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OPEN FILE 7513

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1.0 Abstract

The thickness of Quaternary unconsolidated sediments (overburden) across the Grand Banks of Newfoundland and the Northeast Newfoundland shelf has been compiled and incorporated into a GIS-based geodatabase. It is derived from interpretation of a vast grid of high and mid-resolution seismic reflection profiles collected over about 40 years by the Geological Survey of Canada-Atlantic. This spatial database is in the form of spot thicknesses along survey tracks and thickness-classed zonation interpolated from these points. It comprises over 85 000 point thickness entries, each identifying the stratigraphic unit (or range in units) measured, a code linking to the raw data source, thickness in metres and milliseconds, notes on the source of interpretation and the process and positional accuracy, and generally the stratigraphic unit underlying the sediment at that position. Most records document only the total Quaternary thickness. A total Quaternary thickness zonation map (polygons/contours in six thickness classes) adds considerable interpretive value to the spot thickness measurements. Control for extrapolation and interpolation of the spot thicknesses came from bathymetric shaded relief images (mainly low resolution) where, for example, basins, valleys and ridges, near-seabed bedrock expression and other morphological elements helped provide spatial control for sediment thickness distribution. Till from the last glaciation is dominant volumetrically and locally stacked tills, presumably from older glaciations/statials are also identified. However the thickness database also includes a differentiation of eight separate sediment facies or stratigraphic units. These records are only compiled from select datasets where the appropriate raw data (generally ultra-high resolution profiles) were in a suitable format. This product complements other new map products from the area, both bedrock and surficial geological and a surface and sub-surface geo-features geodatabase.

2.0 Introduction

This dataset comprises a compilation of unconsolidated, Quaternary age sediment spanning the Grand Banks of Newfoundland as interpreted from an irregular grid of remote sensing sonar tracks collected in the last several decades (1969 to 2010). It complements bedrock and surficial geology and surface and sub-surface geo-features GIS database compilations released or pending in a similar (GSC Open File) of across the Grand Banks and the Northeast Newfoundland shelf. It is a first order interpretation (value-added) data catalogue derived from GSC geophysics. It is a simple cataloguing of sediment distribution and thickness containing spot thicknesses, derived along seismic survey lines and contoured thickness zonations. It is derived from existing compilations of a similar nature combined with an extensive new dataset from a recent characterization of digital seismic profiles collected between 2006 and 2011. It also contains a subdivision of stratigraphic map units.

The new spot thickness compilation was used to generate a map (polygons) delineating several classes of total Quaternary sediment thickness (isopach map). Figure 1 shows a map overview. This map was generated through manual drawing of isopachytes (contour lines of equal thickness) in the GIS environment using control from the spot depths but utilizing shaded relief bathymetric/topographic images of the seabed for further control of spot depth interpolations and extrapolations. For example, basins, valleys and ridges, near-seabed bedrock expression and other morphological elements in the seabed map image provide a spatial control on the setting for sediment thickness distribution.

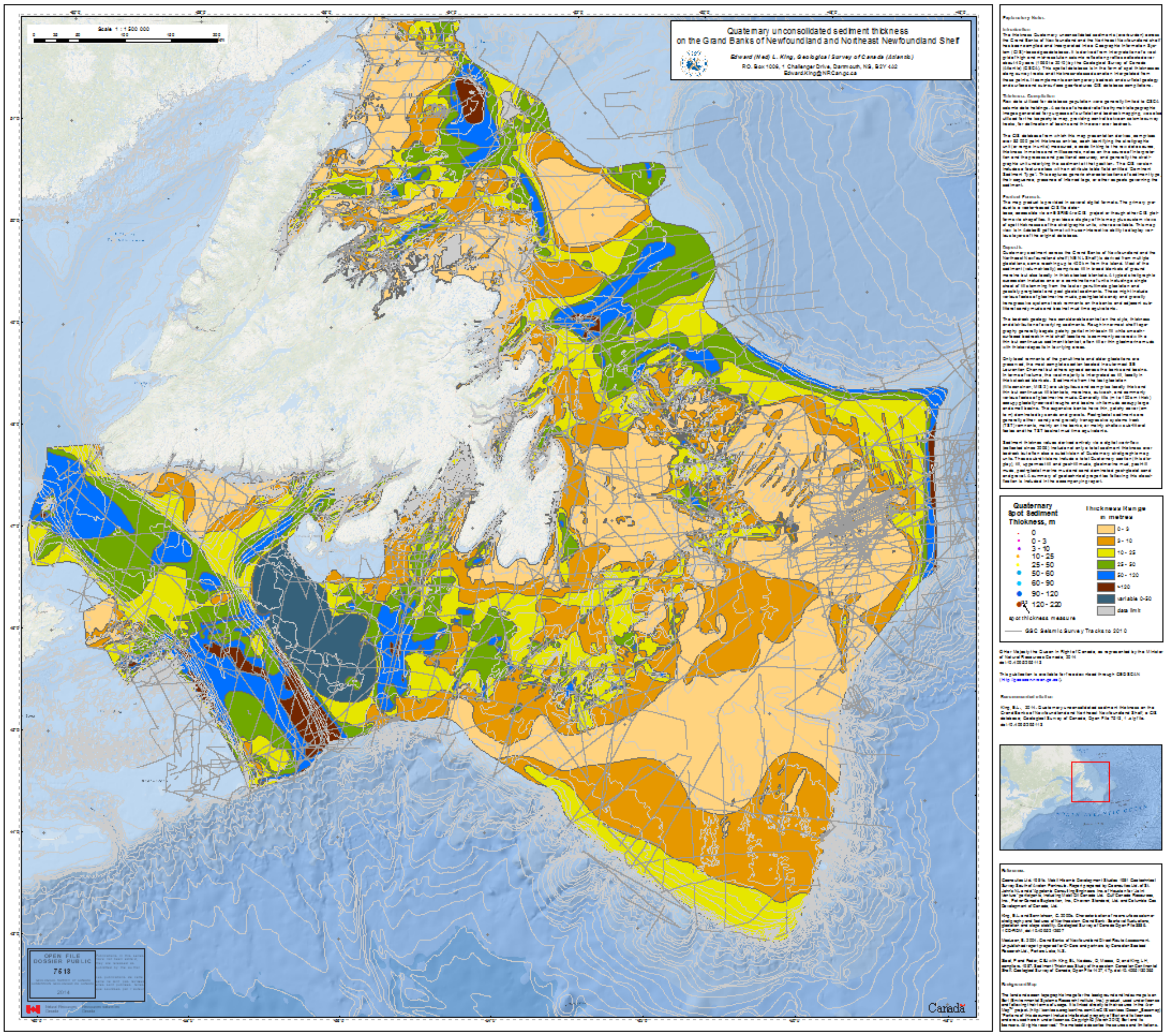

Figure 1. Thumbnail of the map product derived from GIS. Full resolution document available in Isopachyte_Map folder.

Quaternary sediment across the Grand Banks of Newfoundland and the Northeast Newfoundland shelf (NE NL Shelf) is derived from multiple glaciations, some reaching up to 400 km from the island. Most of the sediment (volumetrically) comprises till in broad blankets of ground moraine but also locally in thick stacked blankets. A typical stratigraphic succession includes one or a combination of units including a single sheet of till stemming from the last or penultimate glaciation and possibly pro-glacial and post glacial sediments. These might include various facies of glacimarine muds, post-glacial sandy and gravelly transgressive systems track remnants on the banks and adjacent sub-littoral sandy muds and basinal mud time equivalents.

Only local remnants of the penultimate and older glaciations are preserved, the most complete section located in outermost SE Laurentian Channel but others spread across the banks and basins. In terms of volume, the vast majority is interpreted as till, locally in thick stacked blankets. Sediments from the last glaciation (Wisconsinan; MIS 2) are ubiquitous and comprise locally thick and thin but continuous till blankets, moraines, outwash, and commonly various facies of glacimarine muds. Post-glacial sediments are generally either sandy and gravelly transgressive systems track (TST) remnants, mainly on the banks, or mainly shallow sub-littoral facies and the TST basinal mud time equivalents.

Past and potential users of such information are department and academic scientists, the hydrocarbon industry and supporting engineering-driven firms, seabed usage and management clients, including industry (telecommunications, pipelines, power cables etc.) or other government departments, for fisheries, seabed habitat and Marine Protected Area considerations.

3.0 Thickness Geodatabase Population Method

3.1 Thickness from Existing Maps

Earlier compilations of total Quaternary sediment thickness were a beginning point for the spot thickness. The sources for this compilation are outlined in Appendix I. A Huntec '70 Ltd. 1985 compilation (Open File release, Staal and Fader 1987) was comparable in concept, consisting of paper maps with spot thicknesses and (limited) contours. This was digitized and modified to include in this geodatabase. However, it was limited in scale, area of coverage, limited data, differentiation of sediment types and feature attributes and is commonly superseded with records from this new compilation.

An unpublished compilation of the northern portion of Grand Bank and north of this was resurrected from preliminary maps (Geonautics Ltd. 1981a). Another Geonautics Ltd. report illustration provided a thickness classification south of the Avalon Peninsula (Geonautics/Mobil 1981b). A compilation of sediment thickness across part of the outermost Grand Bank was compiled from interpretive tracings and digitization from paper airgun profiles (King and Sonnichsen 2000b). See processing steps in Appendix I (Process Code 82)

A tabulated compilation of some 1800 values for an area east of the Avalon Peninsula (MacLean, 2004) was modified slightly and incorporated into the database (Appendix I, Code 60).

3.2 Thickness from seismic profiles

Raw data utilized for database population were generally limited to GSC-Atlantic seismic data holdings (collected over decades). Detailed industry-collected data, especially in small-area "site surveys" in hydrocarbon exploration areas could also contribute significantly. It is the intention that with wider distribution, the database be further populated and eventually or periodically updated.

3.2.1 JP2000 Viewer-derived spot thicknesses: Most of the spot thickness postings were derived directly from digital seismic profiles, either directly or through supervision by the author. Specialized seismic profile and sidescan viewing and simple interpretation viewers (non-lossy JP2000 format from SEGY format data) were developed and customized at GSC-Atlantic (Courtney 2007). The JP2000 Viewer tool soon evolved to have flexible ArcMap GIS (shapefile) export capability (point, multipoint, polyline, with various decimation capabilities). The exported shapefile translates to a point presentation in ArcMap containing the x,y, and z values (longitude, latitude and depth below seabed in milliseconds).

As more than half of the raw data were not in fully digital format (ie. pre. 2003), this conversion from paper records was first necessary. A recent development of the JP2000 software suite is the capability of migration of scanned raw records (flat JP2000 format) to SEGY format following scaling and positional (cruise, day, time) tagging of the scan. Subsequent SEGY to JP2000 conversion and embedding of position (latitude and longitude) files matching these tags enables utilization of these scanned records with the JP2000 viewing and interpretation tools. The "Courtney JP2" tools are freely available at ftp://ftp.nrcan.gc.ca/gsc/courtney as part of the JP2 suite of programs.

Interpretation procedure begins with assigning a geo-feature-related "horizon", (eg. seabed, top of bedrock, base of surficial mud, etc.) on a reflection seismic image and manual tracing of these horizons. The horizon trace is then exported as a point or polyline ZM (embedded x,y,z coordinates) GIS shapefile for map display. In many cases, this product is sufficient for further manipulation or display in GIS (merging, ms to m conversion, commenting, source, process and accuracy attribution etc.). A more complete record of the processing is in Appendix II, Process Codes 8 and 9.

3.2.2 DeJitter-derived spot thicknesses: Another technique of extraction of sediment thickness from the seismic profiles was from an earlier phase, which involved considerably more manipulation. This procedure was utilized only for a short duration until the SEGYJP2000 viewer was developed. Main procedural steps included:

Horizons or features picked in a digital version of the SEGY geophysical record using the GSC-A developed viewer "Dejitter" (Peter Pledge, GSC-A). This is a SEGY seismic viewer designed to enable heave (wave-induced) removal as a pre-processing step. Further development enabled simple horizon picking and text-file export. These required considerable manipulation to process and incorporate into the geodatabase. A complete documentation of the process is included in Appendix II, Process Code 10. The outcome of this processing procedure was an inordinate amount of effort and potential for process errors and it was not pursued further.

3.3 Thickness from inferences based on geologic and bathymetric images

A series of shaded relief bathymetric/topographic images, generated for purposes of surficial and bedrock mapping, was also utilized for the isopachyte map, providing control for delineation of basins and thin cover over bedrock. These shaded relief images were generated from spot bathymetric depths supplied by the Canadian Hydrographic Service (CHS) derived from their so-called "field sheets". They were gridded a resolution appropriate for the area (generally ranging from 50 to 500 m grids), applied a shading, generally at 315 degrees illumination angle and mosaicked. As stated in the introduction, such topographic images provided spatial control for extrapolation of the along survey track spot thicknesses following various morphological elements, allowing construction of a contoured thickness (isopach) map (total Quaternary thickness).

This technique is further utilized for high resolution multibeam seabed bathymetric images (only in Placentia Bay) where seabed character allowed confidence in recognition of near outcrop, bedrock with thin sediment cover, moraines and drumlins with relatively thick (till) cover and basins with very thick cover. Thus, despite little or no seismic control, several classifications of thickness could be generated with high spatial resolution distribution but low confidence in absolute thickness. Nevertheless, this was still generally compatible with the broad thickness classifications of the isopach map.

3.4 Contour Map Compilation

The thickness distribution map has six pre-determined thickness range classes and two auxiliary classes. This classification was determined largely by the limitations of the raw data, the compilation techniques but also by the ground conditions. While the precision of a specific thickness unit or sub-unit was determined with precision commensurate with the resolution or interpretation limits of the seismic data (such is the case for the spot thicknesses), spatial extrapolations of thickness (beyond survey line control) is a judgment based on the perceived map unit conditions. For example, thick (ie. tens of m) blankets of till in a shelf-crossing trough can be relatively consistent in distribution over distances of kilometres while on the top of banks, a thick sand unit (several metres) is likely to pinch out or thin over a short distance (100s m). Occasionally, a system in the distribution can be recognized (e.g. a relict shoreface-connected sand ridge), serving to enhance extrapolation confidence. Thus, the imaging limitations and nature of the distribution lead to choice of isopach intervals at classes of 0 to 3, 3 to 10, 10 to 25, 25 to 50, 50 to 120, and greater than 120 metres.

Generally and isopach contour was sketched using the spot thickness and shaded relief and intuition from the nature of the sediment as control. Sketches were generally performed as “graphics curves: (ie. not feature class entities) which enabled real-time bezier curve construction over short distances. Simple deletion and re-draw is instantaneous in the GIS environment. The map was progressively built through an iterative process of completion, or near completion in an area and panning to a new area and repeating the procedure. The graphics were then converted to polylines (an ArcTools function). Breaks in polylines were joined (snapping) and separate elements generally merged and attributed in terms of thickness class. Polylines were closed (endpoint snapping) and vertex adjustments and smoothing performed where deemed necessary. Then a polyline to polygon (ArcTools) function was used to generate polygons. This is also a stepwise process as errors and omissions are discovered and altered. Finally, following successful closure of all polygons, they were attributed according to thickness class and also assigned source, interpretation control note, and a dominant sediment type comment. The two latter comment fields provide the end-user with a qualitative sense of the nature of the sediment beyond a simple thickness value.

4.0 Use and Limitations

Limitations or shortfalls of this database are numerous, despite containing upwards of 85 000 records. Population was limited to original GSC-Atlantic survey data distribution, density, quality, and format. Some inconsistency of interpretation is inevitable where comparisons with the original (OF 1427) are concerned. These are often flagged in the comments field. The capture of early total sediment thickness postings were from scanned paper maps so scaling, spatial resolution and georeferencing, all affect positional accuracy.

The absence of records in the database does not necessarily imply absence on the ground; population of the database was dependent on the bias of data coverage, format and quality. *Not all raw data were rigorously examined for sediment thickness*. Further, separate measures of the stratigraphic sub-division of the Quaternary section were only conducted sporadically, mainly where the necessary high-resolution seismic was readily available in a digital format. The user is cautioned that many features were not populated with full spatial resolution or attributes, largely dependent on source and processing, so inconsistencies or omissions among chosen displays can result.

Positional accuracy estimate, interpretation source, and general process of data capture are included for all records. Limitations are many, due to geographic prioritizations, effort of sub-classification and measurement, limitations of original data distribution, quality, and format.

Section 10.0, of this document (Product Format) expands on the use and limitations of the GIS database format and the Adobe map sheet format.

4.1 Positional Accuracy

The main feature class attribute table contains a numeric code depicting a qualitative measure of positional accuracy. The codes and their respective process and precision are shown in Appendix III. Clearly, accuracy is the culmination of a series of processes, starting with navigational accuracy at sea but this can be retained or degraded with various compilation techniques.

5.0 Grand Banks Geography, Geology and Sediment Thickness Distribution

The rugged topography of Newfoundland generally extends only a short distance offshore where the morphology becomes more subdued with the cover of younger rocks, generally Paleozoic metasediments or Carboniferous sediments, both with a glacially smoothed unconformable surface. These become further covered on the mid-shelf by Cretaceous and Tertiary age coastal plain sediments. A nearly ubiquitous cover of glacial sediments of variable thickness and genesis covers bedrock such that true outcropping is very rare.

The bedrock geology has considerable control on the style, thickness and distribution of overlying sediments; rough innermost shelf topography generally begets patchy partial mini-basin fill, smooth-surfaced bedrock in mid shelf locations is commonly covered with a thin but continuous sediment blanket, often till or thin glacimarine muds with thicker deposits in low-lying areas.

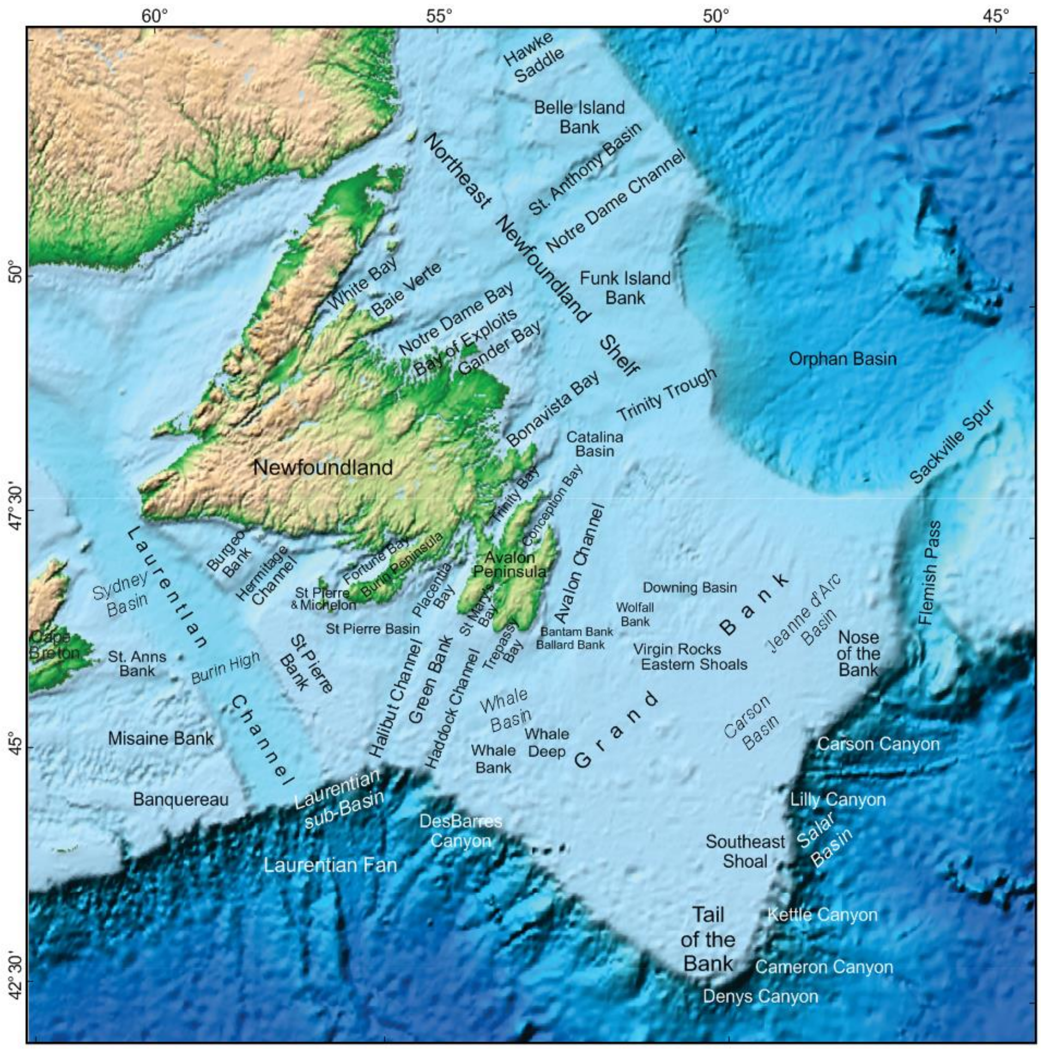

Figure 2. Newfoundland, the offshore Grand Banks of Newfoundland, and the Northeast Newfoundland Shelf with main geomorphic features named; sub-surface elements in italics.

The Grand Banks of Newfoundland are a series of plateaus ringing southern and eastern Newfoundland, including the largest, Grand Bank, 400 km wide east to west from St. John's to the shelf break, and 600 km from north to south (Figure 1). It is generally a plateau with over 140 000 km^2 at 100 metres water depth or less, including the very shallow centrally-located Eastern Shoals and Virgin Rocks. It is cut on margins by numerous canyons, best developed along the eastern and southern shelf breaks with numerous smaller examples on the northern margin flanking Flemish Pass and Orphan Basin.

While the entire Grand Bank has been glaciated in the past (Fader and King 1981, King and Sonnichsen 2000a, Sonnichsen and King 2002, Shaw et al. 2006), the extent, timing and pattern of the last glaciation has been uncertain, partly because the following transgression removed and redistributed most of the glacial record on the banks. Very limited core sampling of the basal part of the glacial sequence in basinal areas over the past few years has enabled some radiocarbon dating, reinforcing the concept of a limited Late Wisconsinan glacial cover, reaching mid- Grand Bank but with shelf-break reaching ice streams via shelf-crossing troughs.

These glacially-excavated shelf-crossing troughs dissect the banks north and south of Newfoundland but the glacial expression is more subdued on Grand Bank. Most emanate from broad bays and all have overdeepened areas, mainly on the inner shelves. The Avalon Channel, over 150 m deep, is a transverse trough which links some of the shelf-crossing troughs. Downing Basin, Whale Deep and an unnamed complex of convoluted valleys north of Downing Basin represent the combined excavation of glaciations at and beyond the contact of hard Lower Paleozoic platformal rocks with the more erodible late Mesozoic and Cenozoic coastal plain rocks. These valleys extend much farther than their present seabed expression, to about halfway across the Bank, but are partially or fully infilled with glacial sediments. They mark active meltwater erosion under multiple glaciations.

The southwest Grand Banks, including Burgeo, St. Pierre, Green and Whale Banks, all reaching shallower than 100 m, are bounded to the south by the broad glacially excavated Laurentian Channel. Burgeo Bank has thin Quaternary cover over a possible Cretaceous outlier while most of the offshore between the Avalon Peninsula and Cape Breton is floored with Carboniferous sedimentary rocks. St. Pierre Basin has been glacially excavated and floored with Carboniferous rocks, with a cover of till and a series of rather complex moraines and locally thick basinal glacimarine muds. Parts of St. Pierre Bank have a foundation of thick Tertiary rocks including Miocene progradational bodies. It is heavily dissected by glacial channels at its surface but most are glacially infilled. A probable sandy moraine or outwash on the outer (western) bank provided sufficient sand which was re-mobilized into terraced sheets on the SE portion with post-glacial sea-level rise, bringing it to less than 50 water depth there.

The Laurentian Channel, with 300 to 400 m water depths, cross-cuts most bedrock lineations including the Burin High, separating the Carboniferous Sydney Basin, to the north from the Laurentian sub-Basin to the south. Glacial processes dominate the shelf morphology and the evolution was toward a straighter, narrower Channel morphology with successive glaciations (King and Pitts 2012, King 2012). A deep and large canyon at its mouth provided accommodation space and preservation potential for multiple tills and upwards of 800 m of Quaternary sediments record mass transport failure scarps and deposits giving way, though time, to stacked tills which likely span all the shelf-break-reaching glaciations (King and Pitts 2012 and King 2012). Though not mapped in this compilation, the steep slope of the Laurentian Fan has caused most of the Laurentian Channel–fed glacial material to bypass the Fan. Mass failures and meltwater floods across the Fan (Piper et al. 2012) impart a channelized morphology.

The core of Green Bank is Tertiary strata with some buried channel dissection and thin overlying sands and gravels reworked during the post-glacial sea-level rise. Halibut and Haddock Channels both carried ice streams which cut the Cenozoic sediments. Halibut Channel preserves a thick complex of old tills and glacimarine sediments in the overdeepened parts but the sill, near the shelf break, survived erosion, preserving late Tertiary sediments. This overdeepening set the scene for deposition and preservation of multiple thick tills. Haddock Channel has a simple glacial stratigraphy of a thin till and minor glacimarine mud in the mid-shelf overdeepened part.

To the east, Whale Deep is a series of small elongate basins cut into Paleogene sediments with glacial fill, including many fully buried examples. The basins are glacially and sub-glacial meltwater excavated and some preserve a sequence of retreat tills interfingered with glacimarine and post-glacial mud. Its shallow position on Grand Bank caused reworking of the upper portions by coastal processes as the post-glacial sea transgressed the basin flanks. Downing Basin and the convoluted basins north of it have similarities to Whale Deep, with a strong glacial erosion and complex infilling. Open, elongated, valley-like basins give way to fully infilled equivalents towards the east and northeast. These are clearly multi-generational and indicate several cycles of sub-glacial meltwater action. Tidewater moraines and associated sub-aqueous outwash linked to the tunnel valleys in the basin complex well north of Downing Basin are preserved at or near the seabed because they deposited below the low-stand (King et al 2001). Presumably such moraines also existed south of this but were destroyed with the transgression, the sandy material transformed to large shoreface-connected ridges and other bedforms.

Southern Grand Bank and the Tail of the Bank is only sparsely surveyed but includes the rather high energy Southeast Shoals, shallower than 50 m and a large province of sand ridges, probably mostly moribund, generated during the transgression. A more muddy wedge flanking the Tail of the Bank may include outwash and relict sub-littoral sands, also remnants of the transgression. Here on the southern and eastern bank shelf-breaks, multiple canyons cut latest Neogene sediments and the wedge of Quaternary sediment (mainly till) is thin and discontinuous. The canyons cut well into Tertiary rocks and Quaternary infill is almost non-existent except for sparse thalweg sands. The canyons are much less pronounced north of Carson Canyon, possibly reflecting a more pronounced hindrance from the cohesive glacial tills at the shelf break (Piper and Brunt 2006) as opposed to more purely low-stand feeding to the south (King and Pitts 2012).

In the Jeanne-d'Arc Basin area (site of hydrocarbon production) bedrock near the seabed is Paleogene and Neogene, including sets of large prograding bodies. The Quaternary record is thin, dissected, modified by sub-aerial processes and not well resolved but likely includes outwash and till covered by the sands and gravels largely redistributed into bedforms. Boulders and cobbles are ubiquitous but may stem from multiple glaciations and ice rafting. Only on the northeastern Grand Bank, toward Sackville Spur are there clear remnants of glaciation in a till blanket worked into long, low relief, linear moraines (King and Sonnichsen 2000) but these are suspected to stem from the penultimate glaciation.

On the north edge of Grand Bank, flanking Orphan Basin, canyons are closely-spaced, fairly linear and activity more related to multi-phase Holocene mass transport events.
North of Grand Bank, Trinity Trough emanates from Trinity and Bonavista Bays. The glacier margin reached the shelf break and deposited abundant glacigenic debris flows on the slope, alternating with periodic meltwater floods (Tripsanas and Piper 2008). One of such flood is apparently responsible for a large mass of till removed from the distal flank of a large arcuate moraine situated mid shelf in the trough (King et al. 2001, King et al. 2007).

The Northeast Newfoundland Shelf is a much deeper shelf, with deep banks and even deeper channels cutting them. The 300 m contour encircles most of the shelf except for the glacially excavated fjords, a broad transverse trough and shelf-crossing troughs. Only Funk Island Bank presents water depths shallower than 250 m. The transverse trough (inside Funk Island Bank) and shelf-crossing channels - Notre Dame Channel is the largest- are all greater than 350 m deep and most are over 400 m, locally over 450 m. The fjords are invariably overdeepened and preserve thick glacial mud sequences commonly over 100 m and locally almost 200 m. All have relatively shallow sills or multiple sills. The inner shelf has a strong imprint of mainly hard and rugged Paleozoic rocks creating local basins with partial infill.

Notre Dame Channel dissects the Northeast Newfoundland Shelf and drained a large ice stream which cut both bedrock and older tills. Large mass transport blocks, mega-scours and ridges both on the inner and outer channel have been recognized as glacitectonic features (Shaw et al. 2012). Locally, thick moranic and stacked tills impart some constructional topography but they are commonly cut by subsequent glacial action. Bell Island Bank is such a constructional, till, cored bank in stark contrast to Funk Island Bank on the southern flank of Notre Dame Channel, with very little Quaternary cover. The outer shelf is largely unknown for lack of survey coverage.

6.0 Sediment Thickness Dataset

A large dataset containing spot thicknesses of sediment overburden (Quaternary cover) includes over 85 000 entries. Thickness values were originally derived from seismic survey lines and compiled from various sources from 1985 to present. Original data format varies greatly, ranging from spot postings on paper maps or hand-generated contours on paper maps to spot postings generated from fully digital seismic sections. One of the largest sources for the thickness database was a compilation of total overburden (Quaternary sediment) thickness across much of the bank (Staal et al 1987) which was transcribed to the database from paper maps. The new compilation adds extent and detail but the 1987 compilation, despite its spatial shortcomings, has a finer contour interval, and some local details not captured in the new map. Accordingly, it is included in this database (Fig. 3). Of course, variability in interpretation, positional accuracy and attribution of the sediment column arises.

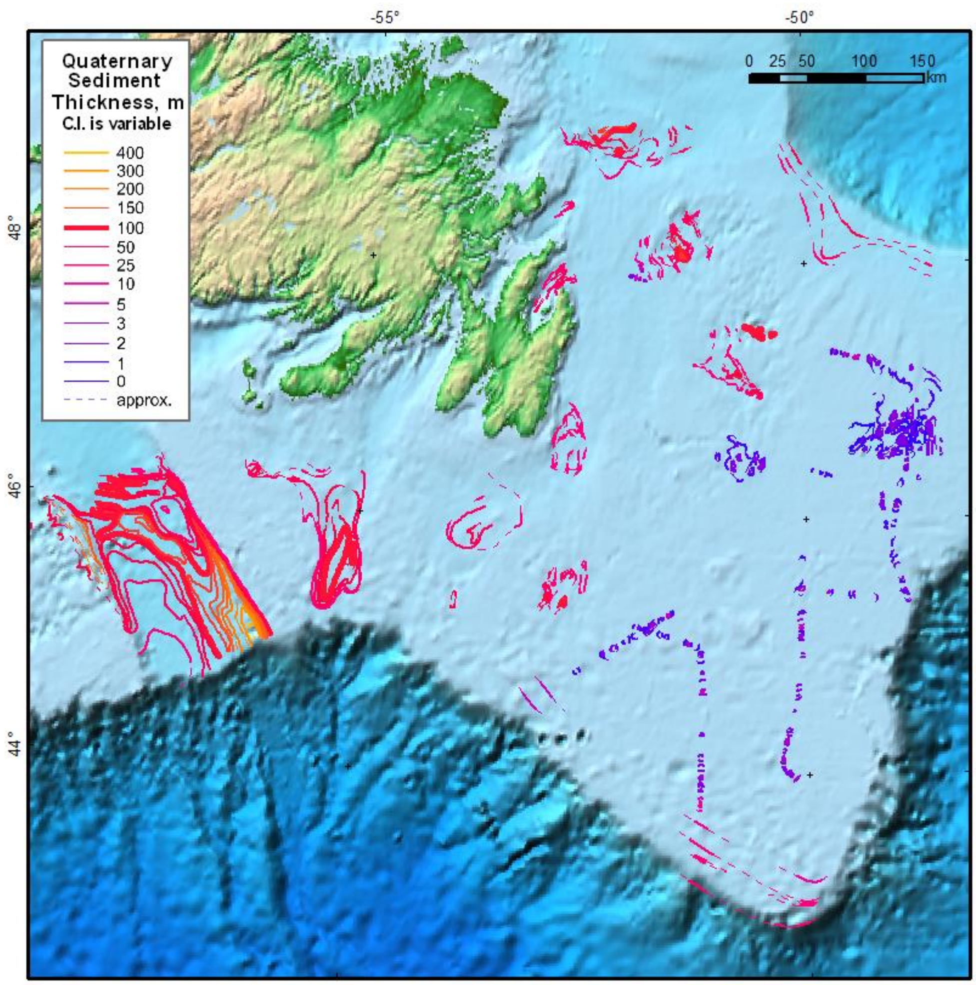

Figure 3. Sediment thickness compilation from 1987 (GSC Open File 1427) is included in the geodatabase but significant improvements have been made.

The user must be aware that in some areas more than one compilation of identical seismic profiles was conducted such that more than one interpretation can overly one another. These are not filtered or re-interpreted so the viewer must evaluate their use. Clearly, the newer compilations are generally more precise in terms of location and thickness but there can arise *differences* in interpretation (or navigation positioning differences) from one compilation to another.

The feature class contains fields identifying the general nature of the sediment, the thickness (in metres and milliseconds), a local (isolated, anomalous) thickness (the "ThickLocal" field), two estimated thickness fields, "EstThkMin" and "EstThkMax", a source, process, navigational accuracy, usually a data identifier correlating it to the original raw profile source, and a comments field. These are briefly expanded upon below.

The Cruise field uses a designation identical or similar to the marine geophysical track database maintained by the GSC (Expedition Database, available on-line via NRCan portals). The feature class also has a DayTime identifier, unique to each record, generally following the standard cruise, julian day and UTC time format. There are exceptions because, for various reasons, this was not always a unique integer. In these cases it was assigned either a dummy value or, for the recent JP2000 software-derived compilations, the seismic shot number was appended (at the end). The process documentation elaborates some on derivation of thickness values from seismic horizon picks in the JP2000 Viewer.

The Comments field often contains a generalized statement referring to the vertical resolution of the posted value, the nature of the base of the designated unit (what lies beneath), limitations in the interpretation or the positional limitations of the posting or a flag as to the presence of other complementary or conflicting interpretations at or near the site. Some of these require further explanation.

Any phrase including "Max. thickness; insufficient resolution" refers to a low resolution profile where the sediment unit is thin and not properly resolved. This arises where seismic profile pulse signature (bubble pulse) is long (typically 5 to 15 m) such that the sediment unit is inferred but not accurately measured. Quantifying a resolution limit is subjective because it is a function of data quality which is sea state and equipment-sensitive. It is also a function of the geology; commonly thicknesses can be estimated to a few metres and well within the bubble pulse width, especially where the geometry of the bedrock surface differs from the seabed shape. Another common situation is where thin sediments cover gently dipping Mesozoic or Cenozoic "bedrock"; the bedrock strata are well resolved but the top of bedrock is not. In this case the strata were traced to as shallow as possible such that their top represents a maximum thickness of sediment cover. In the latter case (constrained by top of bedrock strata), the thickness is likely lesser than that reported.

Any phrase including "minimum thickness" generally refers to the recognition of a specific sediment unit from its character but where its base is not recognized, generally due to lack of acoustic penetration. Thus the thickness is likely greater than that reported.
Figure 4 shows an overview of the total Quaternary sediment spot thickness.

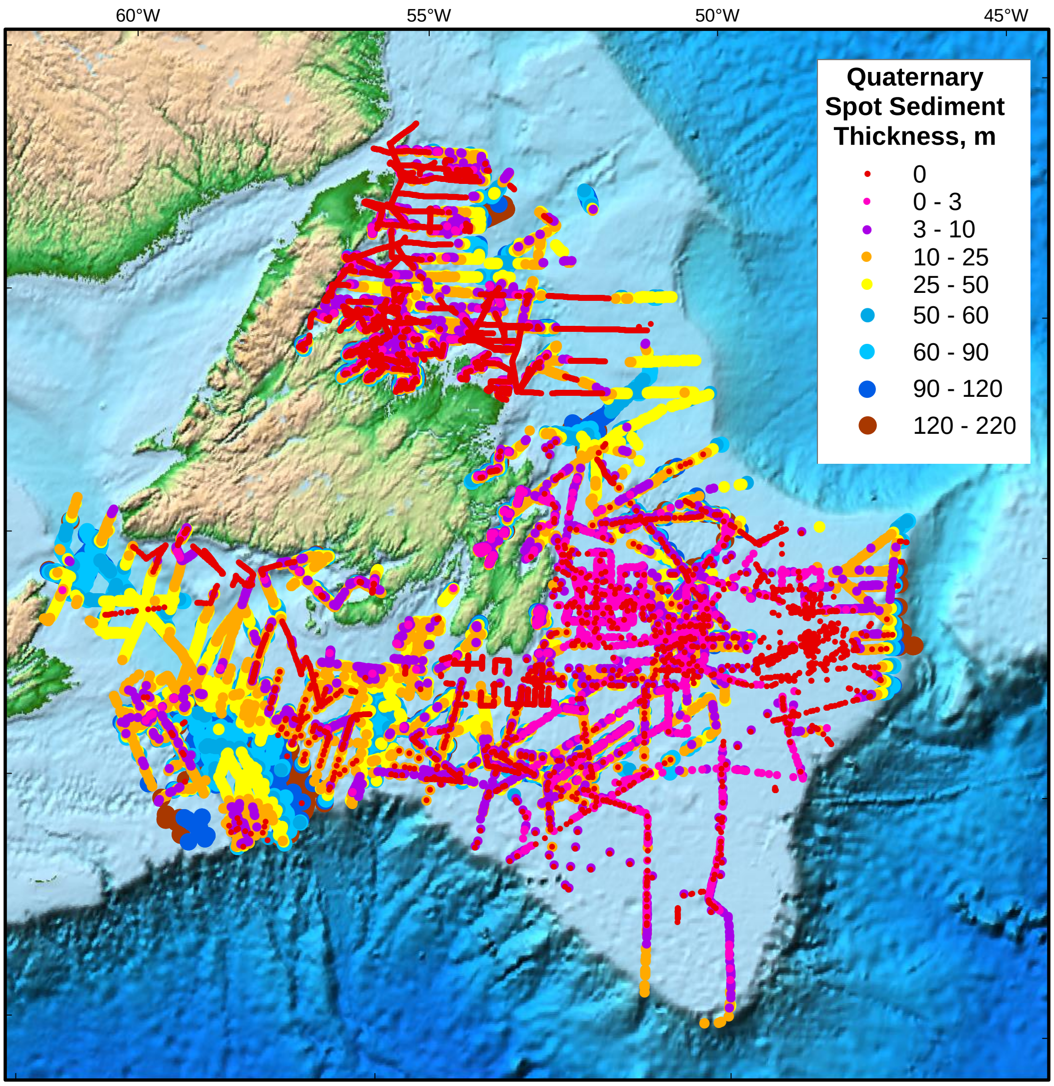

Figure 4. Quaternary sediment spot thickness displayed with similar classification as the polygon zonations. The database contains over 85000 such postings.

6.1 Stratigraphic sub-units with thickness information

A large part of the thickness database is derived from the most recent GSC-A expeditions, from 2006 to 2011, inclusive. These values, derived entirely via a digital work-flow can be considered the most precise in terms of navigation and thickness. They include not only a total sediment thickness over bedrock but often also a subdivision of Quaternary stratigraphic map units:

8. post-glacial marine mud
7. post-glacial sand and gravel; sand dominant
6. Post-Till Muds
5. glacimarine mud
4. uppermost till and post-till muds
3. Till
2. Total Quaternary section
1. Bedrock; thin overlying older bedrock unit

The subdivisions reflect the original seismo-stratigraphic classification of King and Fader (1986) and Fader and Miller (1986) who also reported dominant lithologies, broad age categories and deposit genesis.

Subdivision 1, Bedrock, deviates from the database theme in that it refers to bedrock thickness, not the overlying sediment. It is not a common entry, used in some cases where a thinning wedge of bedrock laps another bedrock type.

Subdivision 3, Till, deposited at the margin or beneath a glacier, is typically a cohesive stiff to hard boulder-clay or diamicton. Some tills can be softer and relatively clast-free. Till thicknesses, per se, are rarely separated from the "total Quaternary section" in this database despite its broad and often thick distribution. This is recognized as a shortcoming in this compilation (see following section).

Subdivision 4 refers to situations where the seismic profile does not readily allow imaging or interpretation of the entire Quaternary section. This is common when limited acoustic penetration images only the upper parts of the Quaternary section (generally Huntec or 3.5 kHz profiler data) or where multiple, stacked tills are present and the basal till or bedrock surface is poorly or discontinuously imaged.

Subdivison 5 generally is restricted to the acoustically stratified muds deposited on retreat of the glacier, with little or no cover of later sub-units. However reported thickness values can include overlying sands and gravels (usually less than 1 m thick) or post-glacial marine mud.

In contrast to subdivision 5, "Post-Till Muds" (6, above) were designated where either the post-glacimarine mud was not present or was not differentiated. A till surface, for example, might be readily imaged on an air-gun profile while a smooth seabed with ponded-style sedimentation suggests an overlying stratified sediment unit (marine mud) whose base is not resolved.

Subdivision 7 is generally has a bank-top distribution, having been deposited following reworking of underlying sediments at times of lowered sea-level. Where this becomes thick enough to resolve on, for example, the Huntec profiles, it is usually in a prograded sheet or a relict shore-face-connected sand ridge or a paleo-sub-littoral blanket. While it can contain gravel, it is generally sandy but typically with a basal gravel or cobble lag.

Geotechnical properties of the stratigraphic subdivisions are provided in Section 9.0.

Excerpts from the GIS attribute table are shown in Appendix IV to illustrate structure and scope of the spot thickness compilation.

6.2 Thickness Values for Stratigraphic Sub-units: To what do they refer?

It is ***important to note*** that although the database generally refers to "thickness" of a particular sediment unit, it is the vertical depth ***below seabed*** to the ***base*** of that unit to which the metre and millisecond values refer. In all cases where the "Total Quaternary section" is reported (in the "Sed_Unit" field), the meaning of the thickness value is clear and there is no issue. However, where stratigraphic ***sub-units*** are noted, the value includes the ***total*** sediment thickness ***above*** the base of the designated unit. For example, in a typical sequence of bedrock, till, and glacimarine mud followed by marine mud, a thickness value with a "Sed_Unit" designation of "glacimarine" refers to the combined thickness of post-till mud (or sand) units.

This "shortfall" might cause some confusion by the user. For example, a "glacimarine mud" thickness of 12 m may or may not include a few metres of overlying "post-glacial marine mud". Upon further inspection, it may be apparent that a very nearby (but not precisely overlapping) thickness posting does, in fact, designate a thickness value for the marine mud. In this case an approximate thickness for the glacimarine mud can be derived (difference between the two postings). Alternatively, the ***lack*** of a nearby posting designating a unit different than the "glacimarine mud" leaves the user uncertain if other sub-units are, in fact, present. The sub-division "Post-Till Muds" was an attempt to limit occurrence of such situations.

All thickness derivations from the JP2 Viewer-enabled data (Source numbers 55, 58 and 65 in Appendix I) utilize an export feature in the where one of the horizons can be designated a "datum" such that all elevation values are relative to that datum (default is zero time; the outgoing pulse). For thickness values in this database ***only*** the "seabed" horizon pick was designated as "datum". Hence the "shortfall" noted above.

The reason for this "shortfall" is simply that data manipulation to derive individual unit thickness is considerably more labour-intensive and was not generally performed. It is possible to derive individual sub-unit thicknesses, most readily from the JP2000 version seismic profiles where horizons have been picked. This is accomplished by designating other horizons as "datum" to derive their thicknesses. However, this involves a separate shapefile export, one for each unit, and a more involved file management scheme and a tedious check that all units of the sequence are correctly registered.

There is an ***exception*** to this, where individual thicknesses ***are*** reported. Those entries that are derived via the "dejitter" program (Source number 66) have been through the process of subtracting thicknesses of overlying sub-units and so report the actual thickness of the designated unit. This was a tedious and labour-intensive exercise with gains considered too little for the extra effort. Compilation techniques using the newer JP2000 software would be less intensive. Process steps are reported in the documentation of this particular source number.

Perhaps conspicuously absent from the database is abundant records of till thickness. Till is very common, especially in areas below the post-glacial low-stand of sea-level. The thickest and most abundant deposit occurs in the Laurentian Channel area. Stratigraphic differentiation and mapping of the Laurentian Channel tills was a separate exercise reported on elsewhere; only total Quaternary thicknesses were derived from that product.
Many seismic profiles have been interpreted and contain information on the tills; further manipulation is fully possible in the future.

6.3 Thickness Measurement Accuracy

Accuracy of the thickness measurement based on reflection seismic profiles is largely dependent on the raw data instrument type from which the sedimentary unit and its thickness were interpreted. Vertical resolution is a function of seismic source impulse length (in the time domain) and sound frequency. A "clean" spike-type wave signature generated from the Huntec Deep-towed boomer, for example, allows one to register horizontal (shot to shot) differences in the range of centimetres (ie. a precision measure) and vertically-separated horizon picks (e.g. seabed to base of mud) to within tens of centimetres. Corresponding values for air gun seismic profiles is one to several metres, very dependant on the source technology employed.

Another error source is related to the estimate of sound velocity for conversion of the two-way travel time, native to sonar, into true thickness (in metres). Simple, single channel reflection seismic data, used for this compilation, do not have the geometric configurations of multichannel equivalents to allow velocity measurement. Here a standard 1500 metres per second two-way travel time was assumed. Experience demonstrates that for water-rich marine muds this probably varies considerably less than 10 %, typically only 2 to 5% (ie. 1470 m/s to 1550 m/s). However, for much harder tills, depending on their water and large clast content, these can have velocities exceeding 1700 m/s. Much of the Quaternary section comprises tills, so a thickness report (in m) can be underestimated by 15%. Accordingly, the native millisecond measure is provided for user-corrections where better accuracy is necessary and the nature of the geological units is understood. The user is cautioned to have this awareness.

Perhaps the most intangible thickness accuracy measurement error source derives from uncertainties in seismic interpretation. This can be a subjective process and if judgments errors are created at this stage, obviously this will result in wrong thickness measurement records. The user must always remain cognizant of the nature and limitations of seismic reflection data and their interpretation. Corroborative data, such as long cores or boreholes, is very rare. If geologic relationships are clear and well imaged, reproducibility of horizon picks should be within a few percent. Where they are not clear this can be much higher. One common geological situation is on the Grand Bank plateau is where a thin till or sand and gravel unit overlies much older (Tertiary and Cretaceous, "bedrock") strata. The bedrock strata present good acoustic impedance contrast (function of density and velocity) while the bedrock surface does not. The reason for this is unclear but likely has to do with roughness on the bedrock surface and a low impedance contrast between the bedrock and directly overlying (dense) gravels. Rather than have the map present no records of thickness in such situations, a "maximum thickness" measurement is provided; the measurement is the shallowest that bedrock strata can be imaged.

7.0 Quaternary Sediment Isopachyte Map

An isopach of Quaternary sediment thickness zonations (polygons) was constructed for most of the Grand Banks area. It is based mainly on the spot thickness derived from the processes described above but strongly supplemented by a series of shaded relief bathymetric/topographic images. It provides the basis for extrapolation and interpolation of the seismic-derived (spot) thicknesses and a strong value-added component to the spot thicknesses alone. This is possible largely because of a strong correlation between sediment thickness and other parameters such as relief, roughness, topographic highs and flat-floored basins and the identification of moraines, drumlins and sediment terraces by morphology. Generally a sediment thickness contour is based on “control” from the seismic and “guidance” from these proxies. Actual contour placement and thicknesses without nearby seismic control are guestimates. The detail and accuracy of the thickness zonations varies across the map, of course, according to seismic data density and resolution of the shaded relief images. Accordingly, some areas (eg, Placentia Bay and a few isolated innermost shelf areas) depict more detail than others, often manifest as more convoluted contour (polygon) boundaries.

Some areas have thick Quaternary sediments but little or no associated seabed character; here the interpolation/extrapolation based on seabed relief images breaks down. This is especially the case for buried channels. Caution is suggested for the user in such areas.

The user should not assume that the highest quality or best quantification of the sediment has consistently been extracted from the all existing raw data. For example, while an attempt was made to compile at least a total Quaternary sediment thickness, supplementary raw data may exist that contains further details. This is particularly true of instances where air gun data were interpreted but accompanying sidescan or high resolution (boomer or sparker) profiles were not.

Isopach interval for the polygons was set at classes of 0 to 3, 3 to 10, 10 to 25, 25 to 50, 50 to 120, and greater than 120 metres. Resolution restrictions for thin sediments imaged only by air gun seismic governed the thinner classes and partly because the shaded relief images allowed a generalization of the thinnest interval based on seabed roughness.

The user is provided with some clues as to interpretation and presentation quality. Interpretation process and the primary raw data source are generally recorded. Examples include “shaded relief seabed image; low resolution; limited seismic control”, or “shaded relief seabed image: medium resolution in limited area offshore eastern Avalon Peninsula; King, 2013 (OF6450). Some seismic control”, or “multibeam image in Placentia Bay only; thickness inferred from morphology. Seismic, surficial mapping and low resolution seabed image elsewhere.” etc.

Another valuable user guide is a classification of the observed or inferred nature of the sediments. This is in a separate GIS attribute table field entitled “Dominant SedType”. It includes over 150 different rather generic characterizations (some very similar), capturing sediment type, the sequence of sediments, presence of inferred lags, or other aspects governing the sediment. Examples are “commonly till, generally sand or mud-covered”, or “generally thin till with glacmarine and post-glacial marine mud cover”, or “mainly gravel and cobble-capped till on bank areas; likely local sand patches”, etc.

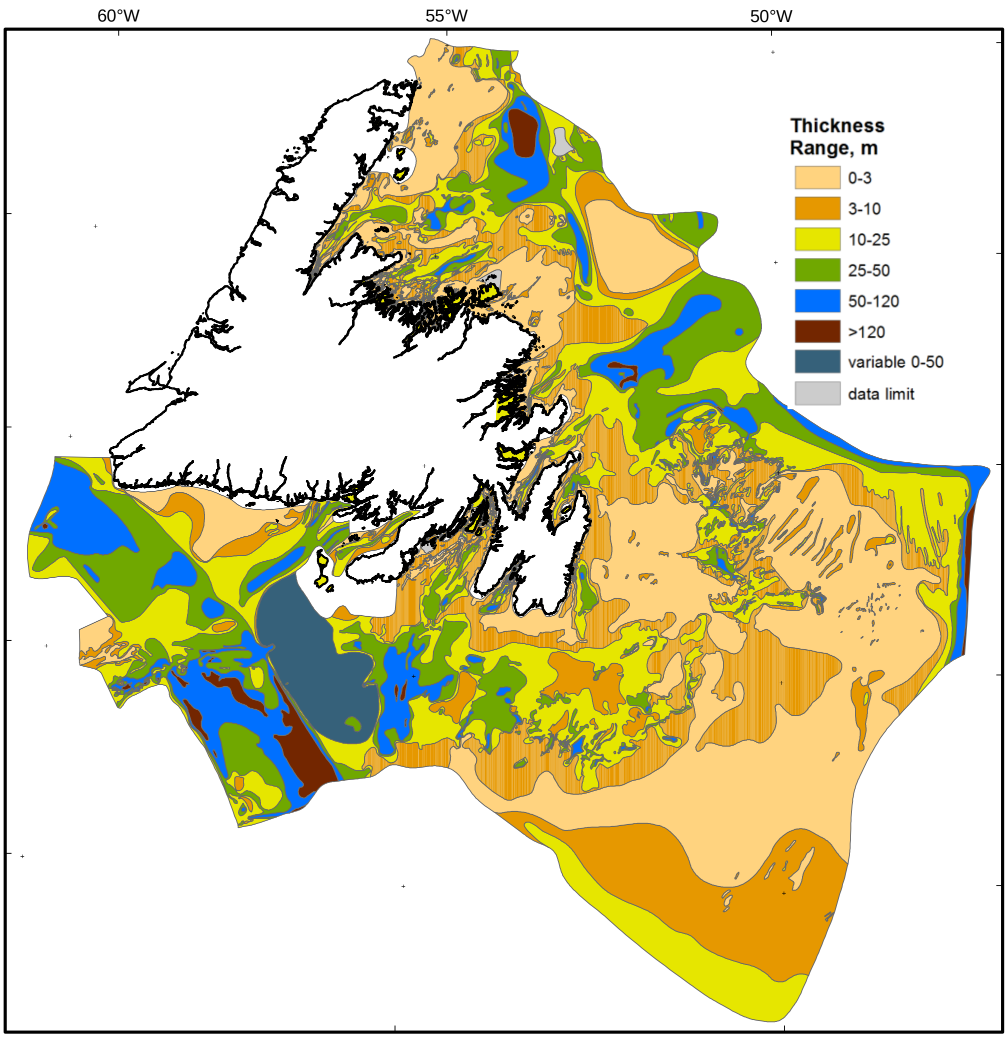

Figure 5. Overview of the Quaternary total sediment thickness distribution.

A brief discussion of geographic areas follows as a guide for characterizing some general provinces of sediment distribution. In addition, a field in the feature class broadly designates the observed or inferred geologic conditions for each polygon.

7.1 Sediment thickness distribution

Saint Anns Bank and Basin (Scotian Shelf) are included in this compilation because of recent surveys conducted for geohazard and benthic habitat and Marine Protected Area (MPA) designation. Geologic mapping from multibeam images in part of the MPA (King 2013b) allowed differentiation of bedrock and thin till provinces and the presence of surficial muds but very sparse sub-bottom profiler data was available. Hence, thickness estimates are crude. In the adjacent basin (the south) seismic coverage was adequate.

Laurentian Channel is the site of two proposed MPAs, the St Anns, noted above, and the eastern side of Laurentian Channel (the NL side). A comprehensive mapping of the Quaternary sequence in Laurentian Channel was conducted as this represents the thickest and most complete in a shelf area (King 2012). A total of 14 stacked tills have been identified, the most complete section partially infilling a large canyon at the mouth of the Channel (Fig. 6). Only one unit, between tills 1 and 3 comprises a significant thickness of stratified sediment, likely an erosional remnant of glacimarine mud. The upper 3 tills (12 to 14) likely record the latest glaciation.

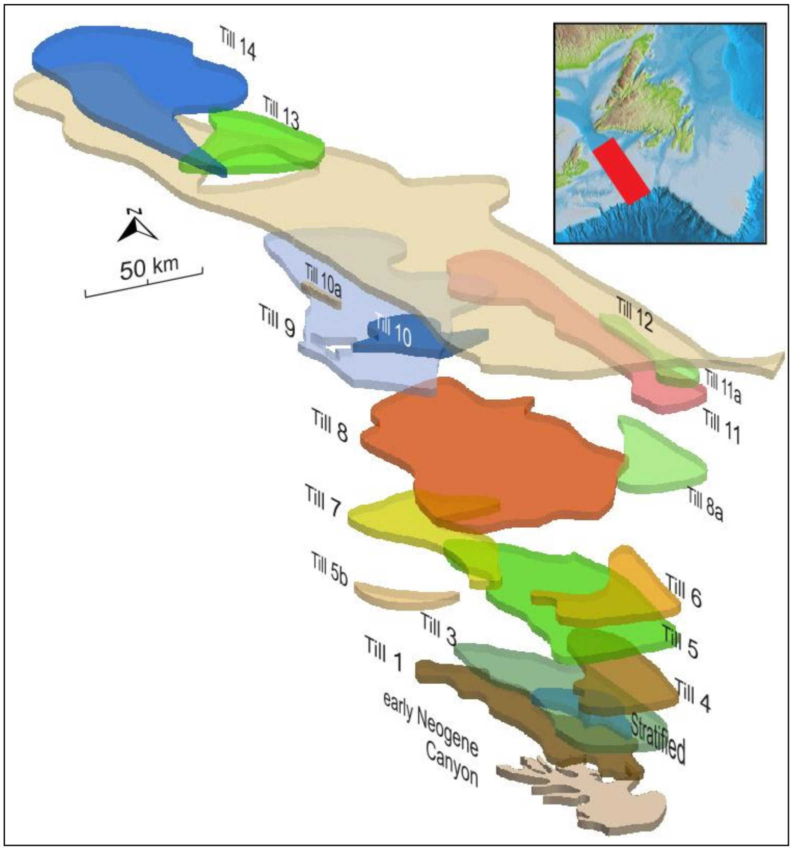

Figure 6. Stacked till sequence in Laurentian Channel. Modified from King 2012.

The banks south of Newfoundland have little seismic coverage so thicknesses are widely extrapolated. Burgeo Bank has thin cover and the glacial troughs have only one recognized till blanket with local glacimarine mud cover. Though several of the fjords have been surveyed, only one example has been compiled here. Fortune Bay and the inner reaches of Hermitage Channel have narrow, glacially streamlined channels emanating from the fjords, containing thick sediment. Aspects of the coastal and innermost shelf are addressed in Shaw (GSC Bulletin, in review). The area surrounding St. Pierre et Michelon and south of the Burin Peninsula likely have thin but variable cover but raw data coverage is too sparse to map. St Pierre Bank also presented a mapping challenge because of sparse coverage in relation to variability. The stacked sand sheets in the SE are captured roughly as are a few narrow channel-fills along its margin but abundant channels, mostly fully infilled, are present but their path and distribution is not recognized; the spot data provide some indication of spatial variability.

Placentia Bay has the only large area coverage of multibeam bathymetric data from which thickness classes could be inferred, much like on St Anns Bank. Thin cover over bedrock presents a rugosity and some bedrock elements on the image. A smooth glacimarine and locally post-glacial mud surface indicates thick sediments and drumlins and moraines have generally been assigned the 10 to 25 m thickness class based on their height and shape. Inter-drumlin areas might be considerably thinner and only the largest reach 20 m thickness. Some of the inner bays have terraced deposits reflecting tidal and paleo-coastal sands and muds, allowing an inferred thickness.

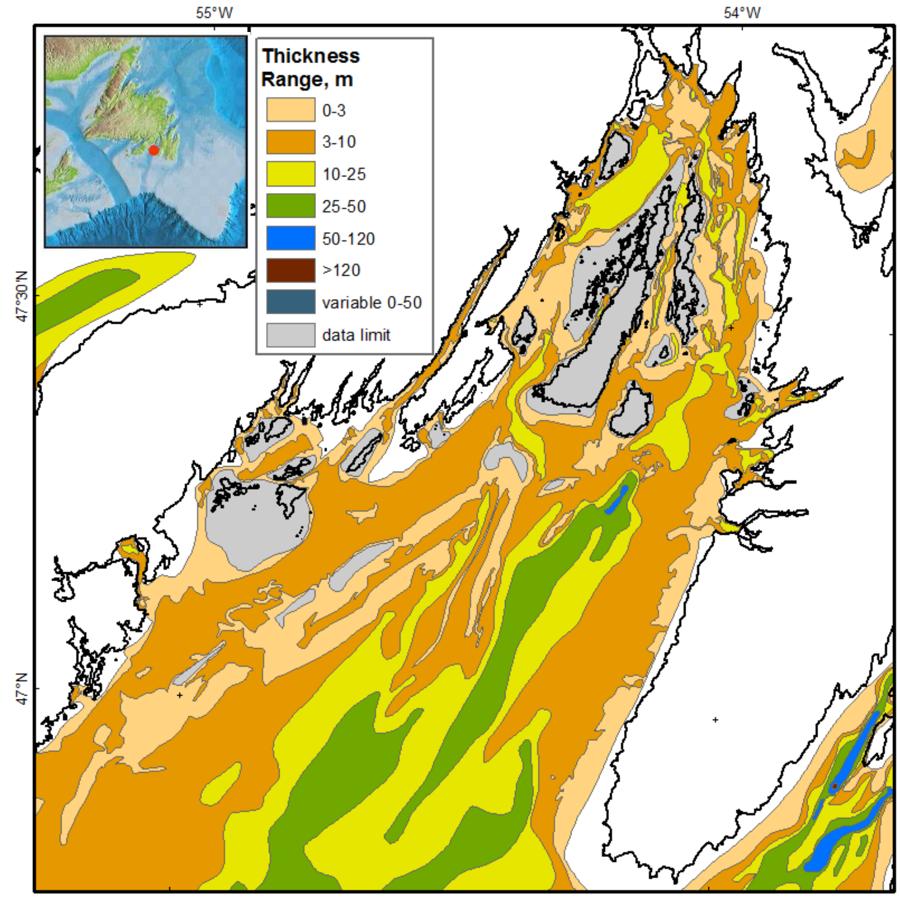

Figure 7. Multibeam bathymetric coverage in Placentia Bay enabled spatial details of sediment thickness distribution though thickness is largely inferred.

The bays of the Avalon Peninsula are generally overdeepened and the depocentre for glacial and post glacial muds. An area off the eastern Avalon (Ferryland and environs) was targeted for innermost shelf characterization (King 2013a and King and Mosthagimi, 2014) so details and limited seismic provide greater confidence and depict the range and variability of this setting (Fig 8).

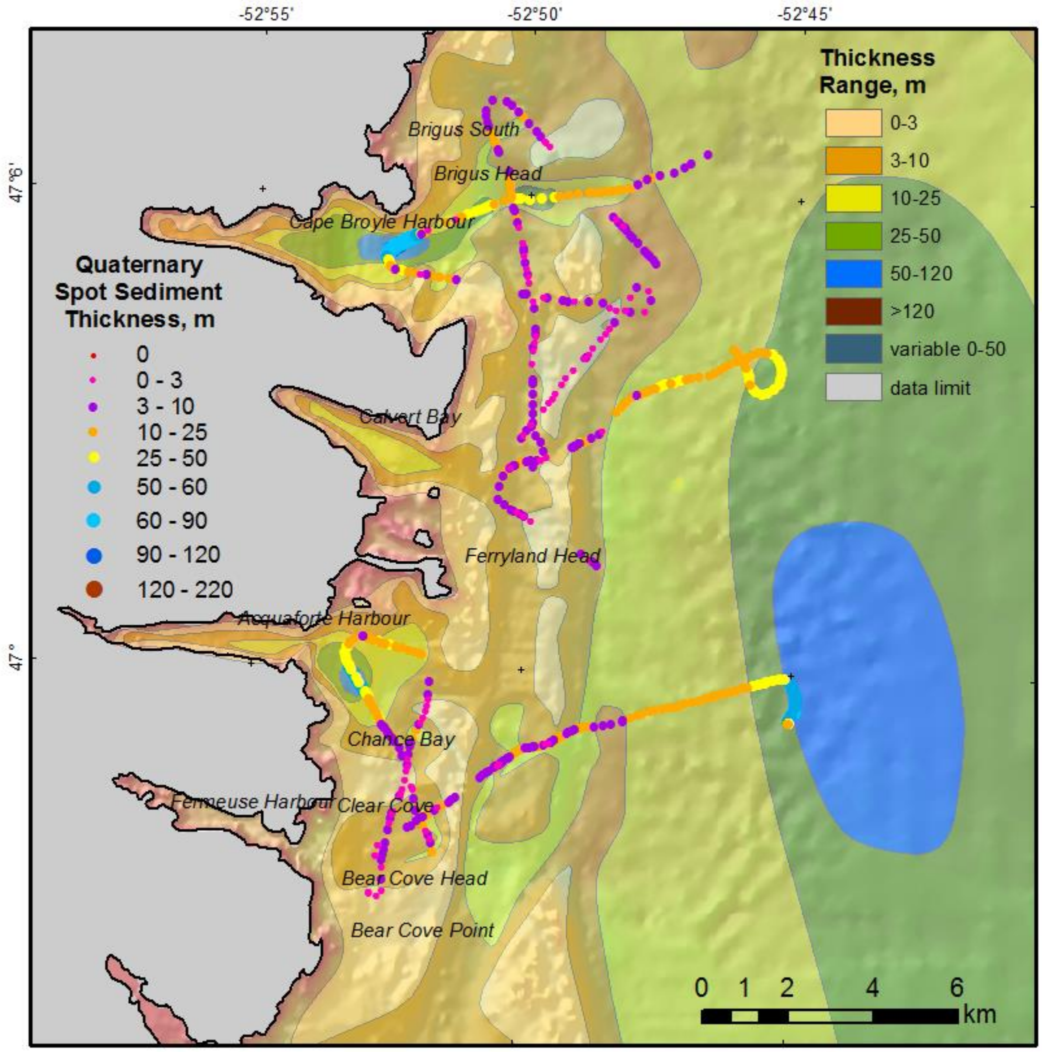

Figure 8. Details of sediment thickness distribution on the eastern central coast of the Avalon Peninsula.

Between Avalon Peninsula and the basins of mid Grand Bank is a broad platform of thin, gravel and cobble-covered till and occasional patches of overlying sand veneer. Thickness is generally between 1 and 5 metres and generally too variable to map with confidence. Some patches in the 3 to 10 m thickness class are shown but their extent and distribution is poorly constrained. True outcrops have not been recognized in this area.

Basins of mid-Grand Bank (Whale Deep, Downing Basin, and the basin complex north of Downing Basin) present another challenge to extrapolation of spot sediment thickness data because the glacially-excavated valleys have both seabed expression (partially filled) and no seabed expression (fully filled). There is generally too sparse seismic control to depict buried examples. Nevertheless an attempt has been made for these areas but it can be schematic locally so the user is cautioned. Figure 9 shows an example across the northernmost area, illustrating the challenge.

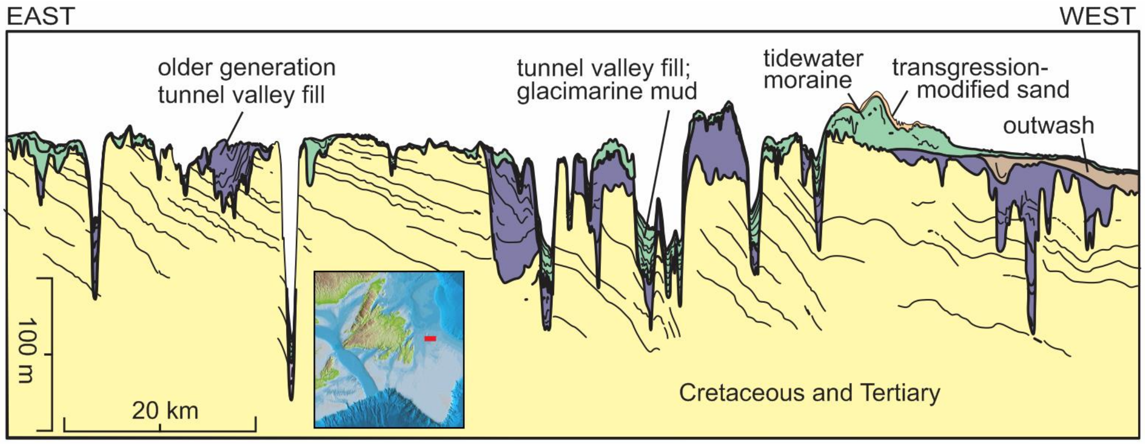

Figure 9. Multigenerational glacial tunnel valley and tidewater moraine excavated into semi-indurated bedrock strata. The buried valleys are a challenge to map.

One large but infilled valley lies at the easternmost limit of the meltwater excavation but survey control allowed some confidence in mapping the flanks (Fig. 10) even though actual thicknesses are estimates.

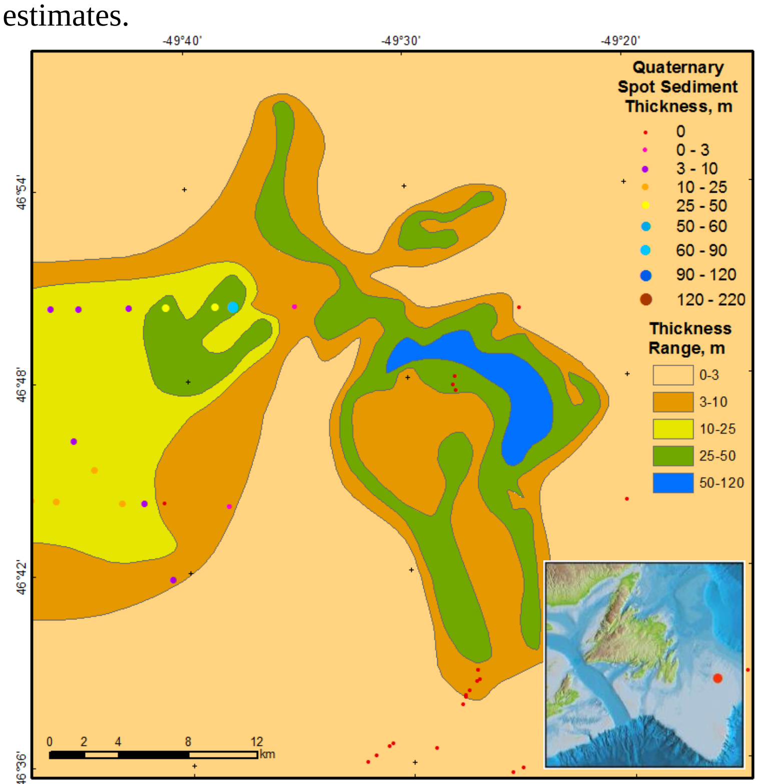

Figure 10. The easternmost tunnel valley is large and completely infilled. Thickness is an estimate but there is fair control on the trace of the flanks.

The Jeanne d'Arc Basin area is much like southern Grand Bank but survey coverage is much better, reflecting the hydrocarbon exploration and production activity there. Quaternary sediment cover is thin, generally under 5 m, and difficult to resolve by acoustic methods. It may contain patchy till, possibly channelized, thin sandy and gravelly glacial outwash which has been transgression-reworked, and continuous bodies of sand or gravelly sand in the form of broad and flat sand ridges. These are generally 1 to 4 m thick and relatively well resolved from the seismic, providing a high enough resolution sound source was used. The spot thicknesses compilation has a “maximum thickness” designation for some areas. This number simply records the shallowest sub-seabed recognition of Tertiary age strata. Below 100 m water depth in this area is a rather continuous thin muddy sand generated in the sub-littoral environment. Its base can be challenging to image on seismic but it rarely exceeds 2 or 3 metres thickness.

A series of broad erosional N-S trending valleys between about 120 and 180 m water depth NE of Downing Basin and the Hibernia hydrocarbon production sites generally have only a veneer of sand and gravel with the exception of a slightly thicker wedge of sand (up to a few metres), generally situated on the eastern flank of the interfluves (western flank of the valleys). It is probably related in origin to the large sand ridges, mainly relict deposits from the time of lower glacial and post-glacial sea-level.
A series of moraines extending from Sackville Spur to the Nose of the Bank (King and Sonnichsen 2000a, Fig. 3) registers as elongate fingers on the sediment thickness map though these hard till and gravel-cobble ridges are only a few metres high.

At the shelf break long much of the flank of Grand Bank is a slope-ward thicknening wedge. It is characterized by lack of stratification on seismic profiles, contrasting with a prograding wedge of sediment in the Neogene sediments below. This is considered the base of Quaternary sediment though there is almost no independent stratigraphic control on this “pick”. Its base is generally not well defined and there are occasional mass transport debrites or failure scarps imaged but much of the material is likely till. The base more likely corresponds to the onset of shelf-crossing glaciations than the chronological base of Quaternary. The wedge generally thins down-slope (not mapped) where Quaternary sediment bypassed through mass failures and canyons but contouritic drifts of Quaternary age are also recognized, likely the upper-slope continuation of those in the adjacent ocean basin (Jacobs, 1989).

The fjord-rich area of coastal northeast Newfoundland has relatively good coverage of medium resolution CHS spot depths so the shaded relief images were used to greatly enhance the maps. Figure 11 shows a typical example of the fjord area. Sediments are locally very thick, comprising mainly stratified muds. A single fjord system can contain multiple isolated or partially connected basins with intervening sills or thresholds. Most all fjord systems have an outermost sill.

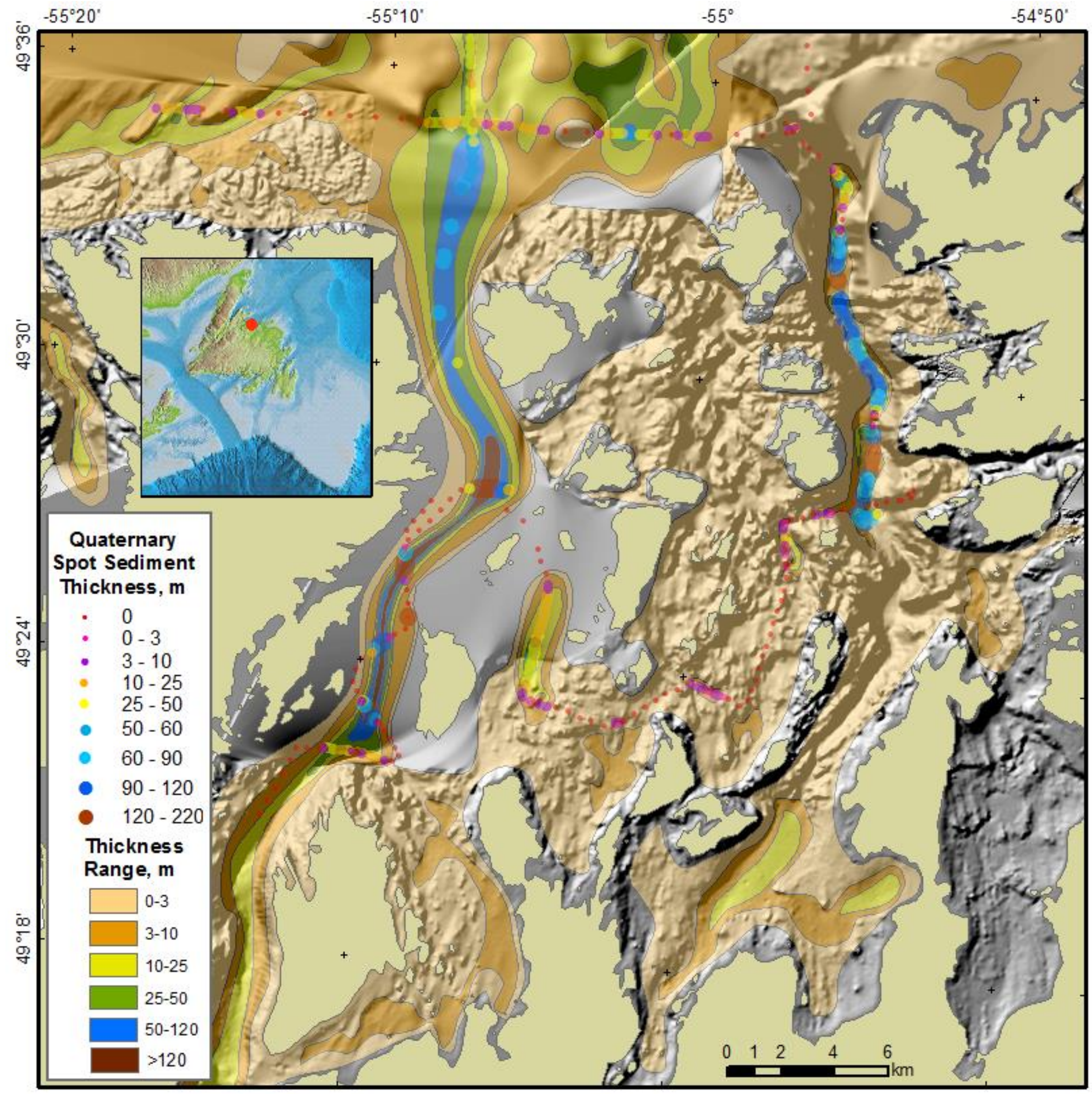

Figure 11. An example of fjords on the northern coast of NL (Bay of Exploits and Lewisport) showing multiple basins and thresholds. This also illustrates the technique of using the shaded relief image generated from CHS spot depths to delineate sediment basins and infer those with no seismic control.

The NE Newfoundland Shelf (Fig. 12)

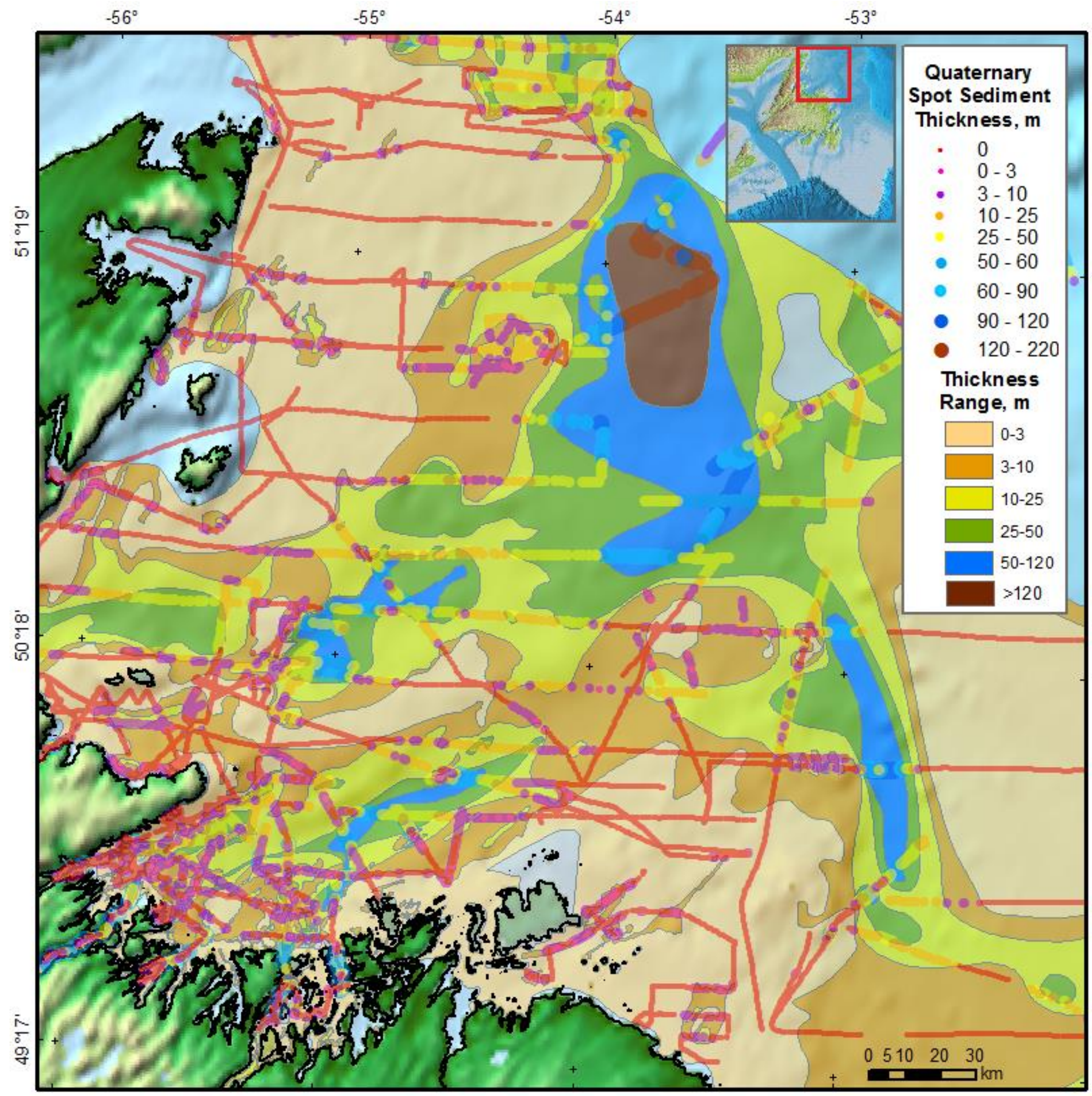

Figure 12. Quaternary sediment thickness classes and spot thicknesses on the NE NL shelf.

White Bay, adjacent the Great Northern Peninsula, has sediment thickness trends paralleling the fault-bounded ridges and troughs in Carboniferous bedrock (Fig. 13). Here also, the shaded relief images enabled enhanced extrapolation of seismic-based thickness measurements.

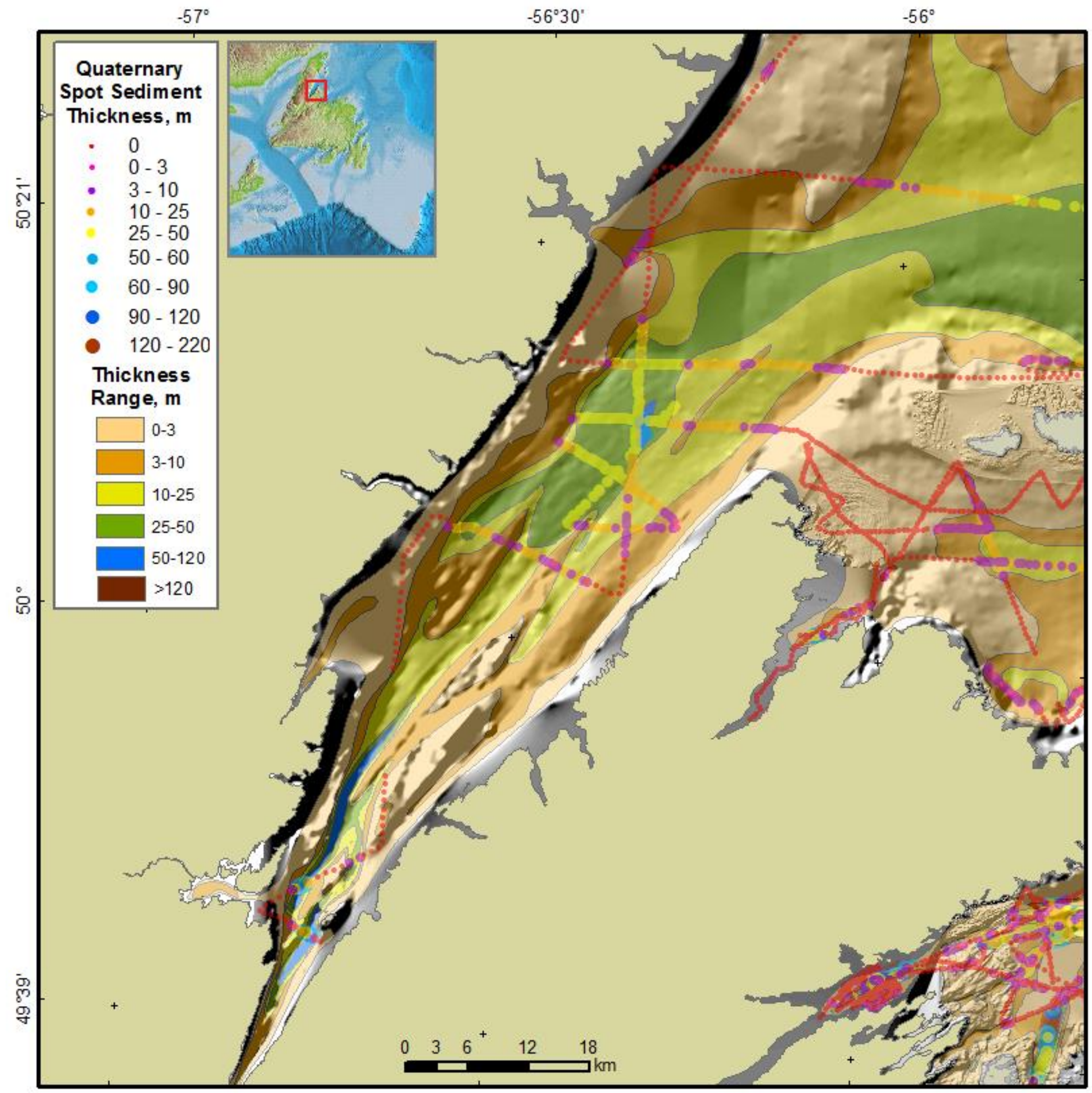

Figure 13. Sediment thickness in White Bay is largely governed by strong tectonic and glacial ridges and troughs paralleling the bay.

8.0 Sediment Thickness ESRI® ArcMap Project

An ArcMap project (versions 10.0 and 10.1, build 2800) is provided for users with this capability. It organizes various displays to guide the user in the variability and flexibility of the dataset. Figure 14 shows the abbreviated legend. Note that the illustrations in this report do not include the stratigraphic unit-by unit classification capabilities of the dataset.

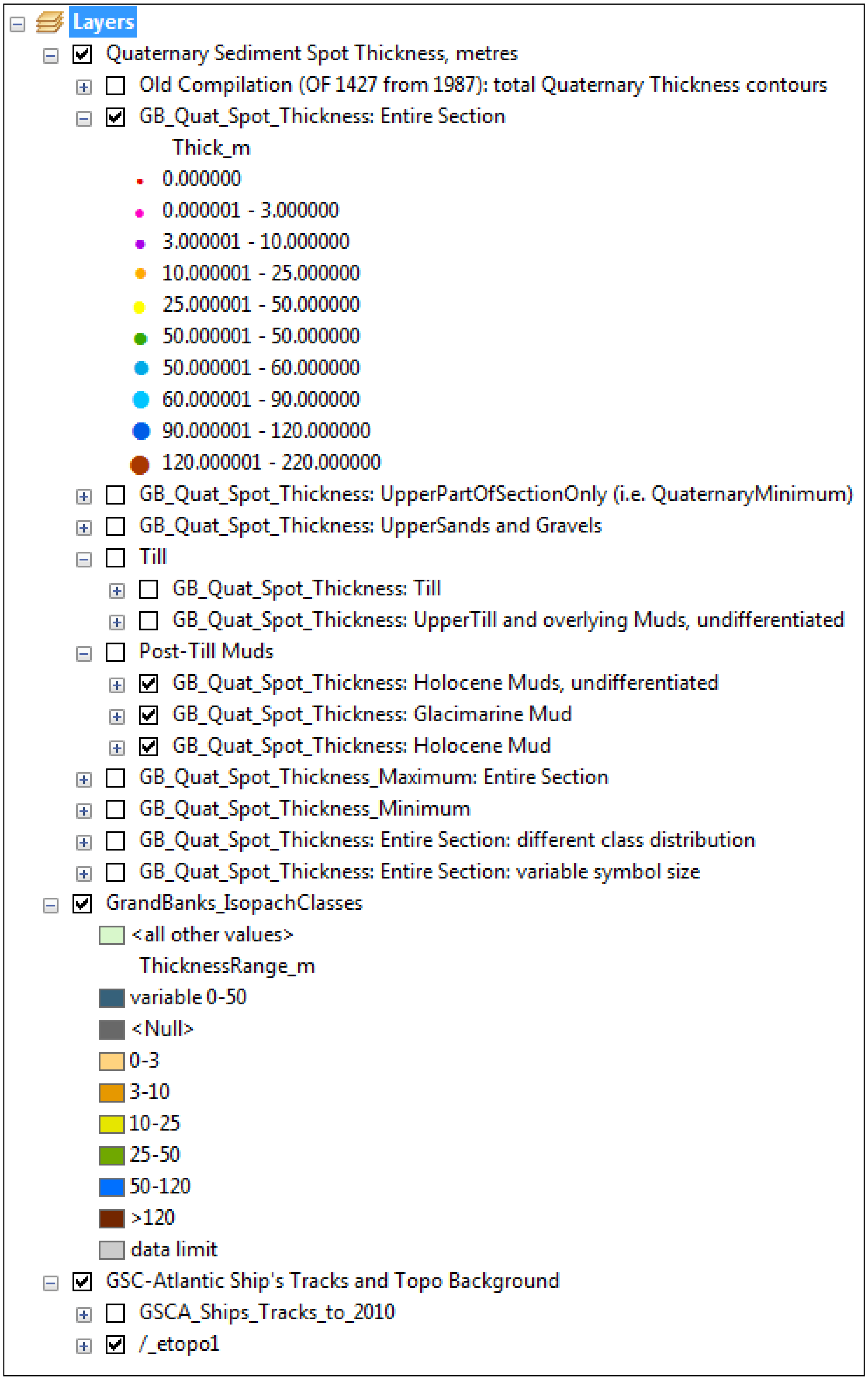

Figure 14. Legend of the Sediment Thickness ArcMap project.

9.0 Geotechnical Properties

The geotechnical properties of the sediments together with their distribution and thickness, their potential for mobility under current and wave stress, and a suite of various surficial and sub-seabed geo-features are factors critical to seabed infrastructure design and maintenance. This has been the subject of investigations and analysis across a broad range of geo-disciplines at GSC-A, some focused on Grand Bank. Though well beyond the scope of this report, an overview of some factors is provided in Table 1. The table is not comprehensive, largely because data and knowledge are still lacking. The aim is to provide some geotechnical sense and constraints to readers unfamiliar with the nature of the continental shelf sediments offshore SE Canada. Better appreciation of the sediment thickness measurements can be achieved in conjunction with these data and surficial geology maps. Stratigraphic Unit numeric designations (left columns) refer to units in Section 6.1.

Table 1: Sediment Geotechnical Property Summary

Sediment Unit*	Lithology with simplified vertical stratigraphic sequence differentiation	Geologic Setting	Distribution Nature	Nature of upper surface	Cone resistance (MPa)****	Geotechnical Parameters: Unit Weight (kN/m3)	Undrained Shear Strength (kPa)	Moisture Content (%)****	Plasticity Index (PI)****	Friction Ratio, Rf (%)****	Internal Friction Angle (deg.)	Perceived Engineering Factors	Typical Sediment Thickness Range	Comments on thickness	Sediment mobility**
2. Total Quaternary section / 7. post-glacial sand and gravel / sand; minor silt and gravel	fine silty sand with gravel and shells	*below paleo-low-stand****; Smooth-surfaced blanket deposit, sand dominated in some areas and gravel dominated in others, usually overlying glacial till. Reaches several meters thick, such as partially filling iceberg scours but locally thins to zero, yielding patchy distribution where gravelly underlying surface protrudes	discontinuous blanket	near planar; minor relief where iceberg scoured	5 - 10	16 - 20	20	ainly according to gravel cc		< 1		loose sediment; some sediment suspension and redistribution; low repose angles	0 to 3 m	sand mainly accumulated in local topographic lows (e.g. base of paleo iceberg scours); thins gradually toward greater water depths	rare, small bedforms; little mobility
2. Total Quaternary section / 7. post-glacial sand and gravel / sand dominant	medium to coarse sand and fine gravel and some shells, well sorted. Includes occasional superimposed fine gravel and shell patches	*above paleo-low-stand****; distribution largely a function of bedform distribution stemming from during period of lower sea-level; shoreface-connected sand ridges represent largest sand bodies; elsewhere thin and patchy with patchyness controlled by bedform type and degreee of development	continuous blanket in thick bedforms; patchyness is common where thin	near planar; minor relief where iceberg scoured; (less than 2 m) or large bedforms (less than 1 m), o rsmall bedforms (cm to 10s cm) or sand ridges (up to several m)	<15	18.0 - 21.0		15 - 20		< 1	36 - 42	loose sediment; some sediment suspension and redistribution; low repose angles	Generally 1 to 3 m thick, but can occur up to 10 m in sand ridges	sand thickness mainly a function of the height of moribund sand ridges; very thin in ridge troughs up to many m thick at ridge apex; only cms to 10s cm thick in sandwaves and ripples	rare, small bedforms recognized; little mobility
2. Total Quaternary section / 7. post-glacial sand and gravel / gravel dominant	gravel cobbles and boulders, minor sand; local erosional remnants of till	basal gravel lag from paleo-coastal working; well developed near *paleo-low-stand****	near-continuous blanket; commonly sand-covered	near planar; minor relief where iceberg scoured		20.0 - 22.5		20			38 - 45	boulders on upper surface and possibly embedded in cohesive matrix (till) below; unlikely that "hardground" (see unit 3) also occurs in this unit	1 to 2m	thickness of gravel lag unresolved; likely < 1 m but may be up to a few metres	n/a
2. Total Quaternary section / 4. uppermost Till and post-till muds / 6. Post-Till Muds / 8. post-glacial marine mud	Cohesive and soft silt and clay with minor sand. Rare Ice-Rafted Detritus (IRD) including gravel	Soft clay and silt ponded in basins Restricted to inner bays and deepest parts of Downing Basin, unmapped occurrences are also present in small mid-self basins. Smooth surfaces are Soft clay and silt ponded in basins; up to 15 m thick; restricted to inner bays and deepest parts of large and small shelf-situated basins; subtly conformable to onlapping internal stratification.	continuous blanket	generally smooth; occassionaly relict iceberg-scoured (not unit 9) or local thin sand with minor gravel		17.5 - 19.5	10 - 90; typically < 35	20 - 65				uppermost muds are soft; limited area of shallow gas in glacial sediments	1 to 10 m, locally thicker in fjords and fjord-like bays	generally continuous blanket, strong trend to thickening basinward	rare; possibly thin sand mobility layer at base of steepest slopes but this is likely relict
2. Total Quaternary section / 4. uppermost Till and post-till muds / 6. Post-Till Muds / 5. glacimarine mud	Cohesive, poorly sorted sandy, silty clay with rare IRD-derived gravel	Mud-dominated deposits; proximal and distal proglacial, rapidly deposited in quiescent (sub-glacial or sub-sea-ice). Poorly sorted, cohesive, relatively barren, sandy, clayey, silt, with minor gravel. Can be laminated or banded on local and regional scales. Conformably overlies basal unit. Generally confined to large and small basins and channels. Local unconformities in channel infill in shallow central shelf area	continuous blanket	Smooth, unscoured (by paleo icebergs) surface for proximal, stratified, draped muds; Occurrences above paleo- iceberg scour depth are turbated, some completely, and have iceberg scour pattern with surface relief of metres								numerous narrow glacial sediment-filled buried channels, both mapped and unrecognized represent a contrast with adjacent, non- channelized surroundings	1 to 10's of m	generally continuous blanket, strong trend to thickening basinward	rare; possibly thin sand mobility layer at base of steepest slopes but this is likely relict
2. Total Quaternary section / 4. uppermost Till and post-till muds / 3. Till / latest (uppermost) till	generally cohesive diamict (poorly sorted clay and silt with gravel cobble and boulders embedded in the matrix), boulders can be larger than 1 m diameter, more concentrated gravel, cobble and boulder content at upper surface; possibly gravel layers, especially where tills are stacked; local overlying sand veneer	Deposited beneath glacier. Occurs as blanket or ground moraine, terminal moraines and rarely as till tongues (wedges deposited at glacier terminus during glacial retreat). Generally thin (<15m) on outer and inner shelf; locally thick (>80m) in shelf-crossing troughs and some bank areas where stacked tills developed (mainly NE NL shelf area). Overlies bedrock in most areas.	continuous blanket, sheet or ridge	Glacial sculpting (depositional and erosional) creates regional ridges and troughs and channels with tens of m relief across many km. NE NL shelf area has examples of very high roughness due to glacitectonics. Local smaller scale roughness due to relict iceberg scour with several metres relief across 10's to 100's metres	6 - 20	18.0 - 20.0	typically less than 100; some tills < 25; can be over 500	16 - 45 typically 30 - 40	N/A; effective cohesion 25 to 35 kPa	3 - 8	35 - 43	spatially variable overburden thickness; Overburden is cohesive with boulders, mostly concentrated at seabed; extent of weakest tills is restricted; relict iceberg scours with cobble/boulder berms create relief of metres over horizontal spans of 10s to 100s m; no surficial sand mobility with exception of rare, small fields; numerous communications cables	highly variable (0 to 100s m); generally thickest in shelf-crossing troughs	locally reduced confidence identifying overburden thickness due to strong acoustic scattering with highest resolution seismic systems	little sand therefore little mobility; isolated small bedform fields
2. Total Quaternary section / 3. Till / older and basal tills					30-60	21.0 - 22.5	110 to 170 typical; 200 and > 500 locally	19-20			32 - 46	as above but high strength may also be a factor; "hardground" experienced in outer shelf areas- may be largely a digenetic "bedrock" phenomenon (de-watering, cementation?) but may also be an old (high strength) till phenomenon			

* generic and stratigraphic classification as in Section 6.1 of report

** Sediment mobility modeling suggests seabed stress sufficient to mobilize the sediment on a frequent basis (during most storms) in areas shallower than 100m. Similarity of textural details over multiple years suggests little uni-directional or long-distance flux.

***Paleo-low-stand of sea-level during the latest and post-glacial phase of low sea-level was situated at about 110 m in outer shelf, 75 m in inner shelf, 50 m in southern NL inner bays

****From Sonnichsen and King, 2002

Full resolution table available in Report Folder

10.0 Map Product Formats

This product contains maps and documents with associated metadata. The map is provided in several digital formats. The primary product is a vector-based Geographic Information Services (GIS) version available within ESRI Arc GIS® projects (versions 10 and 10.1). More generic data formats are provided with the aim to satisfy a wider range of users.

The GIS product is containerized as an ESRI® ArcMap version 10.1 geodatabase. This is presented through ArcMap project (.mxd) files. The feature classes in the database have also been extracted as shapefiles (and associated supporting files). These allow the user to more readily exchange and utilize the product in a variety of other GIS platforms. Figure 15 shows the contents of the various themes in the ESRI geodatabase.

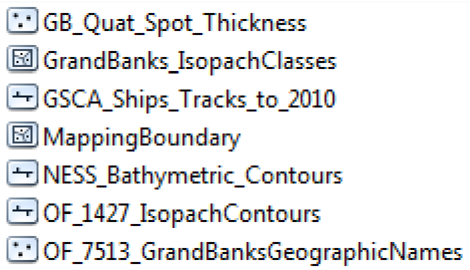

Figure 15. Contents of the geodatabase by theme (feature class).

One of the benefits of a GIS-based database is a relative independence of scale and flexibility in attribution display. Closely-spaced and overlapping features can, for example, be displayed symbolically, re-classified in broad or narrow ranges or specific to other recorded attached attributes. Some guidance as to the depth and breadth of data is provided in this compilation, through the illustrations. The associated ArcMap project file organizes the data to highlight and display various aspects of the data (eg. entire sediment section, till only, mud only etc.) mainly through customized filtering (definition queries). The advantages are many, including access to all attributes, customized display, and incorporation into other datasets. Web links to third-party low resolution bathymetric and topographic relief images are provided for geographic context.

The shortcoming of publishing ArcMap projects is a limited “shelf life” as GIS versions and concepts develop. The GSC is developing robust online portals including those for such spatially-enabled data in anticipation of future needs. The plan is that the dataset will reside in such a site. The critical link for discovery and future compatibility is in adequate metadata associated with the geological data. An attempt has been made to provide the user with sufficient key words, descriptions, purpose, data source, compilation processes, positional accuracy and similar metadata such that as discovery and display platforms evolve, the geodatabase can follow.

A map sheets is also supplied in Adobe® .pdf format. This assembles a title, legend, explanation, references and citation information in a much more traditional and readily readable format, comparable to a paper map. But beyond this, it also enables the user to view, zoom and pan as well as considerable freedom in access, customization and printing. Some viewing customization is available because most of the original GIS themes (layers) are preserved as independently viewable layers in the .pdf format. The level of scale and attribute density and detail presents a challenge to presentation in the Adobe pdf format and there is little of the interactivity, query functionality or metadata of the GIS product.

10.1 Data Discovery and Metadata

Full, ArcGIS Metadata format records included with each Feature class (and shapefile) define the product in terms of summary, descriptions, credits, citations, contacts, access and limitations, interpretation or other sources, compilation procedures (process steps), data explanations, data quality, data extent, etc. Most are compatible with a basic Federal Geographic Data Committee (FGDC) metadata standard but evolution of GSC metadata standards are evolving so formats are not fixed. ArcMap version 10 has a range in population procedures and format and here the “ARCGIS” metadata format is utilized with the expectation that this can be readily converted to new standards. XML format files are also provided for the shapefiles. Many of the procedures are also presented in this document, generally in greater detail, for the sake of the reader without GIS or computer access to these files. Abundant keywords are supplied for discovery purposes.

11.0 Acknowledgments

Some of the geodatabase population was conducted by undergraduate students as part of the joint Public Service Commission of Canada-University cooperative education “COOP” program. Jody Cooper (Saint Mary’s University) compiled parts of the Laurentian Channel using the dejitter software, Nader Mostaghimi (University of Waterloo) compiled a coastal area east of the Avalon Peninsula and Mathew Pitts (Acadia University) derived thicknesses from 1980s era hand-drawn and scale-reduced interpretations by L. H. King, both using early versions of the JP2000 software. Also, a significant contribution came from GSC-A contracted compilation of the Jeanne d’Arc Basin area by Helen Neilson following georeferencing of scanned seismic records.

12.0 References

Courtney, R, 2007. Storage and Dissemination of SEGY Data in JPEG2000 Format. American Geophysical Union, Fall Meeting abstract #IN51B-0402.

Fader, GB, King, L H. 1981. A Reconnaissance Study of the Surficial Geology of the Grand Banks of Newfoundland; In, Current Research Part A. Geological Survey of Canada, Paper, 81-01A, 45-56.

Fader, GBJ, and Miller, RO. 1986. A reconnaissance study of the surficial and shallow bedrock geology of the southeastern Grand Banks of Newfoundland." Current Research, Part B. Geological Survey of Canada Paper 591-604.

Geonautics Ltd. 1981a. Geological Zonation of the Northern Grand Banks of Newfoundland and Northeastern Newfoundland Shelf. Lambert Conformal. 1:250000. Unpublished compilation.

Geonautics Ltd. 1981b. Mobil Hibernia Development Studies 1981 Geotechnical Survey South of Avalon Peninsula. Report prepared by Geonautics Ltd. of St. John's NL and d'Appolonia Consulting Engineers Inc. of Houston for "Joint Venture" participants, including Mobil Oil Canada Ltd. Gulf Canada Resources, Inc. , Petro-Canada Exploration, Inc., Chevron Standard, Ltd. and Columbia Gas Development of Canada, Ltd.

Jacobs, CL. 1990. Deep-sea sedimentary processes off Newfoundland: an overview. Canadian Journal of Earth Sciences, 27, 426-441

King, EL. 2012. Mineral resource assessment of the shallowest bedrock and overburden, Laurentian Channel, Newfoundland: potential marine protected area. Geological Survey of Canada, Open File 6969, 27p, doi:10.4095/289847.

King, EL. 2013a. Geological conditions off the Avalon Peninsula, offshore easternmost Newfoundland: bedrock and glacial features, deglaciation pattern and chronology, mass failure and attributes and constraints to engineering; Geological Survey of Canada, Open File 7360 (revised): Poster, doi:10.4095/292593.

King, EL. 2013b. Seascapes of St. Anns Bank and adjoining area off Cape Breton, Nova Scotia. Geological Survey of Canada Open File 7114. doi:10.4095/294226

King, EL, Fader, GBJ and Sonnichsen, GV. 2001. Quaternary Geology of the Northeast Newfoundland Shelf: Contrasts in Late Wisconsinan glacial regimes, Geological Association of Canada (GAC/MAC) Annual Meeting, St. John's May 27-30.

King, E.L. and Mostaghimi, N., 2014. Quaternary geology offshore Avalon Peninsula, Newfoundland and Labrador; Seal Cove to Motion Bay; Geological Survey of Canada, Open File 6450, 4 sheets. doi:10.4095/294836

King, EL and Pitts, M. 2012. Shelf-based early and mid Pleistocene glacial records on the Grand Banks of Newfoundland. GAC-MAC, Abstract. May 2012. (ESS Cont.# 20110430)

King, EL and Sonnichsen, G. 2000a. New insights into glaciation and sea level fluctuation on northern Grand Bank. Current Research, 2000-D6, Geological Survey of Canada, 8p. doi:10.4095/211175

King, E.L. and Sonnichsen, G. 2000b. Characterization of near-surface seismostratigraphy and features of Northeastern Grand Bank: Sea-level fluctuations, glaciation and slope stability. Geological Survey of Canada Open File 3886. 1 CD-ROM. doi:10.4095/212607

King, EL, Tripsanas, EK. and Shaw, J. 2007. Possible late glacial catastrophic discharges related to ice streams: Evidence from a shelf-crossing trough on the Northeast Newfoundland shelf. Abstract. CANQUA June 7, 2007.

King, LH, and Fader, GBJ. 1986. Wisconsinan glaciation of the Atlantic continental shelf of southeast Canada. Bulletin 363. Geological Survey of Canada, 72p.

MacLean, B. 2004. Grand Banks of Newfoundland Direct Route Assessment. Prepared for C-Core and partners by Canadian Seabed Research Ltd., Porters Lake, N.S.

Piper, DJW and Brunt, RA. 2006. High-resolution seismic transects of the upper continental slope off southeastern Canada; Geological Survey of Canada, Open File 5310, 77p.

Piper, DJW, Deptuck, ME, Mosher, DC, Hughes-Clarke, JE, and Migeon, S. 2012. Erosional and depositional features of glacial meltwater discharges on the eastern Canadian continental margin. In: Application of the Principles of Seismic Geomorphology to Continental Slope and Base-of-slope Systems: Case Studies from Seafloor and Near-Seafloor Analogues. B. Prather, M. Deptuck, D. Mohrig, B. van Hoorn, and R. Wynn. Editors. SEPM Special Publication 99, 61-80.

Shaw, J, Piper, DJW, Fader, GBJ, King, EL, Todd, BJ, Bell, T, Batterson, MJ and Liverman, DGE. 2006. A conceptual model of the deglaciation of Atlantic Canada; Quaternary Science Reviews 25, 17-18, 2059-2081.

Shaw, J, Piper, DJW, Skulski, T, Lamplugh, M, Craft, A and Roy, A. 2012. New evidence for widespread mass transport on the Northeast Newfoundland Shelf revealed by Olex single-beam echo sounding. Geo-Marine Letters, 32, 1, 5-15.

Shaw, J, Potter, DP (in review). Surficial geology of Newfoundland coastal waters. Geological Survey of Canada Bulletin xxx.

Sonnichsen, GV and King, EL. 2005. Grand Bank seabed and shallow sub-bottom geology in relation to subsea engineering design. In: R. Hiscott and A.Pullham A. (Editors). Petroleum Resources and Reservoirs of the Grand Banks, Eastern Canadian Margin. Geological Association of Canada Special Paper 43. 11-27 (GSC Cont.# 2002018).

Staal, P and Fader, GBJ with King, EL, Nadeau, O, Maass, O, and King, LH, compilers. 1987. Sediment Thickness Study of the eastern Canadian Continental Shelf. Geological Survey of Canada, Open File 1427, 47p. doi:10.4095/130265

Tripsanas, E K, and Piper, DJW. 2008. Glaciogenic debris-flow deposits of Orphan Basin, offshore eastern Canada: Sedimentological and rheological properties, origin, and relationship to meltwater discharge. Journal of Sedimentary Research, 78, 724-744.

Background Map:
The land and ocean topographic image for the background and index map is an Esri (Environmental Systems Research Institute, Inc.) product, used under license and following their terms of usage. It is linked directly to their source in the ArcMap project. (http://services.arcgisonline.com/ArcGIS/services/Ocean_Basemap)
 The metadata describe the sources and limitations.

Appendix I. Coding of sediment thickness interpretation source

27	Geonautics Ltd. 1981. Seabed Features	Geonautics Ltd. 1981 unpublished compilation. Geological Zonation of the Northern Grand Banks of Newfoundland and Northeastern Newfoundland Shelf. Lambert Conformal. 1:250000. *Largely compiled and written by E.L. King. Final report likely does not exist as the firm went into insolvency during final report phase.*
28	Geonautics/Mobil 1981. Pipeline survey South Avalon	Mobil Hibernia Development Studies 1981 Geotechnical Survey South of Avalon Peninsula. Report prepared by Geonautics Ltd. of St. John's NL and d'Appolonia Consulting Engineers Inc. of Houston for "Joint Venture" participants, including Mobil Oil Canada Ltd. , Gulf Canada Resources, Inc. , Petro-Canada Exploration, Inc., Chevron Standard, Ltd. and Columbia Gas Development of Canada, Ltd.. *Five chapters plus figures and Appendices.* *Database values derived from Fig. 22, an Overburden map; along-track classification. Interpretation based on Huntec Deep Towed System boomer seismic. Survey from M/V Fogo Isle, 12 Sept to 14 Oct. Survey Included Huntec DTS, sidescan, echosounder, 5 kJ sparker, magnetometer, brab sampler, camera, vibrocorer and corer.; ARGO nav. 964 line km survey. Report included information on surficial geology type, stratigraphy and thickness, iceberg scour depth and frequency, bathymetry and seabed roughness, and potential geohazards.*
55	GSC-A Contract to Helen Neilson, 2010	**Includes a large portion of the thickness measurements in this (2013) compilation.** *Surficial Sand Thickness, Jeanne d'Arc Basin, Grand Banks. Contract between GSC-A (E. King) and H. Neilson, Summer 2010, for georeferencing and interpretation of high resolution reflection seismic in the Jeanne' d'Arc basin map area (Grand Banks) for purposes of characterizing surficial sand thickness. Neilson performed seismic horizon picks in JP2 Viewer. E. King performed quality control on most of the interpretations, exported the features to shapefile and compiled and normalized the dataset for the database.*
58	Geofeatures; King 2013	**Includes the majority of thickness measurements in this (2013) compilation.** *E. King, interpretation of horizons and geo-features from 2006 to 2011 Expeditions, (2006048, 2007016, 2007020, 2009036, 2009044, 2010020), winter 2012-2013, using JP2000 tools. Also included were the cruises for which there existed SEGYJP2000 seismic records converted from scans, including but not restricted to 72009, 73006, 77011, 78012, 87016, 90031, 91026. Also included were a limited number of compilations from industry data. Horizon data were used for sediment thickness postings. Includes total Quaternary overburden thickness for most areas and for some areas a sub-classification of individual stratigraphic units making up all or part of the overburden.*
59	Sediment thickness; King 2013	Edward (Ned) King: Compilation of Quaternary thicknesses directly from interpreted horizons in SEGYJP2000 geophysical records via the JP2000 Viewer. *Towards this product. Includes total Quaternary overburden thickness for most areas and for some areas a sub-classification of individual stratigraphic units making up all or part of the overburden.*
60	C-CORE and Brian MacLean, 2004	MacLean, B. 2004. Grand Banks of Newfoundland Direct Route Assessment. Prepared for C-Core and partners by Canadian Seabed Research Ltd., Porters Lake, N.S. *An excel spreadsheet incorporated into GIS with some modification/normalization for compatibility purposes.*
65	OF 6450	**Includes a significant portion of the thickness measurements in this (2013) compilation.** King, E.L. and Mostaghimi, N. 2013. Quaternary Geology offshore

		Avalon Peninsula, Newfoundland; Seal Cove to Motion Bay. Map and poster. *Most thickness measurements originally derived by Nader Mostaghimi, U. Waterloo COOP term, 2009 and exported from JP2 format to shapefiles and then formatted for database by E. King.*
66	GSCA COOP term; Jody Cooper, 2007	*Compilation of Quaternary stratigraphic horizons for GSC-A cruises 2006048 and 2007016 in the Laurentian Channel, Grand Banks of Newfoundland. Using GSC-A developed software "DeJitter", a SEGY viewer for seabed auto-pick and user-defined stratigraphic horizon picks; this use of the software since outdated by the JP2 Viewer.*
81	OF 1427: Contract report by Huntec 70 Ltd.	**Includes a significant portion of the thickness measurements in this (2013) compilation.** Staal, P. & Fader, G.B.J. 1987. King, E.L., Nadeau, O. Maass, O., King, L.H., compilers. Sediment Thickness Study of the eastern Canadian Continental Shelf; Geological Survey of Canada, Open File 1427, 47 p, 11 maps. doi:10.4095/130265. *This was an early regional compilation of this sort, duplicated later in more localized regions, by different techniques and map scales, with different formats and goals. New data coverage and differences in interpretation locally lead to conflicting reported sediment thicknesses. Nevertheless, this was a comprehensive compilation worthy of perpetuating. Data are in spot thicknesses and locally contour maps, the latter clearly more subjective. Some conflicts with later compilations are more apparent than real (ie. different thickness classes, different scales of presentation) and the user must be discriminatory.* *King made minor but more recent GIS modifications (smoothing, generalization, line closures and some contour additions and modifications.*
82	OF D3886	King, E.L. and Sonnichsen, G. 2000b. Characterization of near-surface seismostratigraphy and features of Northeastern Grand Bank: Sea-level fluctuations, glaciation and slope stability. Geological Survey of Canada Open File 3886. 1 CD-ROM *Contains files with various Cenozoic horizon elevations and thicknesses; Quaternary units extracted.*
90	GSC-Expedition Database (ED): Ship's Navigation	*Excerpts of ship's tracks with survey day and time stamps and instrument type derived from online database; accessible via NRCan portal(s). Metadata on most marine data holdings at GSC are accessible via this database and most are ties to positional data via a julian day and time stamp.*

Appendix II: Processes for compiling spot sediment thickness measurements from existing maps and for extracting from seismic reflection profiles.

Process code 2; From an existing map:
Sediment thickness records created by digitization of values in the ArcMap GIS environment from a georeferenced location map derived from a scientific paper.

Process code 3; From existing maps:
Those values with a process source code of "3" (source code of "81") stem from an early paper-based compilation comprising numerous 1:300 000 scale maps. The OF 1427 report outlines the procedures, map symbol formats and limitations of the interpretations. The conversion from paper to GIS involved several processes, some of which were not well documented. See "Code 3 Process steps" (below) which briefly outlines the main procedures.

Ten 1:300 000 scale paper maps (Transverse Mercator projection), in all (including coverage across the Scotian Shelf but not included here) contained periodic spot thickness postings along survey tracks from seismic data collected between 1969 and 1985, primarily-GSC collected. Thickness measurements are typeset characters. Those with a "-" prefix denoted a maximum thickness measurement, those with a"+" , a minimum, and those with an arrowhead denoted isolated values, not typical of the surrounding area (e.g. channel fill or moraine). The maps also have contours of thickness in some areas (mainly basins). Solid and dashed lines on the paper maps represented good quality and high confidence interpretation while dashed lines represented assumed isopach trends using geology maps, geological trends, and contoured bathymetric maps as guides.

A recovery of the values along with their spatial reference was desired as reconstruction of the analysis from original records at the time was an unfeasible effort. These maps were scanned at 300 dpi. They were digitized through a DSS contract to Scan Conversions Inc., a British Columbia based firm. They performed a four point "georeferencing" in AutoCad . It is doubtful if any projection information was preserved or if "rubbersheeting" was conducted despite the paper maps having associated TIFF world files. The contractor then performed OCR (Optical Character Recognition) to arrive at spatially enabled digital thickness values. The contractor was also supplied with shapefiles of the geophysical track navigation (points, at one minute survey intervals, from the GSC Expedition Database, ED) with the aim to attribute the shapefile records with the nearest OCR-generated character (this reproduces digitally the link between map placement and thickness value). The OCR was very reliable, likely given the good quality typesetting and possibly reliable quality control (QC). The assignment of the OCR points to the ED=derived navigation points was sub-contracted and documentation did not follow. A buffering and attribute assignment technique followed by adequate QC is assumed. The next process step is uncertain; either the product was supplied as a CAD product and imported into GIS or it was a shapefile-compatible format. There is some recollection of the requirement for some rescaling and adjustment to fit to the original shapefile points but this is uncertain.

Likewise, the linework was auto-recognized, assigned a layer code as to its dashed versus solid character, and a CAD product was generated. This was imported as a .dwg or .dxf format. Commonly, such an operation requires some rescaling, originating from the fact that default base units in AutoCad is usually inches. This was followed by a reformatting of line type, confidence and thickness label field values and text, and an assignment of process, positional accuracy and source field population numeric codes. These correlate to explanations both in the accompanying OF 7513 report and quality reports in this metadata record.

Process code 5; derived from original CAD:
The CAD (Computer Aided Drafting) drawing was derived from digitization of existing hand-drafted (paper-based) maps as existing GSC Open Files.

Process code 6; From hand-drawn Seismic Traces on Velum:
Those values with a process code of "6" (source code of "82") stem from a complex process of scanning of hand drawn line (horizon) interpretations of seismic data and manipultation in CAD and spreadheets before incorporation into GIS. See "Code 6 Process steps" (below) which briefly outlines the main procedures.

Hand drawn tracings of the interpreted base of Quaternary (and most other seismic reflectors) were performed on individual (17 inch long) sheets of velum overlaid on a paper seismic role. These were half-size continuous paper copies of original ship-board graphic seismic printer outputs. The tracings incorporated, in addition to all reflectors of note, depth registrations (every 100 or 250 ms) and time-based fiducial marks with corresponding day/time annotations (generally every 5 minutes). These are necessary for subsequent depth and geographic positional scaling in the CAD program.

These were reduced on a photocopier, scanned on a piecemeal basis, vectorized, and then re-assembled (aligned and scaled for differing aspect ratio) in a batch technique in a CAD package (Computer Aided Drafting; vector-based Cartesian coordinate system). In the 2-dimensional CAD software the along track axis of a geologic profile corresponds to the X-axis while the Y-axis displays depths (in travel time). A datum for the traced horizon was established (sea level set at "0" Y-value).

The geologic profile was then registered to navigation by performing integral lateral scale adjustments to fit time-based position references (the fiducials noted above) on the profiles to distance-based true geographic position. For N-S oriented survey lines, the profiles were oriented such that Y-values correspond to along-track distances and X- values, to the horizon depths. The scanned and vectorized tracings were scaled (still in CAD) such that the X axis corresponded directly to the true UTM map Eastings for E-W oriented seismic traverses. Similarly the Y axis corresponded to true UTM Northings for N-S oriented traverses (i.e. not true map scale). That is, the horizontal scale of the geologic profile corresponded to only the eastern *component* for E-W oriented seismic lines (northern component for N-S lines). Thus, for E-W or N-S oriented lines the profiles are presented at true horizontal scale but deviations from this projected as shorter profiles. This process was undertaken in order to preserve one component of the map coordinates for purposes of later export of the data to a spreadsheet.

The "lost" or "omitted" Northings or Eastings component derived in CAD was then "recovered" in the spreadsheet. This is accomplished by calculating the linear equations for straight line sections of the entire ship's track (Y=mx+b) from the CAD-based track plot. In practice, the entire cruise track was subdivided into numerous straight line approximations of the track and the slope and y intercepts found. These equations were then solved for "Y" in the spreadsheet with the true UTM Eastings (or Northing) values. The actual ships track usually deviates between 0 and 20 m from these straight line segments but could be as much as 50-60 m locally. Thus, the UTM position for any given depth or thickness value used in map production could have a Northing (or Easting) error within this range. This is considered meaningless in relation to the errors associated with seismic picks on these generally flat-lying horizons.

The seabed and the base of Quaternary horizons were then correlated throughout the profile data set (assigned specific colours and layer). Such a profile maintains all the detail of the original hand tracings. Depths of key horizons are then exported as a text file and imported into a spreadsheet and further manipulated to calculate true depths (elevation below sea-level) and thicknesses (in time units) for equally spaced geographic positions.

The original Open File product took this format but incorporation into GIS involved an import from the spreadsheet (UTM coordinates). These were re-projected to geographic coordinates (WGS-84). This process lost the correlation between survey Julian day and time (at the CAD geo-profile stage) and this was not recovered in this compilation.

Process code 8; From Scanned Seismic converted to SEGY and JP2000 Formats:
This process was developed for most sediment thickness compilation after November 2012. Starting with a georeferencing of scanned geophysical records, geo-horizons were interpreted in the SEGY JP2000 Viewer software, shapefiles exported followed by further manipulation in ArcMap. This involved the following basic steps using the GSC-A "Courtney" software tools:

1. Scan the record and create a Jpeg2000 file (a non-SEGY JP2). These were already available for all Newfoundland-based compilations after April 2013.
2. Register the scanned JP2 file using RegJP2000 and convert to SegY file.
3. Convert SegY file to "Courtney" style (SEGY-JP2) file using the Segy JP2 tool.
4. Add navigation by using the GSC-A "ED Offline" software, also known as "MergeNav".

This created an interpretation-ready seismic record. The next steps were to:

5. Add interpretation (ie. pick seabed and base of geologic units) using the SegyJp2Viewer.
6. Export shapefile (point, picks only format) from JP2 Viewer
7. Import shapefile into ArcMap, add and populate ancillary fields.
8. Import into the sediment thickness geodatabase
9. Manipulation of shapefile exports through filtering and merging and formatting to comply with the geodatabase structure and populated fields.

Step 2, above, is a fairly involved process so the process are further documented here. This is not a comprehensive recipe for registering scanned records but it provides the user of the data with an appreciation of the process (and thus some inherent and possible error sources).

A) Copy required seismic scans (JP2) files from the GSC archive server to a more local drive and ensure its properties are changed from "read-only" to "archive" status. Then open a JP2 scan in the "RegJP2000" application: Three input windows will open:
a) The Expedition Window requires population of the expedition (cruise) number and survey year. This window can then be hidden.
b) The main Register JP2000 window, shows an image of the selected scanned record. It has pan and zoom capabilities. This is where scaling and georeferencing (registering) attributes will be assigned to the scan.
c) The Zoom window provides and interactive zoom of the main window view.

B). Registration of the seismic record begins with assigning a horizontal datum (the sea-level or a shot time delayed equivalent) and a similar horizon at the base of the record. Both need assignment of two-way time values (TWT, in milliseconds). This is accomplished via the "Define Horizontal Registration Lines" selection in a drop-down menu on the "Register" tab. This opens a value in a "Horizontal Registration lines" window. A trace of a selected horizontal "travel-time" line is then traced and assigned the correct TWT. It can be duplicated, moved to align with a different “travel-time” line selection at the base of the scan, and similarly assigned a two-way travel time. Some detective work may be necessary to arrive at correct values, depending on original record annotation.

C). Registration of the vertical lines (fiducial or fix marks, generally assigned a Julian day/time value or a fix number on the original paper record) is performed at a spacing/number appropriate to deemed navigation accuracy. Eventually, each vertical registration line will be assigned a navigational coordinate and positions between successive lines will be interpolated. Thus the compiler should be cognizant of significant changes in ship speed, gaps in the record, etc.

D). Upon completion of selected vertical registrations and saving of the registered seismic image file, it is then converted to SEGY format. This is accomplished via the “To SEGY” tab. An opportunity to verify the metadata and edit TWT if needed. Both horizontal and vertical resolution options are presented.

E). Upon successful conversion to SEGY format, the file is ready for further conversion to a SEGY-derived JP2 format. This is a “smart” image (essentially non-lossy) which can be further attributed with interactively tagged horizon (polyline) and marker (point) entities (according to the user’s geological interpretation needs) in the JP2Viewer application. These data are embedded in the JP2 image, preserving the geo-interpretations. Some user-defined frequency filtering (hi and lo cut), wave mode and dynamic range capabilities are available in the SEGY to SGYJp2 converting application. Generally this is not performed for SEGY files originating from scans as the paper records were presumably optimized and further processing is limited.

F). Navigation is then embedded in the SEGY-JP2 file using the “MergeNav” or “ED Offline” application. For GSC-collected data, this is a very seamless operation as the application recognizes and correlates daytimes to navigation coordinates (generally geographic coordinates) but external navigation files, when properly formatted, can be also merged with the image. An opportunity for a single layback value (distance between seismic receiver and ships navigation antenna, in m) is offered.

Process code 9; From SEGY Seismic converted to JP2000 Format:
This is the same as for Code 8 but rather than begin with the seismic georeferencing process, a seismic record acquired directly in SEGY format was used to generate the JP2000 for further interpretation in the SEGY-JP2 Viewer (ie. Steps A through F in Process 8 are not conducted).

Process code 10; From batch SEGY Seismic in “De-Jitter” application:
Horizons or features picked in a digital version of the SEGY geophysical record using the GSC-A developed viewer “Dejitter” (Peter Pledge, GSC-A). This is a SEGY seismic viewer designed to enable heave (wave-induced) removal as a pre-processing step. Further development enabled simple horizon picking and text-based export. This procedure was utilized only for a short duration until the SEGYJP2000 viewer was developed (Bob Courtney (GSC-A). Main procedural steps included:

1. autopick or semi-manual pick of seabed.
2. “pick” colour-coded horizons,
3. export to .txt,

4. Merge text files in ArcMap, filtered (definition query) to specific horizons. This involves a transposition of rows/records of identical horizon definitions containing depth below datum (generally sea- level) to corresponding fields (columns) in order to then perform arithmetic across horizons.
5. calculate depth below seabed pick (in milliseconds), (i. assign a unique ID to every record, usually cruise number, julian day and time and shot number concatenated, ii filtered according to stratigraphic horizon unit or type, iii. Subtract horizon depth from seabed to obtain thickness in milliseconds)
6. Convert to metres.
7. Purge at an appropriate rate (because every shot has been assigned a value); typically this is at least a dissemination to every 5th or 10th shot but can be more.

A more complete documentation of the process follows:

Processing involved horizon picking limited to one hour survey duration files. The seabed was filtered to remove wave-induced heave (dejitter). The horizon picks were then performed, subdividing a large range of sub-units (not limited to those reported in this document). The different sub-units were assigned fixed colour designations at this stage which could then be exported as ascii x,y,z values for every seismic shot. Output included the following column headings:
Layer(geo-horizon), Shot, DateTime(Julian Day and time with semicolons), Latitude, Longitude, and Depth (time in ms)

File format was such that one horizon's entire listings were output in a contiguous listing followed sequentially by the other horizons values. Hourly file values were manually merged (copy and paste) in a text editor, one for each survey day, prior to importation into ArcMap. Obtaining unit thickness required subtraction of one value from the other (eg. bedrock surface from seabed to obtain total Quaternary section) at the identical x,y position. This required a reorganization of the tabulated listings such that elevation values for all of the sub-units were presented in a single row (eg. the column headings above followed by a separate column for each of 15 different geo-horizons). The factor common to each horizon's position is the shotpoint number, which is unique for the entire cruise. A further ID, to differentiate the different cruises was generated, containing Cruise, Julian Day, and shot number. A complicating factor was that with outputs for every shotpoint, and multiple horizons and multiple survey days and cruises the listings soon reached unmanageable sizes once merged in this way (nearly 2 million points and therefore slow ArcMap presentations). This required a decimation of points to every tenth shot. A shapefile was generated for each survey day of each cruise. On a cruise, by cruise basis, these shapefiles were filtered (definition query) to display only one geo-horizon. They were exported as new shapefiles containing only values specific to one horizon. All cruises for each geo-horizon were then merged. At this stage each geo-horizon-specific shapefile contained the following columns (fields):

Layer, Shot, Cruise, Date, Time, Latitude, Longitude, Depth_ms, YLoc, Colour, elevation, CruiseShot, ShotDtime

A new but empty master file was created, containing empty columns for each geo-horizon. Based on the new and unique ID long integer the master was "joined" (an ArcMap function) to the individual geo-horizon filtered shapefiles. The master could then be populated by copying (Field Calculator) elevation values to the appropriate column. This join and copy was done separately (sequentially) for each geo-horizon-specific shapefile. With all horizons for a specific shot now recorded in one row, the differences between selected horizons could be calculated. In practice, this was a tedious task because:

1. the stratigraphy was rarely a “layer-cake” sequence; many units were or were not present so simple subtraction of entire columns was not possible (meaningless zero and negative values would result)
2. the “Seabed” was not designated as belonging to one or another stratigraphic unit, necessitating use of the surfical geology polygon map as a further filter to then assign the seabed stratigraphy
3. The end product differentiated sub-units more broadly than the interim product
4. There were a few anomalous values derived from a variety of issues such as incomplete spatial overlap of horizons, gaps in horizon picks etc.

The solution was to derive relatively complex and nested definition queries to display the desired horizons and elevations and perform some quality control at most steps making sure the results made “geologic” sense. This process yielded a master shapefile with the following fields in addition to those listed above.

Seabed, Holo_Clay, GlaciSlump, Glacimarin, TillUndiff, GlacTurbat, GUnconform, TillStack0, TillStack3, TillStack2, TillStack1, TillTongue, Cretaceous, Carbonifer, BedrkUndif, Surf_Unit, SrufUnit2, Holo_Thick, GMThick, GmTurbThk

From this the appropriate thickness values were selected and added to the final thickness feature class. Generally this involved interim shapefiles or at least their modification to include fields of identical name and type to enable ready copy and paste from filtered versions of source files to the final Quaternary sediment thickness product. The final outcome was that this represented an inordinate amount of effort for the gain and was not pursued further as the much more appropriate JP2000 suite of applications were developed.

Process code 18: From Existing Spreadsheet:
Those values with a process code of “18” and a source code of "60" originated from a spreadsheet, coded to a map position by the GSC-A standard Julian Day/time stamp. The sediment thickness postings were derived from GSC-A reflection seismic interpretation compiled as part of a contract to C_CORE, NL by Brian MacLean, GSC-A (source number 60). The contract product was an Excel spreadsheet with 1785 records of total sediment thickness over bedrock covering the offshore area east of the Avalon Peninsula. This required some reformatting for compatibility with the sediment thickness geodatabase compilation (King, 2013 Open File 7513).
The spreadsheet contained cruise, daytime, and bedrock depth measurements. The thickness measurements in text format with alpha-numerics including “?”, “<”, “>”, “+” “-m”, “no data” and thickness ranges such as “3-4m”. These had corresponding “start” and “end” of segment UTM coordinate listings. The measurements were reformatted to calculate averages for the ranges, with “maximum” and “minimum” field assignment according to the “<” and “>” values respectively. A single position was calculated mid-way in the segment defined by start and end coordinates. Accordingly, the reader can infer that the measurement applies equidistant on either side of the posting but that it does represent an average. These were imported and a shapefile created, fields corresponding to that of the geodatabase, populated with the appropriate field values, and imported into the geodatabase.

Appendix III: Coding of Positional Accuracy

5	Scanned, georeferenced and digitized from paper or mylar map depicting interpretations. Accuracy determined largely by linework or symbology scale on the paper map and the georeferencing accuracy. Mid-scale original map.	1: 300 000 scale maps likely georeferenced to better than the precision of the symbol placement representing the thickness measurement. Generally within 200 to 400 m Errors up to several hundred metres, rarely 1 km.
6	Scanned, georeferenced and Digitized from paper or mylar map depicting interpretations. Large scale map. Generally technique 7, below was applied.	Generally within 200 to 500 m but error could exceed 1 km.
7	Digitized from scanned and georeferenced paper or mylar map depicting interpretations along survey line. Point-based symbology snapped to closest adjacent GSC-Atlantic Expedition Database (ED)-based ships track navigation in order to reconstruct original position and thus improve accuracy. Applies mainly to very large scale maps (1: 1 000 000 to 1: 5 000 000)	Variations up to 1 km off-line improved to within 100 to 300 m .
8	From raw geophysics survey, no layback correction; from scanned JP2000 geophysical record	Generally within (better than) layback "error": 100 m for Huntec, 30 m for airgun, up to several hundred metres for sidescan- derived interpretations
9	From raw geophysics survey, with an assumed, measured or post-survey calculated layback correction; horizon segment or marker picks from JP2000 Viewer or georeferenced sonar image	Nearly always within 100 m; More recent surveys, with short baseline navigation on towed bodies consistently achieve approximately 20 m accuracy
10	Digitized from scanned and georeferenced paper or mylar maps at scales between 1 : 500 000 and 1 : 250 000 scale depicting interpretations along survey line. Feature position snapped to superimposed or closely adjacent GSC-Atlantic Expedition Database (ED) -based ships tracks position to improve accuracy	Variations up to 1 km off-line improved to within 100 to 300 m

Appendix IV: Excerpt from the sediment thickness table showing most of the attribute fields.

CruiseNo	NewDaytime	Sed_Unit	Thick_m	Thick_ms	ThickLocal	EstThkMin	EstThkMax
2010020	20100201610212	Total Quaternary section	0.8601	1.146799	0	0	0
2010020	20100201610212	Total Quaternary section	0.634469	0.845958	0	0	0
2010020	20100201610212	Total Quaternary section	0.437974	0.583966	0	0	0
2010020	20100201610212	Total Quaternary section	3.701345	4.935127	0	0	0
2010020	20100201580351	Total Quaternary section	28.829526	38.439368	0	0	0