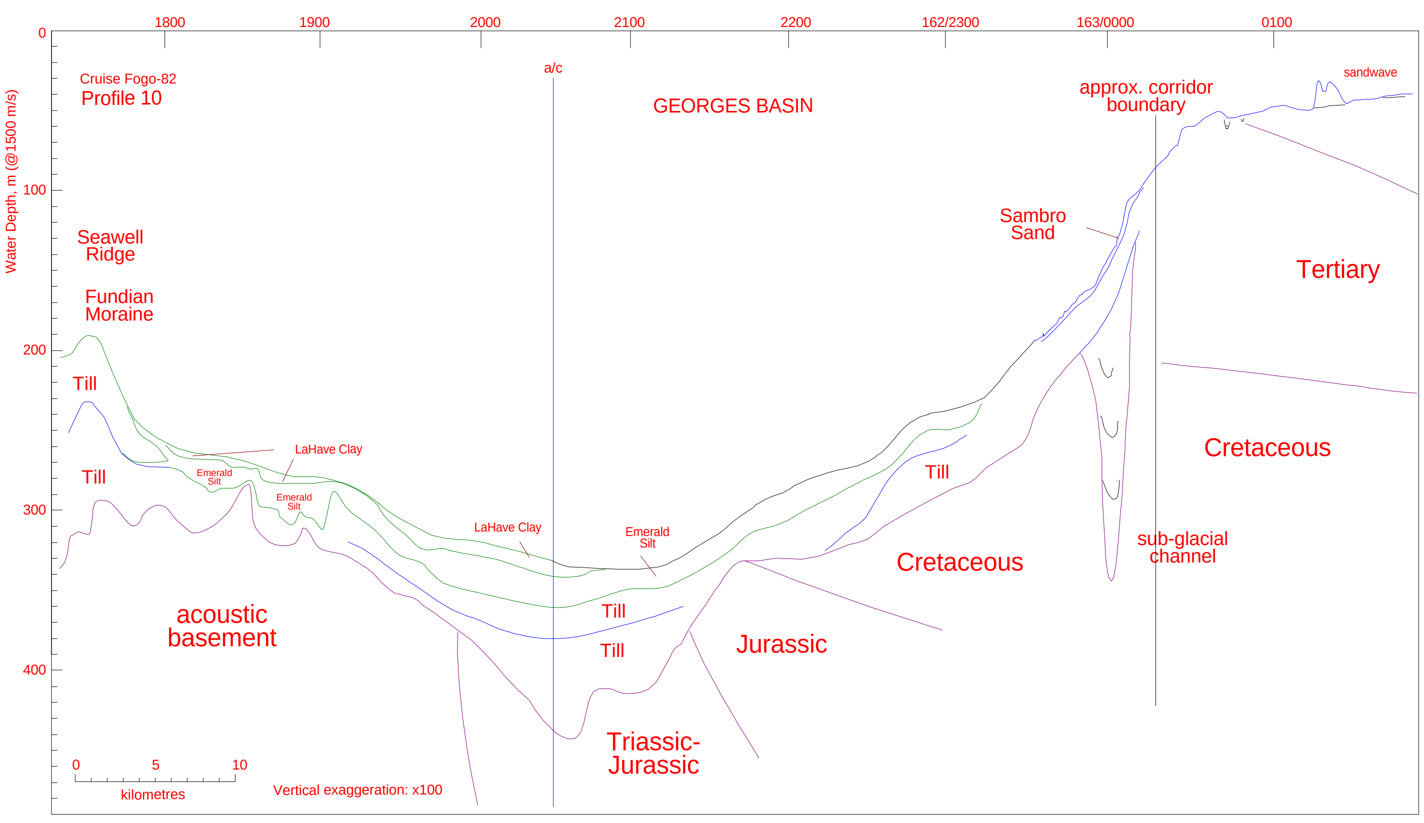
Projection: UTM Zone 20
Datum: NAD83



Natural Resources Canada
Ressources naturelles Canada

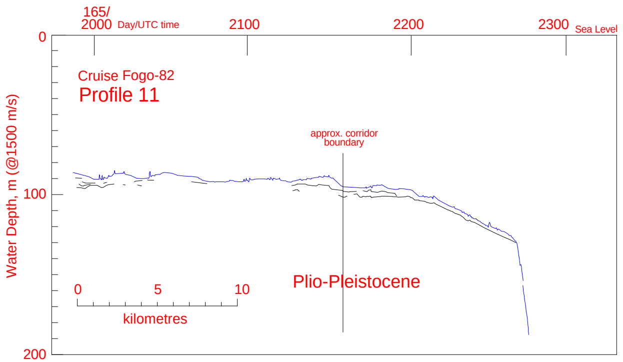
Enclosure 11

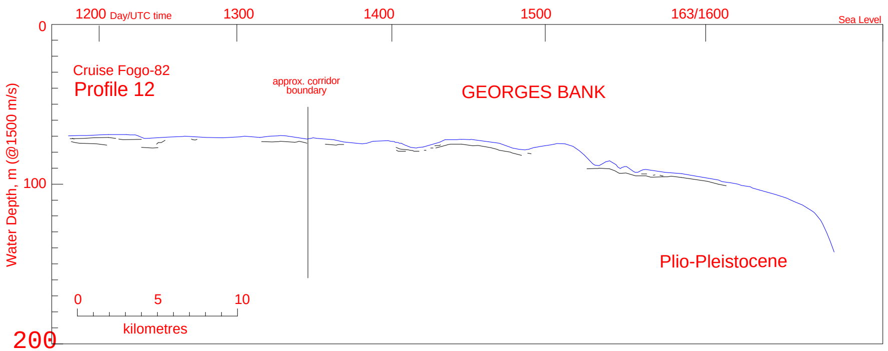


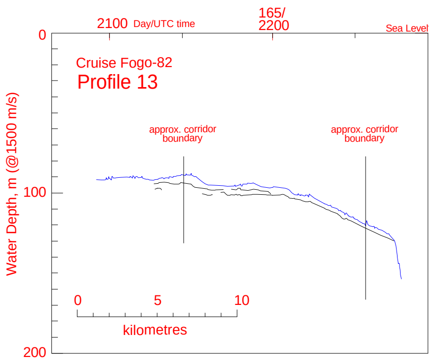


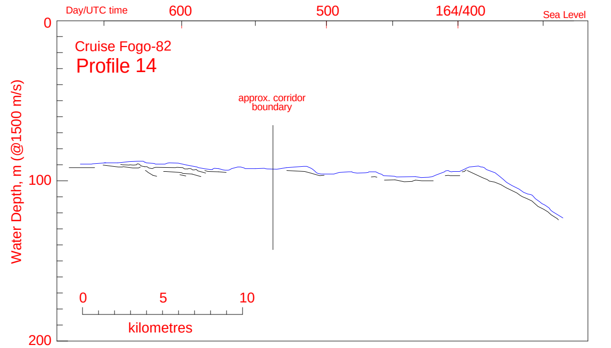
Note on accuracy:
Lateral and vertical waterdepth accuracy vary depending on original data type and compilation technique; in basin areas vertical accuracy -+8 m or better. On bank +-4 m or better.
Lateral accuracy +-400 m or better, commonly +-100m.
Depths of sub-bottom horizons relative to seabed are generally +-0.5 m in the near sub-surface.

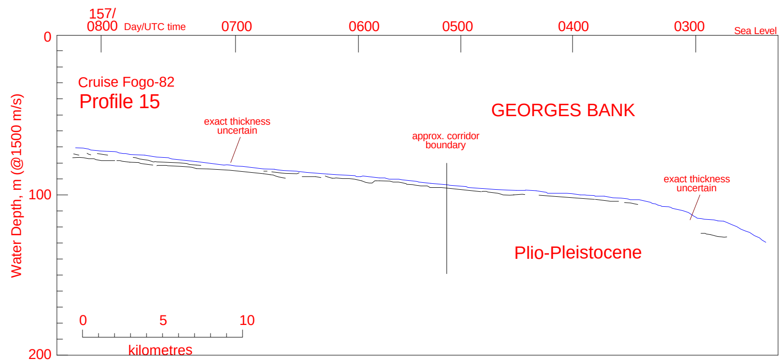
Enclosure 12

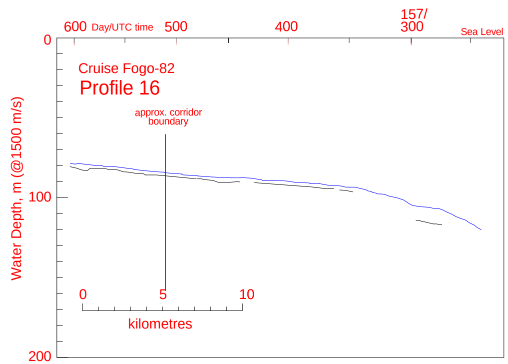






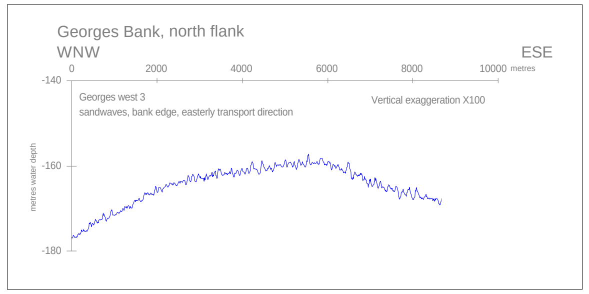


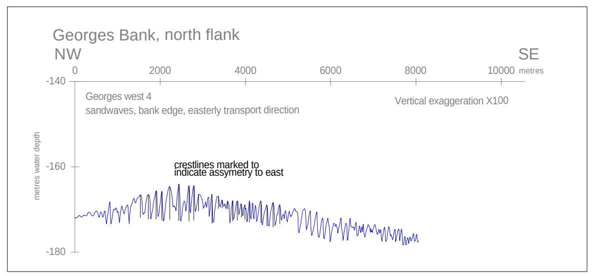


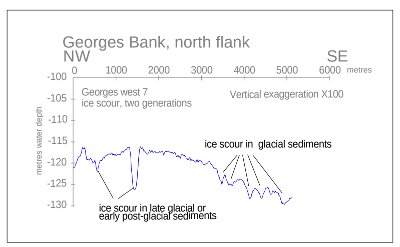


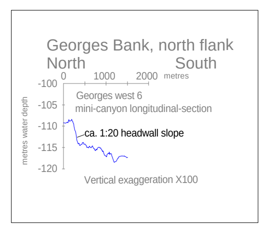
Enclosure 13

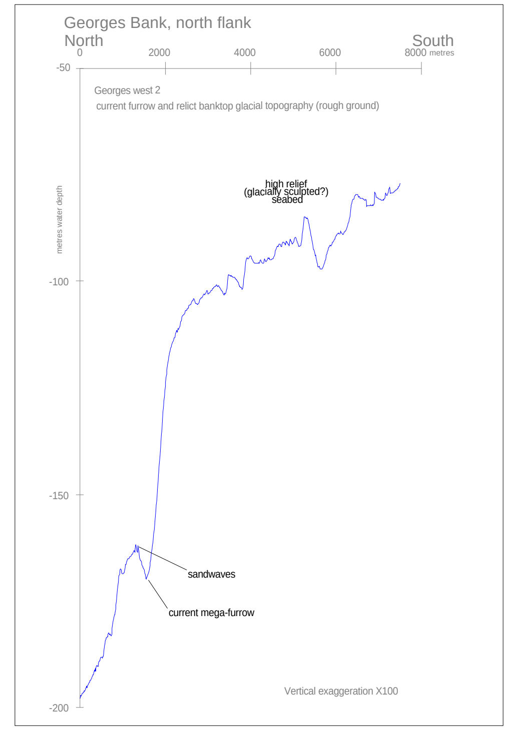
Georges Bank, north flank

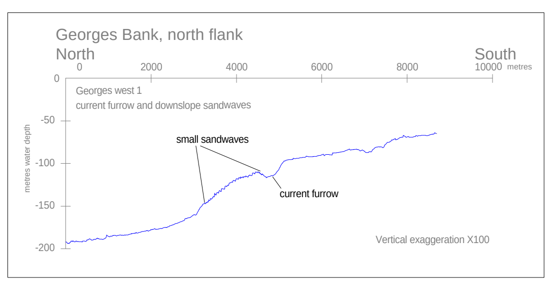


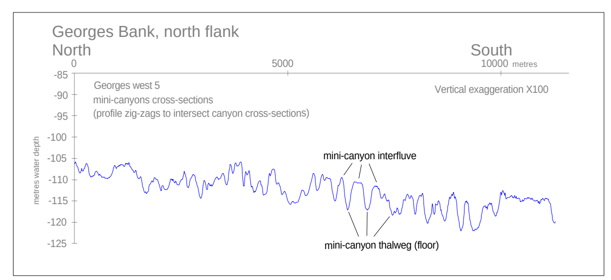




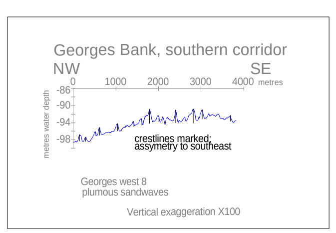


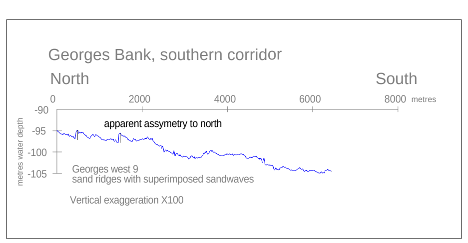






Georges Bank, southern corridor





ENCLOSURE 14

GEORGES BANK AND NORTHEAST CHANNEL PROFILES FROM MULTIBEAM

Northeast Channel