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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

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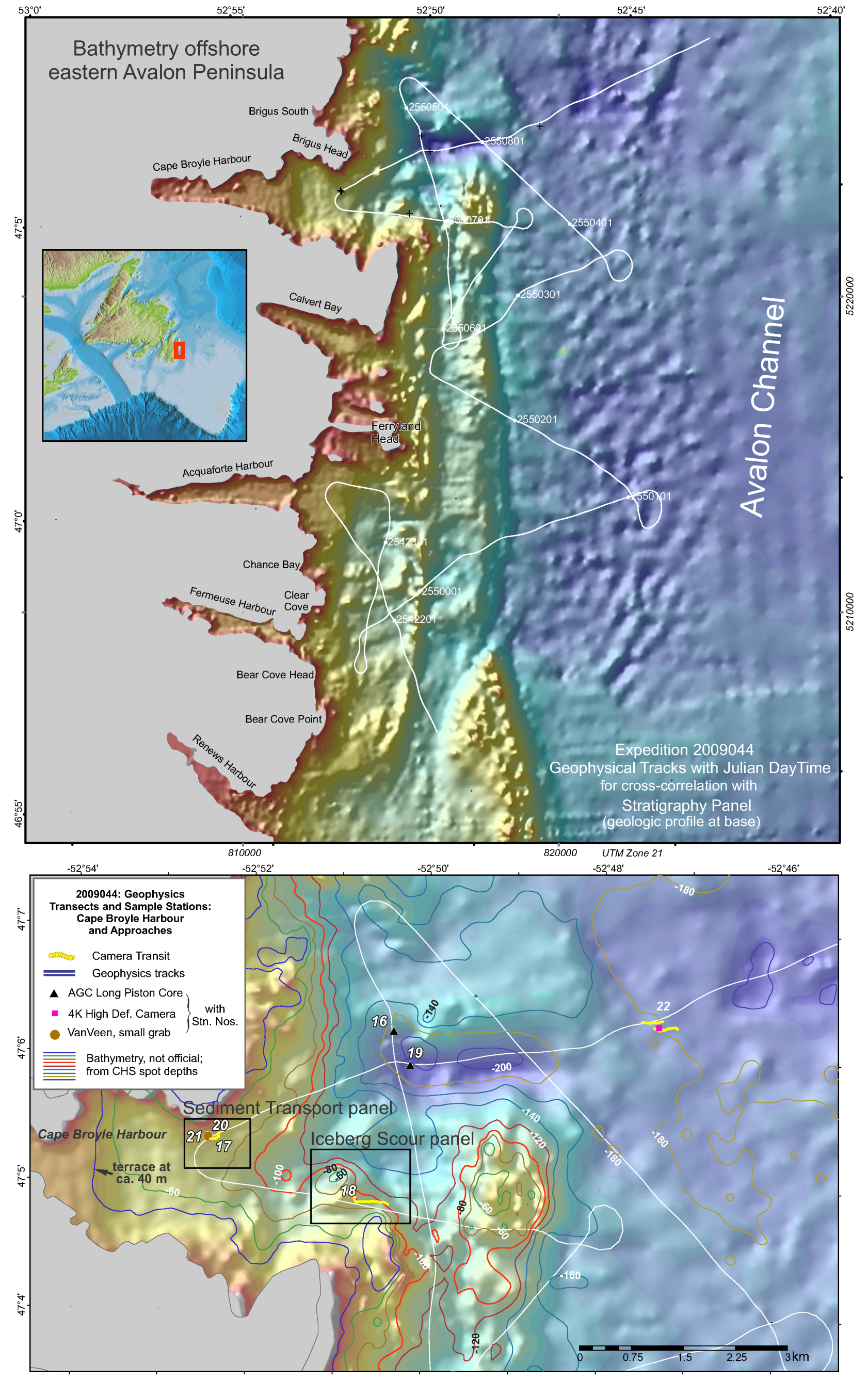
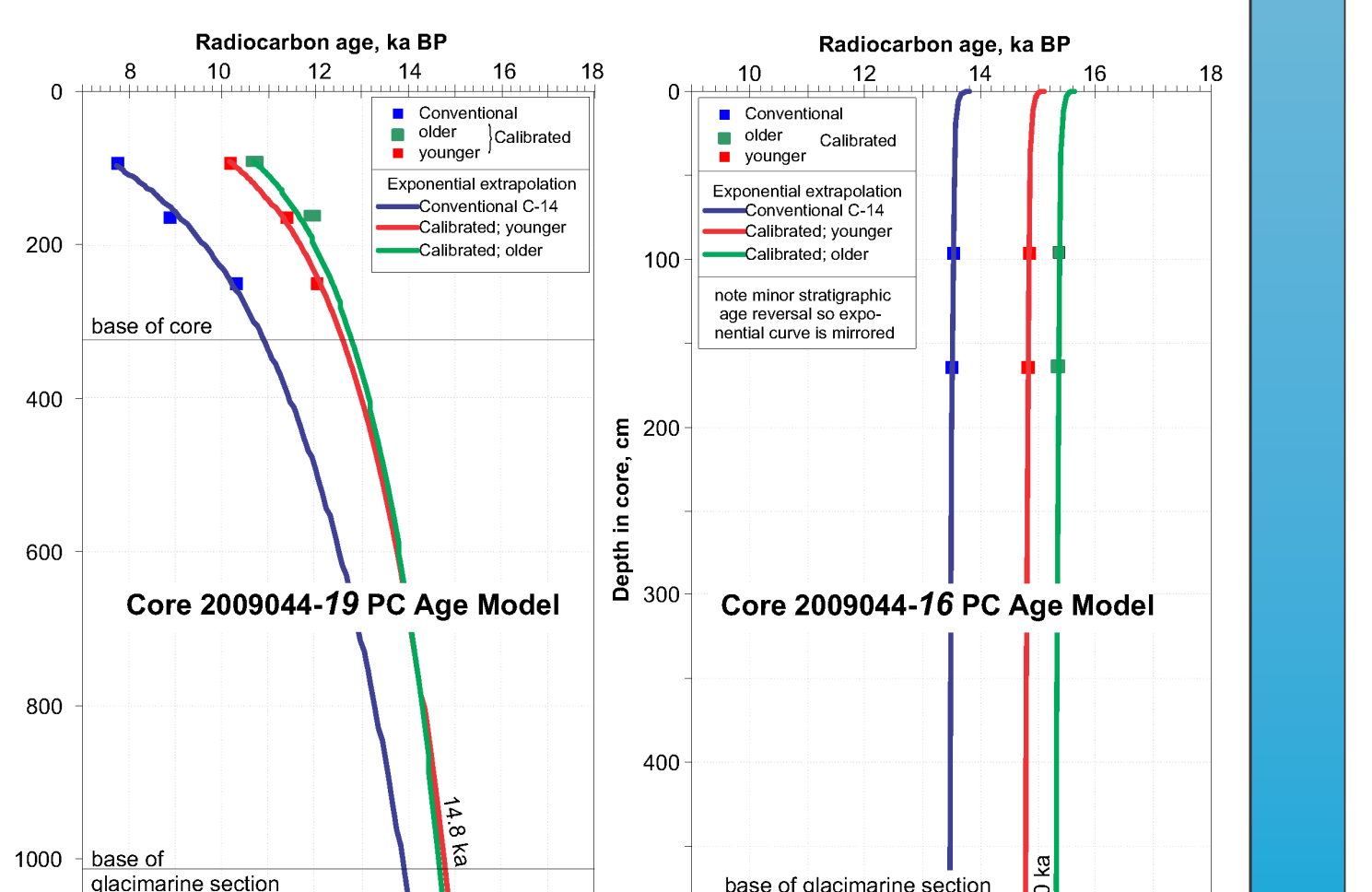


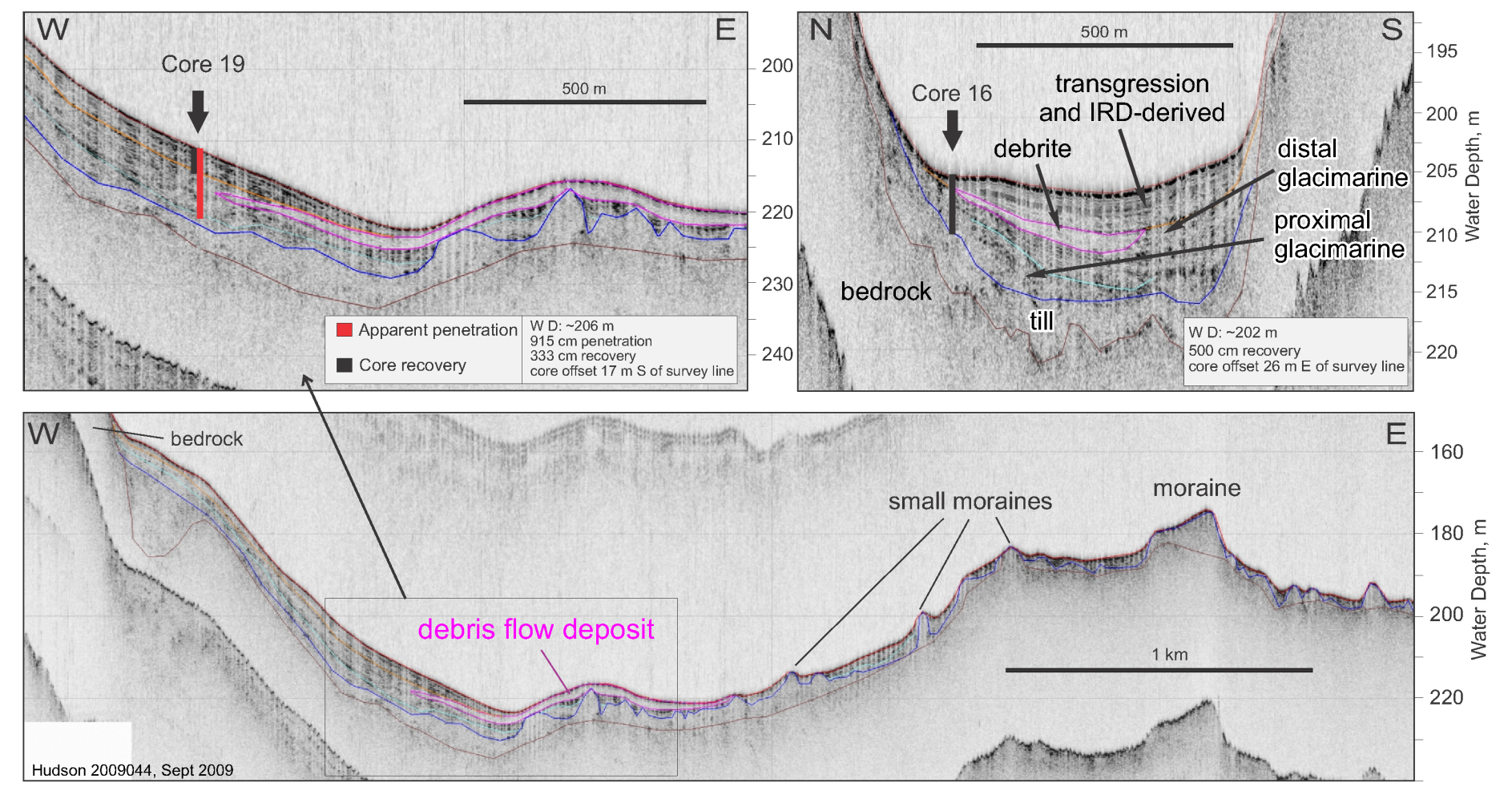
Data Set

A zig-zag pattern geophysical survey (expedition 2009044) was conducted to characterize the geology of the innermost shelf off the Avalon Peninsula (upper panel) and identify the past and present seabed processes. Detail of the sample stations visited in the Cape Broyle Harbour area of the Avalon south shore (lower panel). Rectangles correspond to locations of the designated panels.

Deglaciation Chronology & Mass Transport Event

Two cores, 16 and 19, from a small glacially-overdeepended basin off Broyle Harbour (location in panel above) intersect a till (with moraines) and deglaciation sequence near the toe of a mass-transport deposit (debrite). Other dated cores near the Avalon Peninsula indicate an exponentially diminishing sedimentation rate following glacier retreat. Limited shell dates (see table of dates, centre of poster), exponentially extrapolated to the top of till based on the seismic profiles suggest rapid deglaciation beginning ca. **14.8 to 15 ka** (CAL) with extreme sedimentation rates. This was followed by the mass failure and debrite emplacement at the cessation of local glacimarine supply, that is, immediately after deglaciation at about **14.8 ka** (CAL). See core details in panel to the right. The debrite is relatively small with an estimated volume of **10^6 m^3**.





Huntec boomer profiles across a small basin with an 8m thick glacimarine section. It is interrupted near the top by a homogeneous lense up to 2 m thick and several hundred metres broad. This is a mass failure deposit derived from soft glacimarine sediments on the steep bedrock-dominated cliff on the basin flank immediately following deglaciation. Two cores were recovered, (2009044-16 and 19) located just beyond the seismically homogeneous debrite lense. Core 19 penetration was sufficient to reach the base of the glacimarine section but recovery was limited. At the base of the core, gravelly intervals at this base of slope setting represent either intensification of IRD from the Labrador Current, the local affects of transgression across the bedrock ridge at the top of slope, or alternatively, very small MTD activity. Core 16 had full recovery, shows evidence of the seismically-identified MTD debrite (see Cores panel, to upper right) and enabled C-14 dating of the event.

Introduction

The innermost shelf off the Avalon Peninsula was completely unexplored in terms of geophysical surveys and bathymetric surveys until a summer 2009 GSC-A expedition (2009044). A series of surficial geology-related maps (panel at right) derives from the new survey and related findings are presented here.

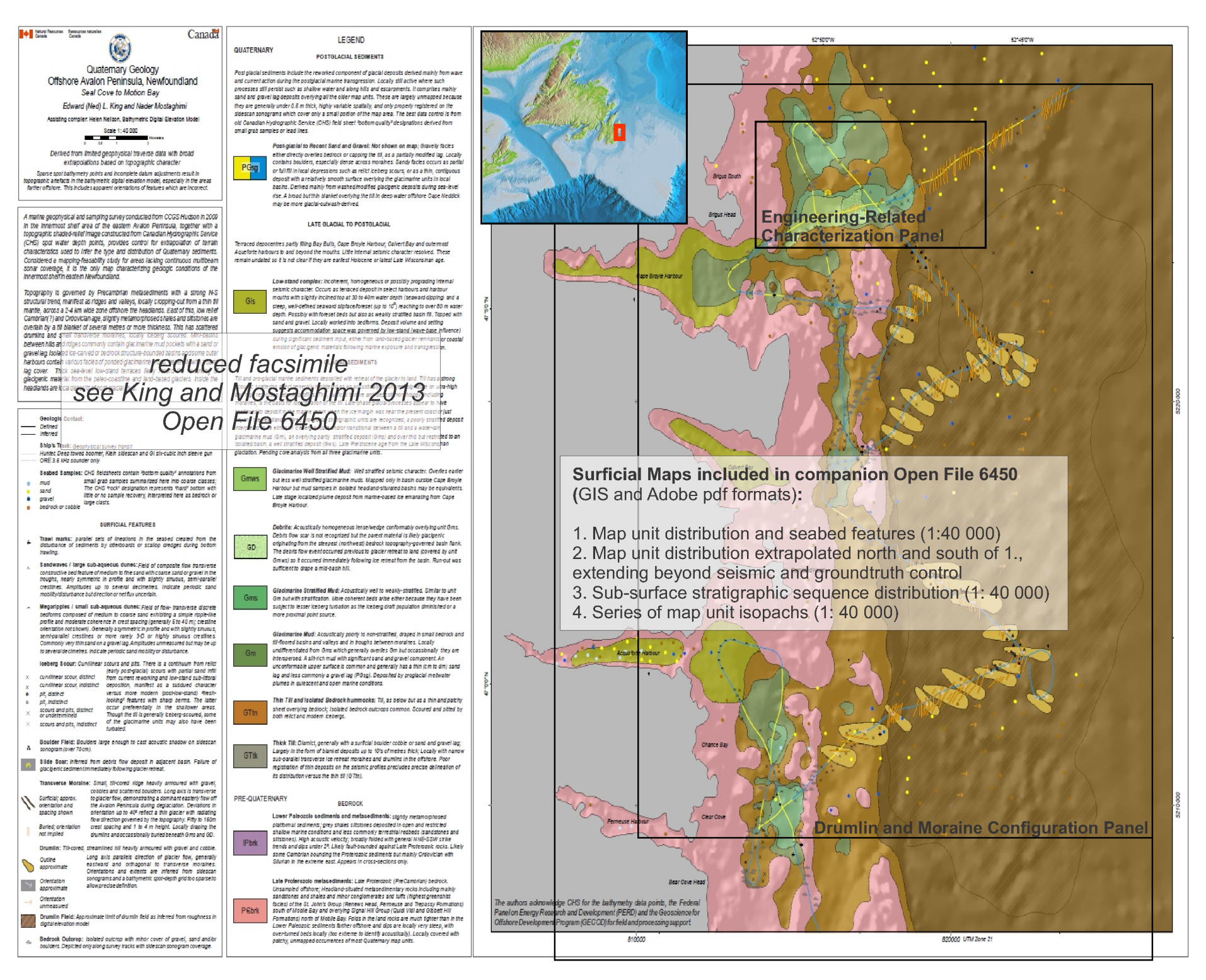
Topographic shaded-relief renderings generated (pre-expedition) from Canadian Hydrographic Service spot depths significantly enhanced topographic features and indicated a mix of bedrock lineations, variable sediment cover, and small basins with some sediment cover. While much of Newfoundland's inner shelf has been examined with respect to glaciation, sediment deposits and glacial chronology (Shaw 2002), the Avalon area remained largely unstudied.

This is a unique terrain, contrasting with the relatively flat-lying, till-blanketed Avalon Channel, to the east. The more rugged topography of the late Proterozoic tectonized metasediments extending several kilometres from land creates fjord-like bays, fault-governed ridges and isolated basins. This contrasts with less indurated and more flatlying Lower Paleozoic age metasediments which floor Avalon channel and provide the platform for a large part of Grand Bank.

The area was transgressed by the rising post-glacial sea-level and would have bounded a proto-Labrador Current offshoot through the adjacent Avalon Channel. A paucity of Quaternary deposits on land that might afford dating potential has restricted understanding of the late glacial history and it was suspected that the basins and harbours might provide a datable sequence and a record of lower sea-level. One goal was to explore for datable sediments in, for example, isolation basins, marking the retreat of the ice sheet and the terrestrial to marine change. Glacier flow directions, ice margins and timing and the origin of Avalon Channel were also element to address. The potential for a gas pipeline landing, originating from the Jeanne d'Arc Basin, was also a driver; this seascape had never been characterized in terms of geology and morphology.

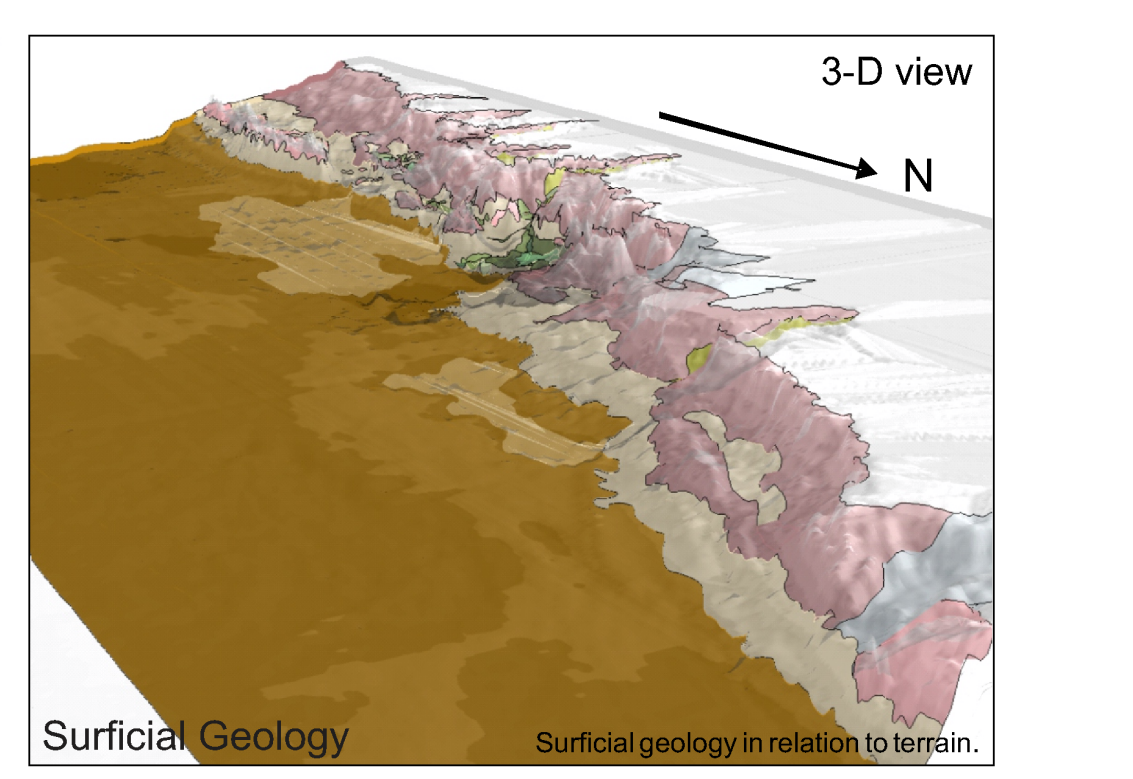
Multibeam bathymetric data across the Grand Banks is sparse, so simply establishing geo-feature geometries (eg. bedrock and glacial lineations, drumlins, moraines, iceberg scours and sedimentary bedforms) requires considerable survey and compilation effort. However, spot depths from Canadian Hydrographic Service were accessed and gridded at appropriate bin size for point spacings between 50 and 500 m in order to derive a digital elevation model (DEM), a contour map, and a colour-coded shaded-relief image of the seabed. This involved manual digitization of one area, to fill a data gap, involving manual digitization of over 40 000 points. The DEM (panels at left) provided the control for survey targets and for extrapolation and interpolation of map unit distribution as derived from the new seismic profiles and samples.

Surficial Geology map series: separate Open File (6450)

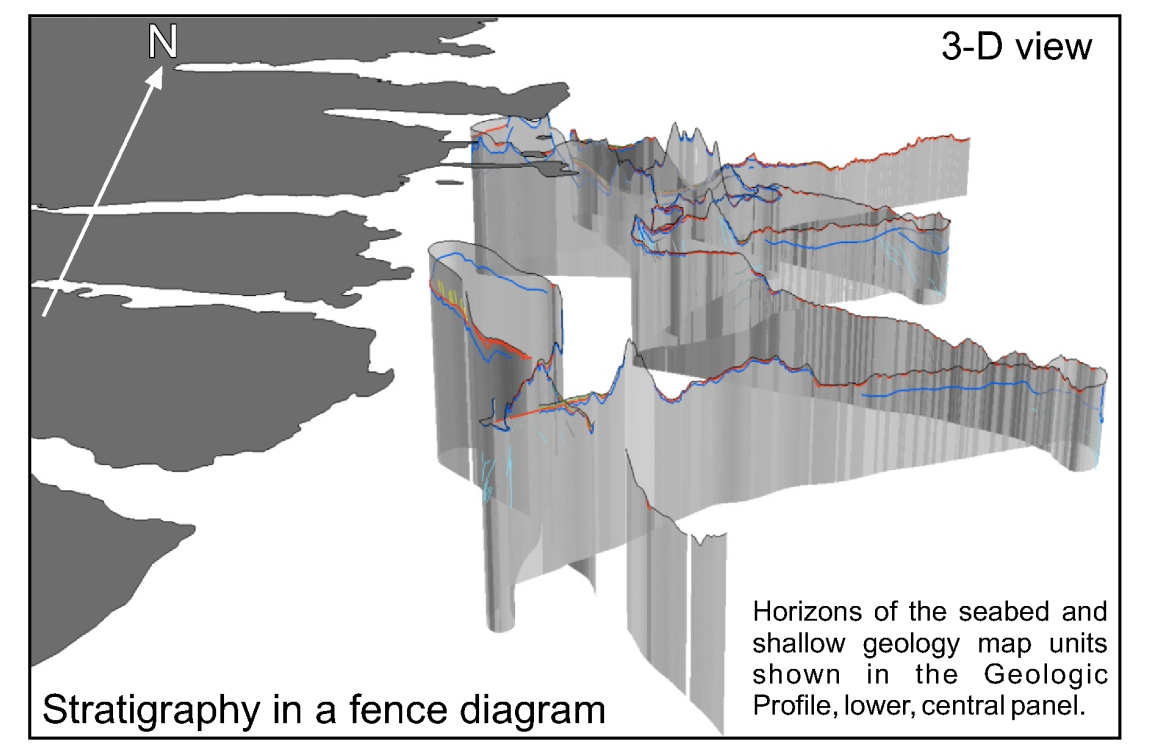


Surficial Maps included in companion Open File 6450 (GIS and Adobe pdf formats):

1. Map unit distribution and seabed features (1:40 000)
2. Map unit distribution extrapolated north and south of 1., extending beyond seismic and groundtruth control
3. Sub-surface stratigraphic sequence distribution (1: 40 000)
4. Series of map unit isopachs (1: 40 000)

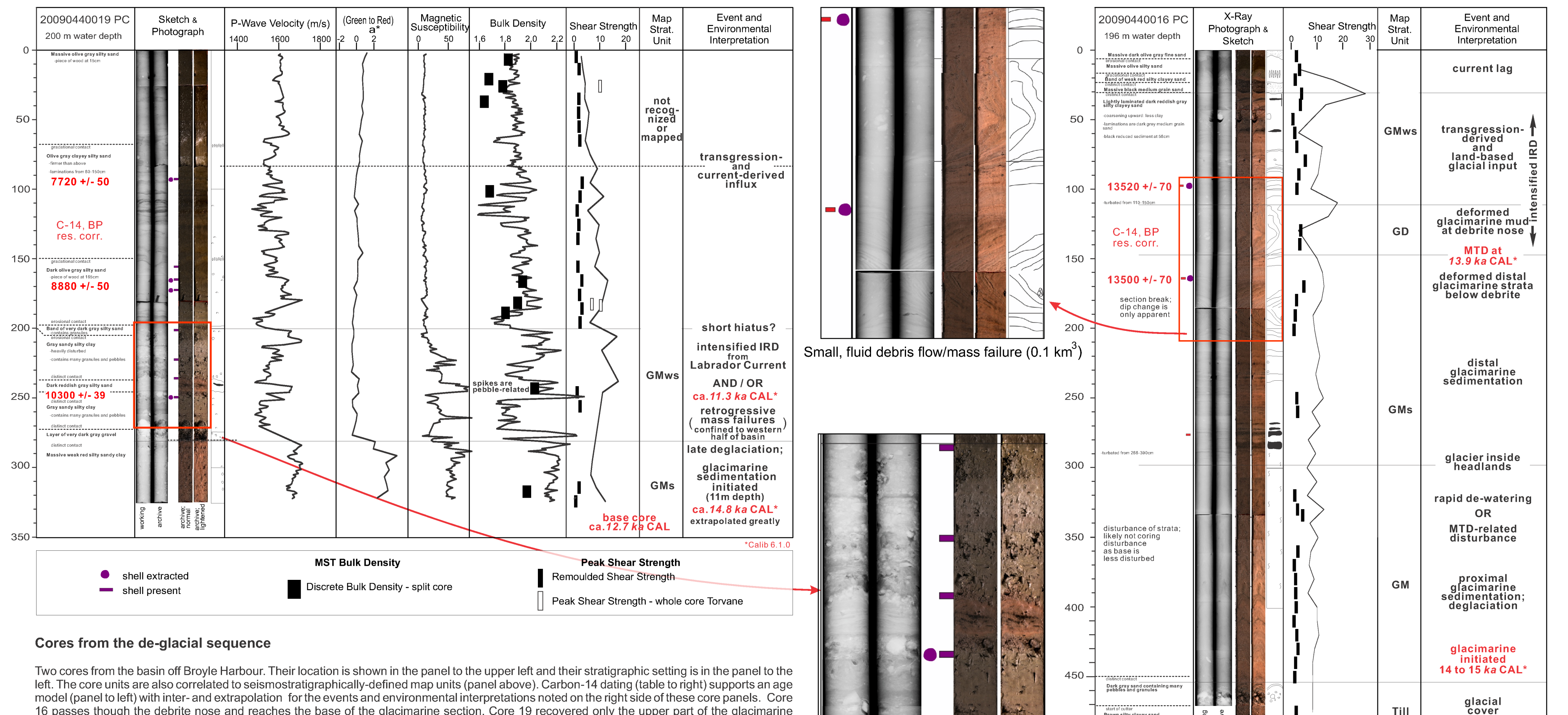


Surficial geology in relation to terrain.



Stratigraphy in a fence diagram

Horizons of the seabed and shallow geology map units shown in the Geologic Profile, lower, central panel.

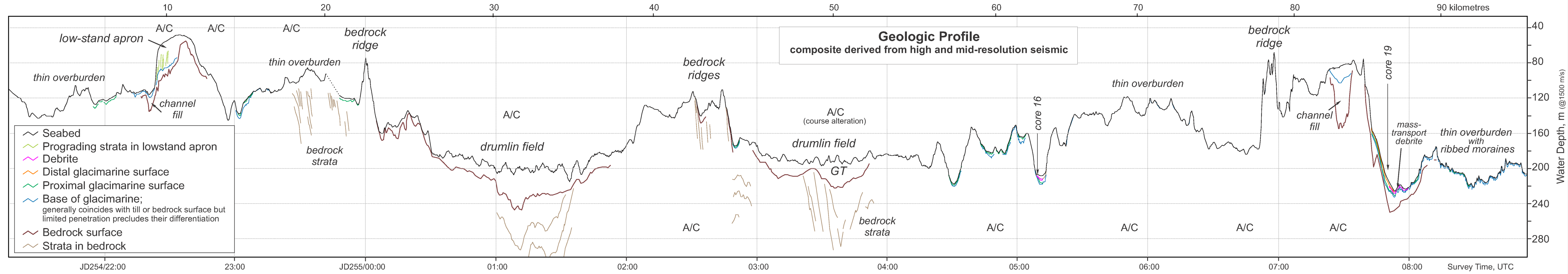


Cores from the de-glacial sequence

Two cores from the basin off Broyle Harbour. Their location is shown in the panel to the upper left and their stratigraphic setting is in the panel to the left. The core units are also correlated to seismostratigraphically-defined map units (panel above). Carbon-14 dating (table to right) supports an age model (panel to left) with inter- and extrapolation for the events and environmental interpretations noted on the right side of these core panels. Core 16 passes though the debrite nose and reaches the base of the glacimarine section. Core 19 recovered only the upper part of the glacimarine section and a disorganized shelly-pebbly unit whose derivation is unclear. At this time, nearby transgression was underway, supplying erosion products, the Avalon branch of the proto-Labrador Current was likely in operation, and small mass failure may still be occurring.

Seismic Stratigraphy

This interpretation from a combination of sleevegun and deep-towed boomer outlines the general stratigraphy and morphologic features. The lower scale allows correlation with position on the ship's track in the far left panel.



Bedrock and Surficial Geology

The innermost shelf of the Avalon Peninsula is characterized in terms of bedrock geology, Quaternary sediment sequence, thickness and distribution, surficial texture, and glacially-related features. The latter include overdeepened and partially filled basins, drumlins and moraines, deglaciation pattern and timing. The recent survey also allowed recognition of a paleo-mass transport event, lower sea-level indicators, sediment mobility under currents, iceberg scour distribution, including a recent event, and a spatial representation of quantified seabed roughness.

Higher elevation and relief on the innermost shelf compared with the Avalon Channel reflects the bedrock change from Lower Paleozoic low-grade metasediments below till in the Channel and harder, more deformed Late Proterozoic metasediments inside the ca. 150 metre isobath, about 5 km off the headlands.

Deglaciation

Glaciations carved small valleys normal to the dominant N-S tectonic fabric of the bedrock which locally but rarely breached N-S offshore ridges and created locally overdeepened basins. Thick and thin till provinces were left, the thicker in shallow basins on the Avalon Channel floor (outside this area, the till is generally only 1 to 5 m thick) and the thinner, more patchy on the bedrock ridges areas. The offshore orientation of the drumlins and moraines shows that the last vestiges of glaciation emanated from the Avalon ice dome, traversing normal to the Avalon Channel. It was vigorous enough to generate drumlin fields but on retreat the ice sheet became thin enough to be sensitive to local topography; it assumed a lobate regime locally, reflected in trends of transverse (Rogen-like) moraines but while still streaming in the valleys.

Seismic reflection profiles together with two sediment cores help characterize the de-glacial and post-glacial sequence. Post-till deposition was followed by a stratigraphic succession of three mappable units, similar in depositional style but with a trend from poorly stratified to well stratified, both seismically and in the cores. The lowermost is barren of shells and spurious investigation revealed few foraminifera, some reworked and some typical glacimarine species. It is interpreted as meltwater-influenced, with some IRD emanating from the glacial margin while it was positioned within the catchment of the basin. At some point, the margin likely lay at the SW basin flank just outside Cape Broyle Harbour. Timing of retreat to the headlands is roughly constrained by the cores, with extrapolated radiocarbon ages of about 15 ka (calibrated) at the till-glacimarine mud contact. Soon after, the basin was inundated by the ocean at least one small mass failure occurred, at about 14.8 ka (cal.). This was followed by retreat from the small basin to the harbours where it deposited glacifluvial or ice contact deltas, probably under the influence of a rising relative sea-level.

Post-glacial

Recent seabed iceberg scouring is evident in sidescan images and seabed photography. The frequency and magnitude of impact of relatively small icebergs in shallow water and the location, magnitude and conditions of sand transport are both largely unknown and relevant to pipeline or communications cables. Initial observations suggest both processes are locally active.

Engineering

Previously unknown glacially-cut valleys are rare but afford potential pipeline routes where issues with rugged terrain, difficult trenching materials, shallow water ice scour and landfall can be minimized.

Conclusions

The innermost shelf of the Avalon Peninsula, like the coastline, has a high relief, where morphology is dominated by Proterozoic bedrock with strong structural elements. Yet glacial erosion has locally cut offshore extensions of some harbours, often with overdeepening. The offshore contact with the younger (lower Paleozoic) and more erodible rock sequence coincides with a till-dominated terrain.

A series of surficial geology maps complement this poster (separate product) and include 3-dimensional information, such as sediment thickness and Quaternary stratigraphic succession distribution.

Drumlins and moraines indicate a relatively thin and lobate ice configuration emanating from the Avalon Ice dome before deglaciation.

The overdeepened basins are the site of glacimarine sediments that recorded deglaciation initiating at about 15 to 14.8 ka with high sedimentation rates (>4 metres per kyr).

A small (1 million cubic m) debrite is dated about 14.8 ka; much smaller event might have occurred as late as 12 ka.

Thick low-stand deposits were likely fed by coastal glaciers at stands about 45 and 35 m present water depth. These help constrain the regional understanding of post-glacial rebound.

The survey covered areas too deep to identify isolation basins (lakes drowned with post-glacial sea-level rise) yet small examples may be present.

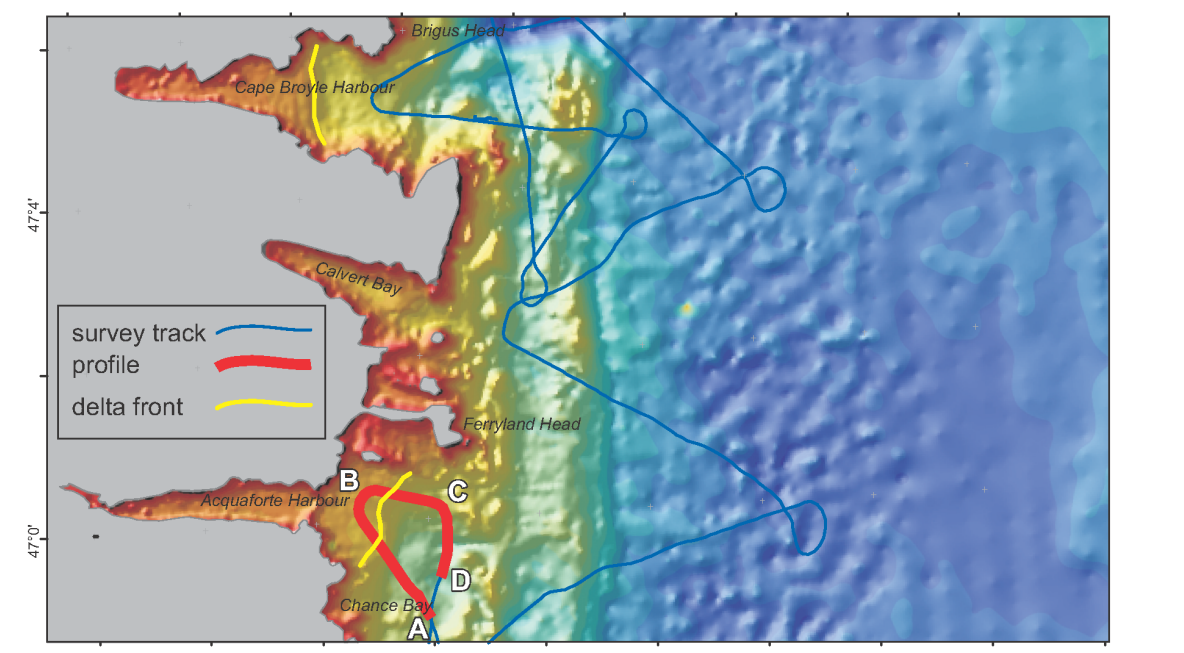
Sand mobility under current influence periodically activates thin bedforms, likely only with storm events.

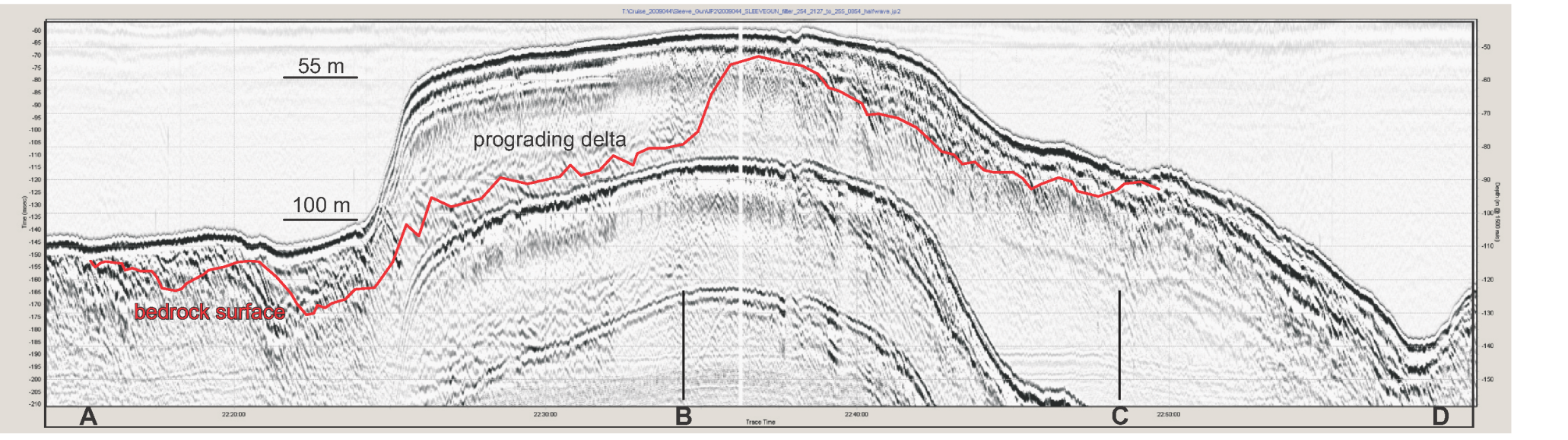
A modern and relict iceberg scour population is recognized with fresh scours on the topographic highs.

A glacial imprint on the Avalon Peninsula east coast presents elements introducing constraints and mitigating opportunities for avoidance of difficult terrain for routing, burial and landfall of any potential gas pipeline.

Sea-level Low-stand Deposit

A sleevegun profile from Aquaforte Harbour approaches (location A-B-C-D on map) shows a 40 m thick prograding delta deposit emanating from the harbour mouth. It marks a sea-level-stand at about -45 to -50 m following glacier retreat. A similar body is inferred in mid Cape Broyle Harbour (top of map) where a terrace top at -35 m and a forset base at -60 m, constrain a deposit likely 25 m thick. These deposits strongly resemble inner-fjord submerged deltas in southern Newfoundland interpreted as low-stand deposits (eg. Shaw & Forbes, 1995, Fig.8). However, here they were not fed by cutting and reworking of high-stand glacial deposits as in western Newfoundland, because relative sea-level was always lower than present. Thus, the large amount of material suggests a more direct glacial source, possibly with a margin pinned on the harbour mouth bedrock ridge. Constraints here are contributing to a more regional reconstruction of the crustal shape in early post-glacial time.



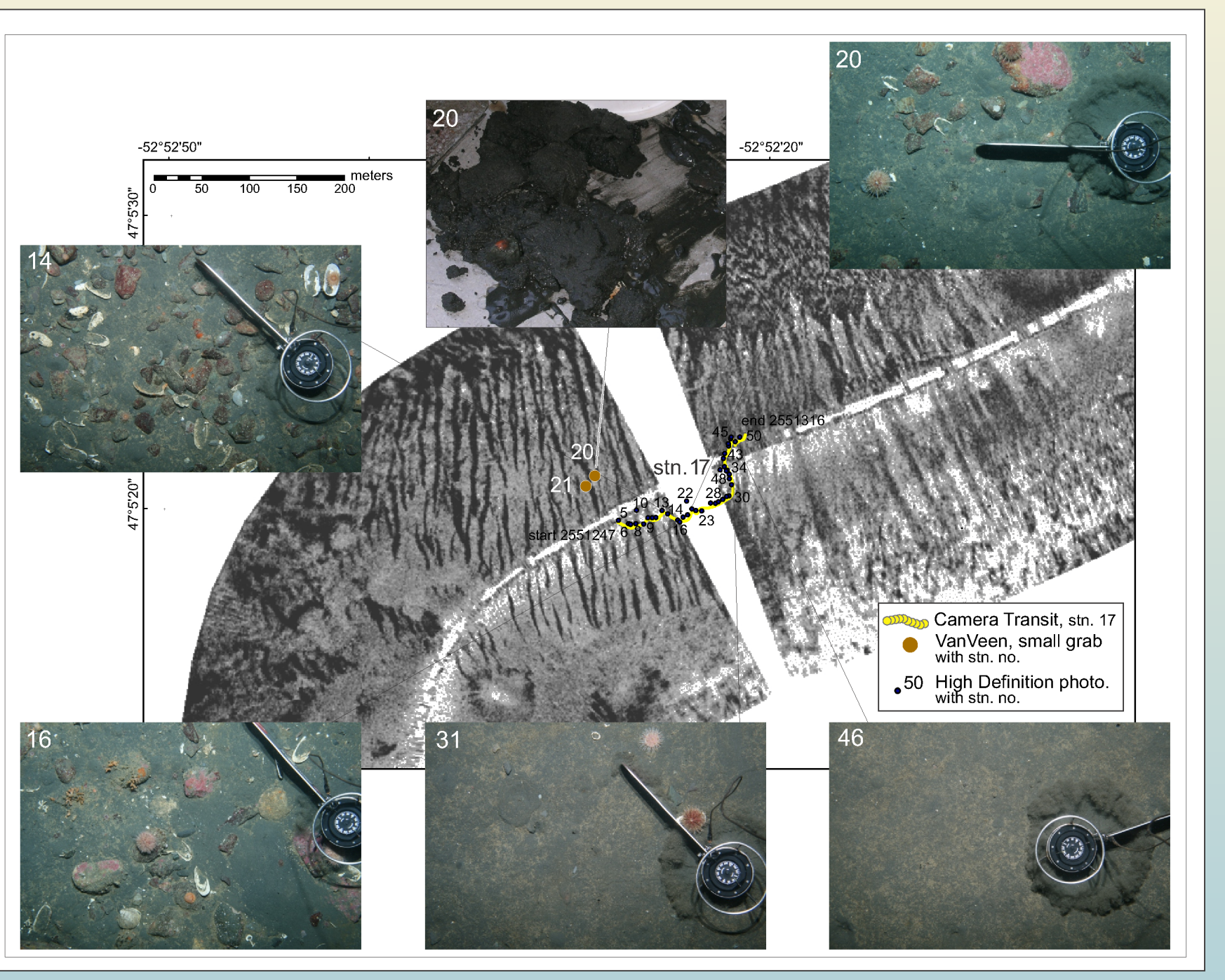


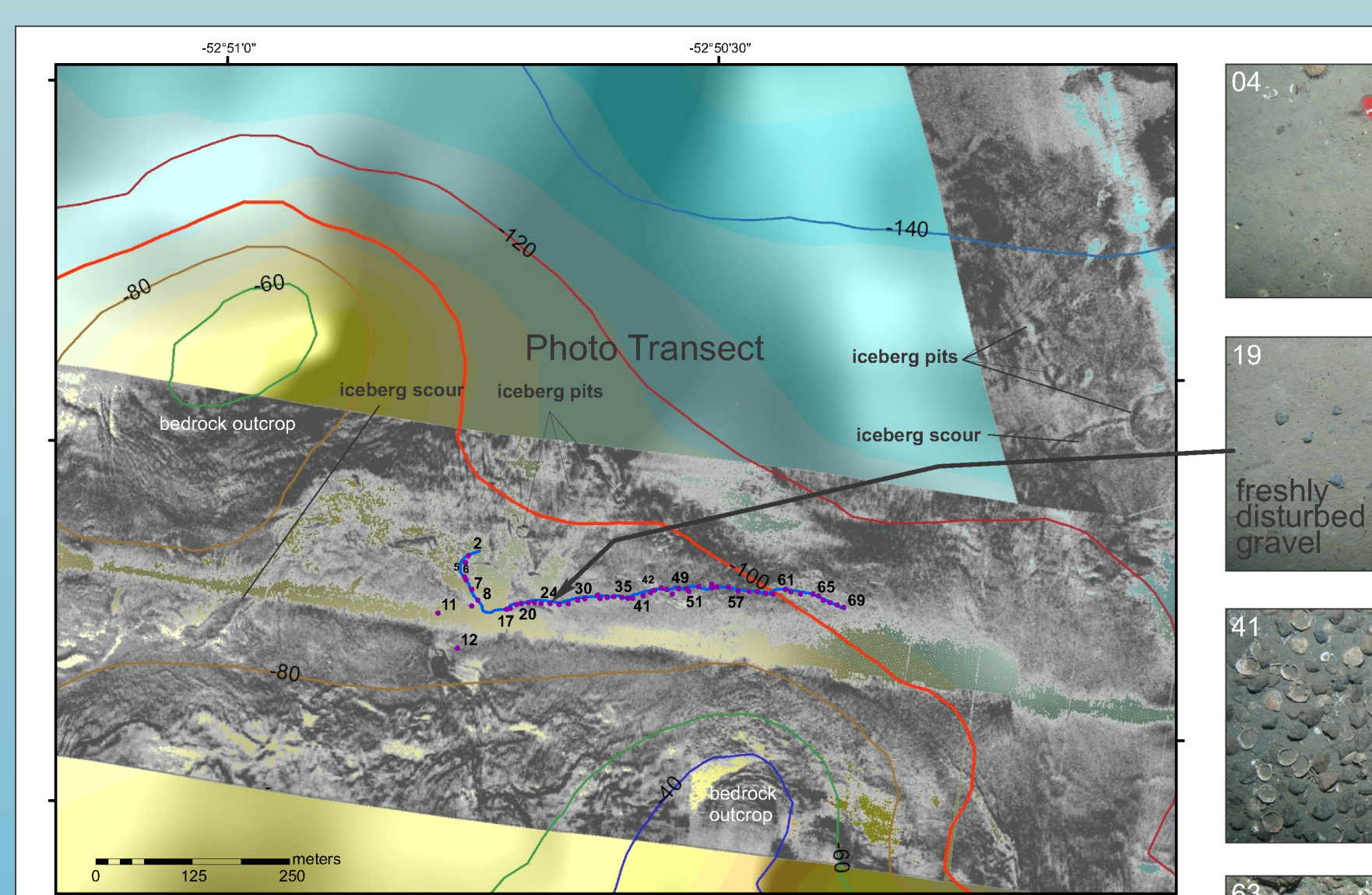
Expedition-Core No.	Sample Interval cm	Species or Genus ID	GeoSetting	Conventional C-14 (BP)	Calib.* Median, BP	Calibrated* Range, BP	Calibrated* Range, Calendar	Lab. & No.
2009044-0016	95 - 97	Yoldiella sp.	mid-section of the uppermost late glacimarine unit (Gmws)	13920 +/- 70	13954	14393 to 13626	16343 to 15576	Beta-276646
2009044-0016	163 - 165	Yoldia limatula	top of the uppermost late glacimarine map unit (Gmws); matches the top (immediately above) of the seismic-defined debris flow	13900 +/- 70	13911	14526 to 13252	16476 to 15202	Beta-276655
2009044-0019	92 - 94	Geukensia demissa	small basin flank; seismic shows several m well stratified fill (map unit Gmws) on SW basin flank; this is highest stratigraphic level with shell	8120 +/- 50	6239	6341 to 6168	8291 to 8118	Beta-276647
2009044-0019	164 - 166	unidentifiable	core intersects stratified shell-rich debris near base; transgression related storm, tsunami or debris flow deposit; very shell-fragment rich	9280 +/- 50	7593	7666 to 7514	9616 to 9464	Beta-276657
2009044-0019	248 - 250	unidentifiable	core likely does not reach debris flow horizon; coastal shells transported with transgression related storm, tsunami or late debris flow	10700+/- 25	9330	9383 to 9258	11333 to 11208	UC Irvine-87625

*Using Calib 6.1.0, One Sigma

Sediment Transport

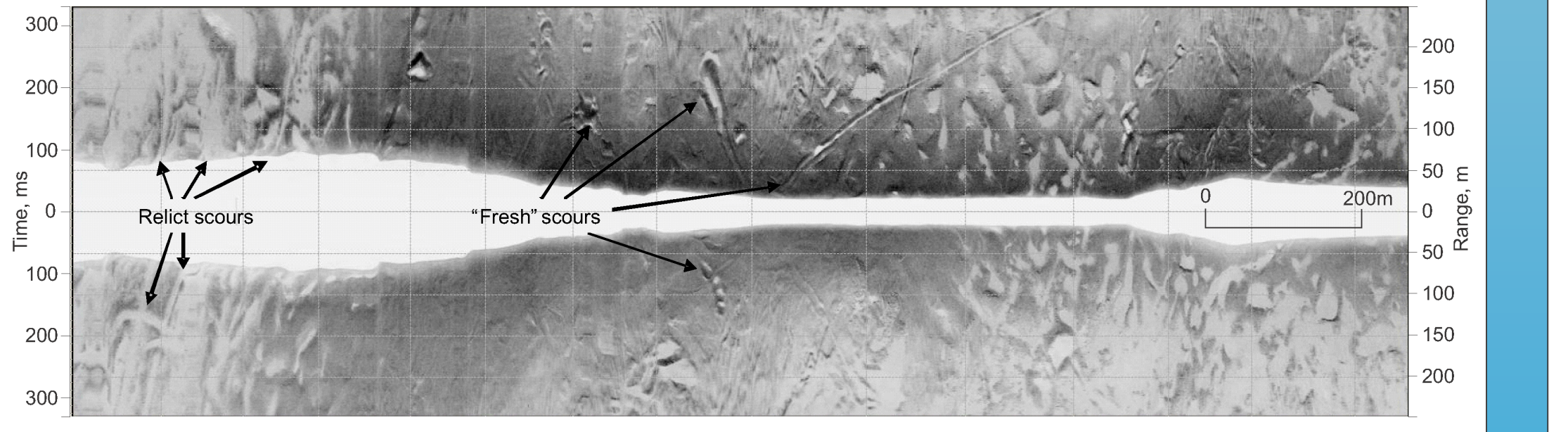
Seabed photographs in a Cape Broyle Harbour megaripple field just south of Brigus Head (stations 17, camera and 20-21, Van veen grabs). The megaripples are very low relief, about 10 m wavelength, and manifest as a veneer of sand on a gravel lag which supports considerable biota. The grab samples yielded a well sorted fine dark grey sand and several pebbles of assorted lithologies. A dusting of flock on the fine to medium sand suggests current activity is not only tidally-generated and that storm-related currents may be influential.





Iceberg Scour

Seabed photographs (Stn. 18) across a bedrock, till, mud and iceberg scoured terrain immediately seaward of Cape Broyle Harbour (location, panel far left). The background is a low-resolution bathymetric DEM with contours and superimposed sidescan imagery showing a variety of features. The mud is very thin, just covering gravel and cobbles. A dusting of flock covers the seabed; photo 19 is an exception where iceberg scouring has disturbed coarse gravel, though fishing activity may also be responsible. An apparently disproportionate number of fresh-looking ice scours occurs on the till-covered hummocks of the area; those in the basins are more sediment-filled.

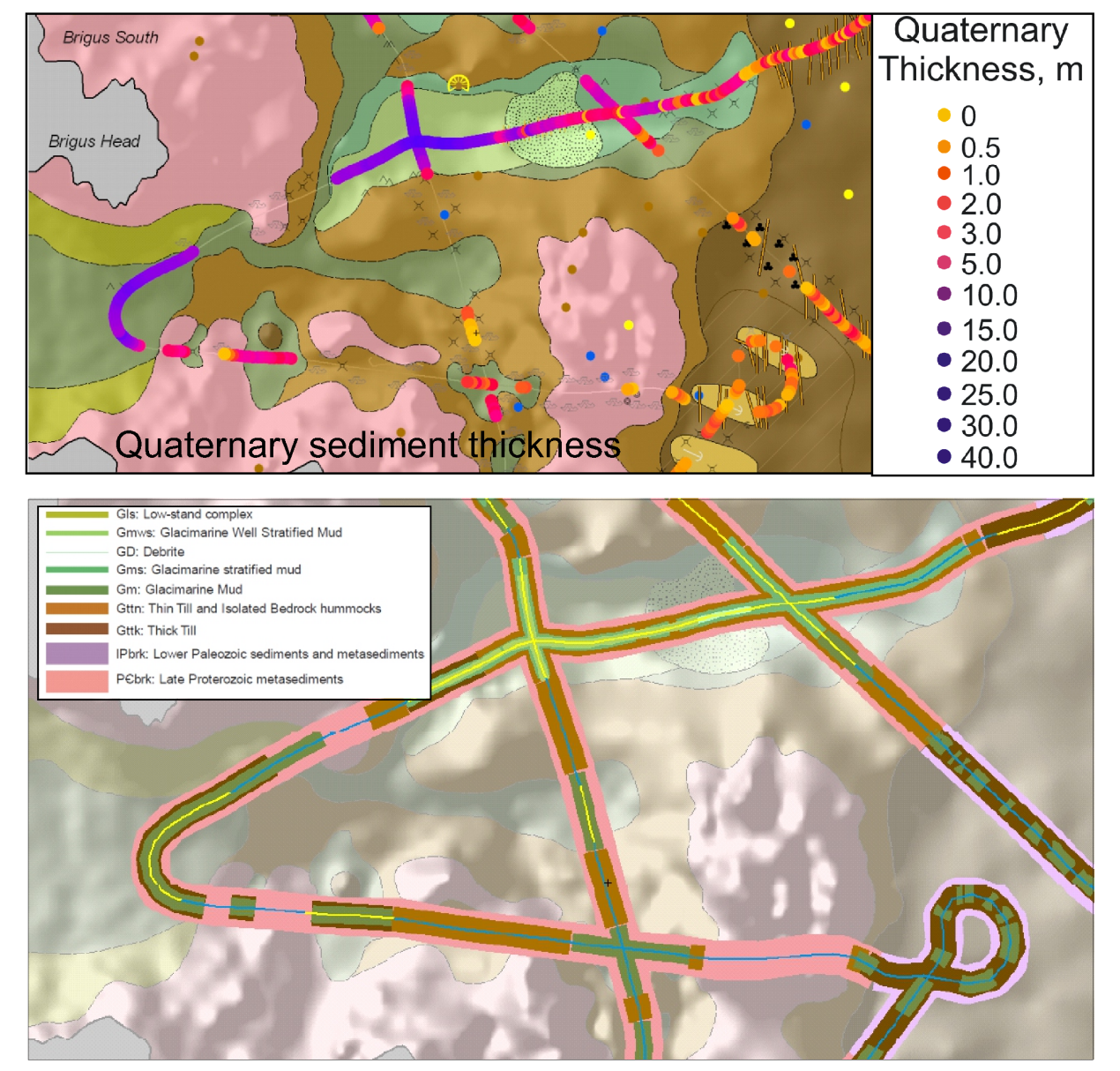


Engineering-Related Characterization

This study was partly aimed at investigating the innermost shelf in terms of bedrock, terrain and Quaternary geology that might be encountered should a gas pipeline be routed directly from the hydrocarbon production areas on Grand Bank. A seabed roughness characterization displays columns proportional to elevation deviations from four smoothed classes (technique to right).

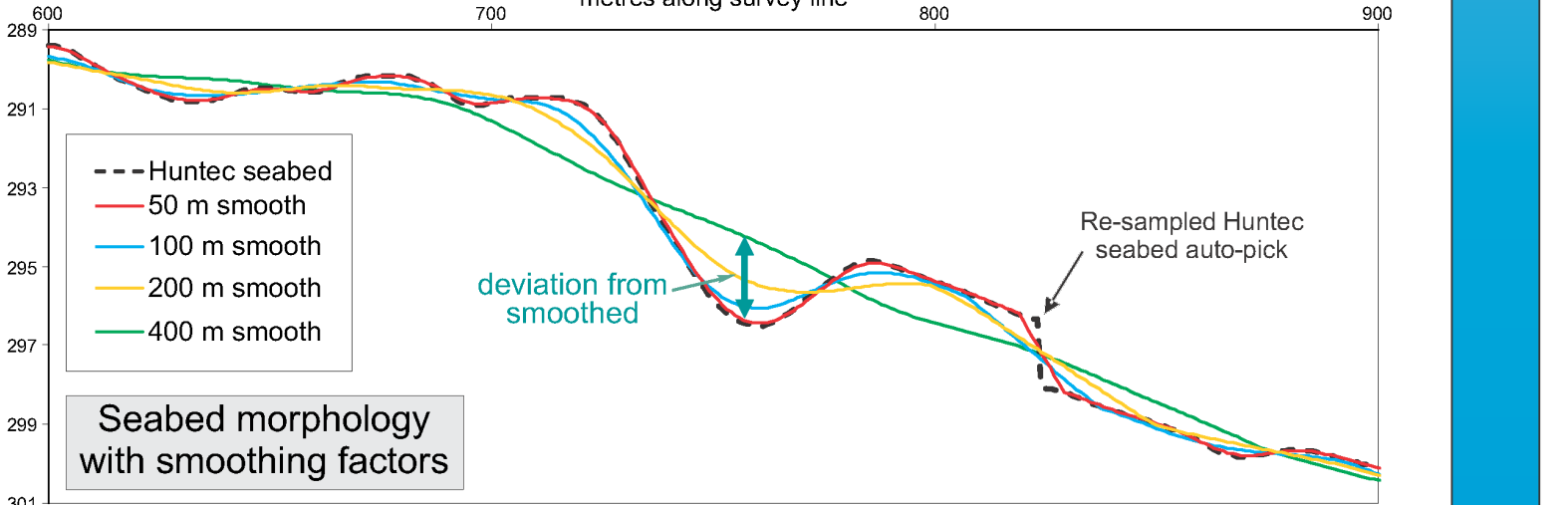
Relatively soft sediment-filled glacially excavated channels afford potential pipeline routes leading to shoreline cliffs, should it be advantageous to avoid adjacent high relief hard bedrock and sediment.

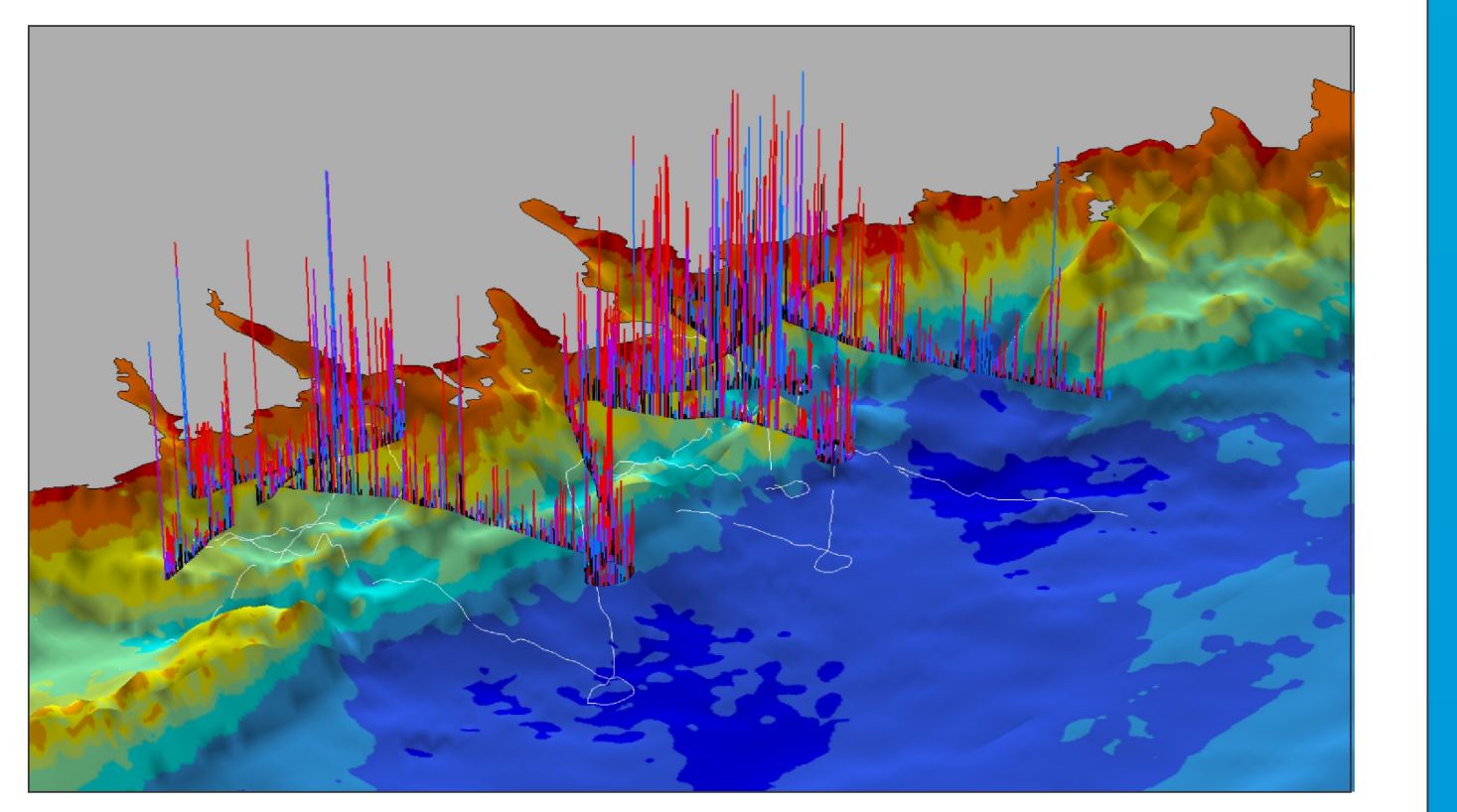
The two panels below are enlargements of maps depicting thickness and distribution of the stacked sediment sequence.

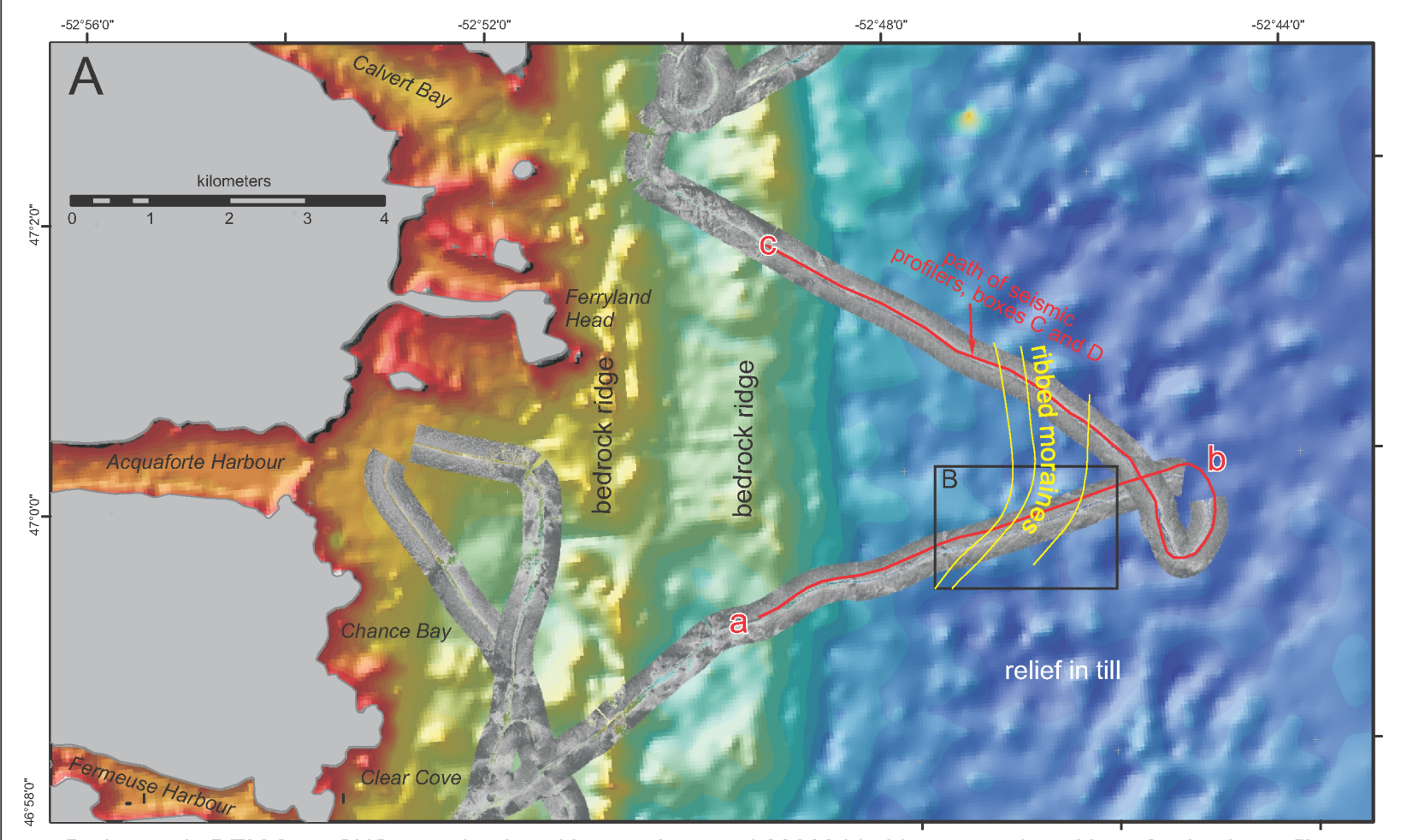


Calculation of Seabed Roughness

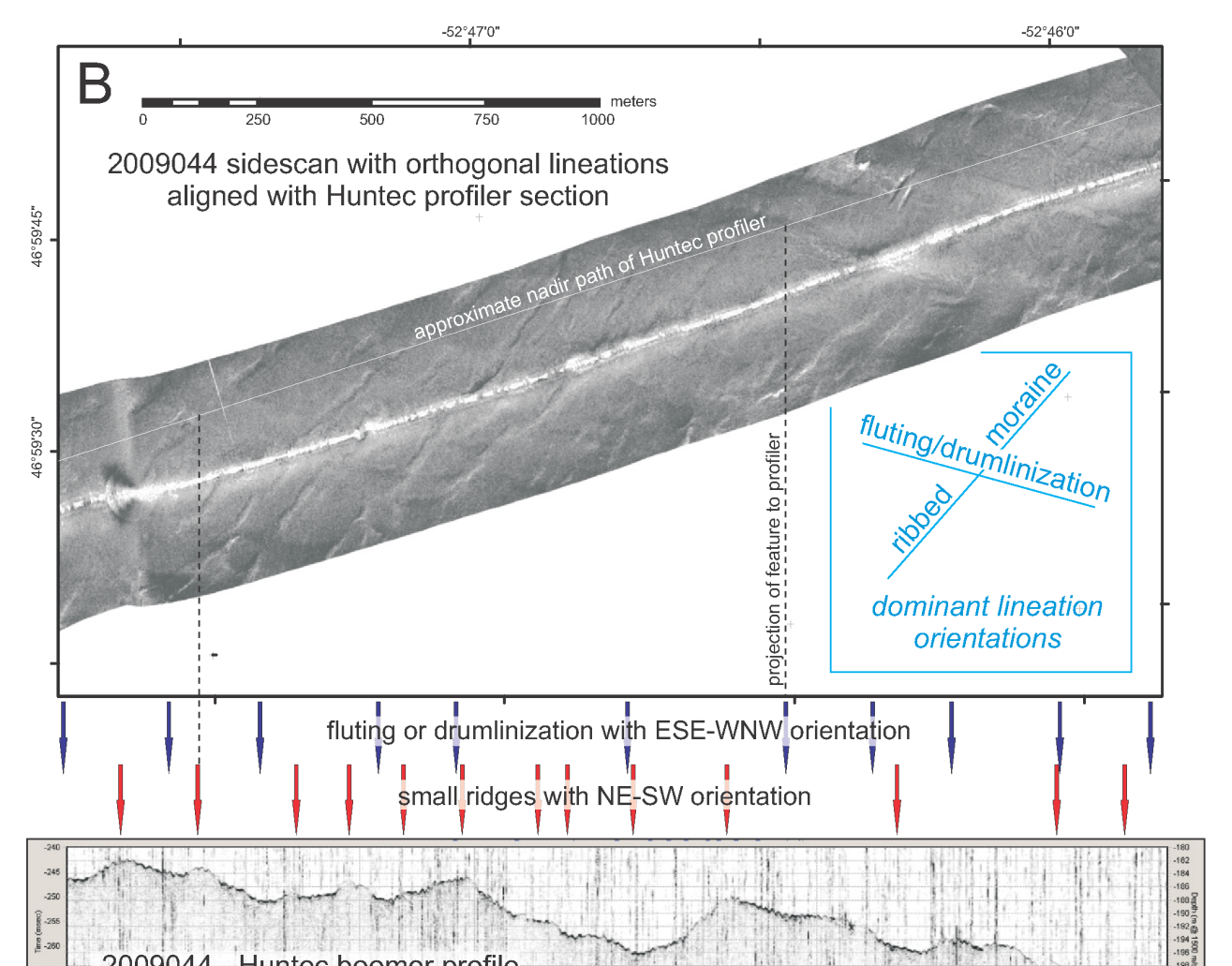
Meso-scale seabed roughness from Huntec DTS sounder profiles was calculated through four smoothing classes. A guided autopick of the seabed (ie. bathymetric readings) was first smoothed to remove wave-action created heave using a GSCA-developed heave filter program (DeJitter-P. Pledge). The other colours represent progressively greater filtering (running averages) to establish different seabed trends. The deviations from these trends are then calculated and plotted as columns superimposed on the 3-D topography rendering. Meso-scale roughness represents the irregularity attributed to seabed features such as bedrock, iceberg scours, pockmarks, buried channels, drumlins and smooth sandy or muddy seabeds.

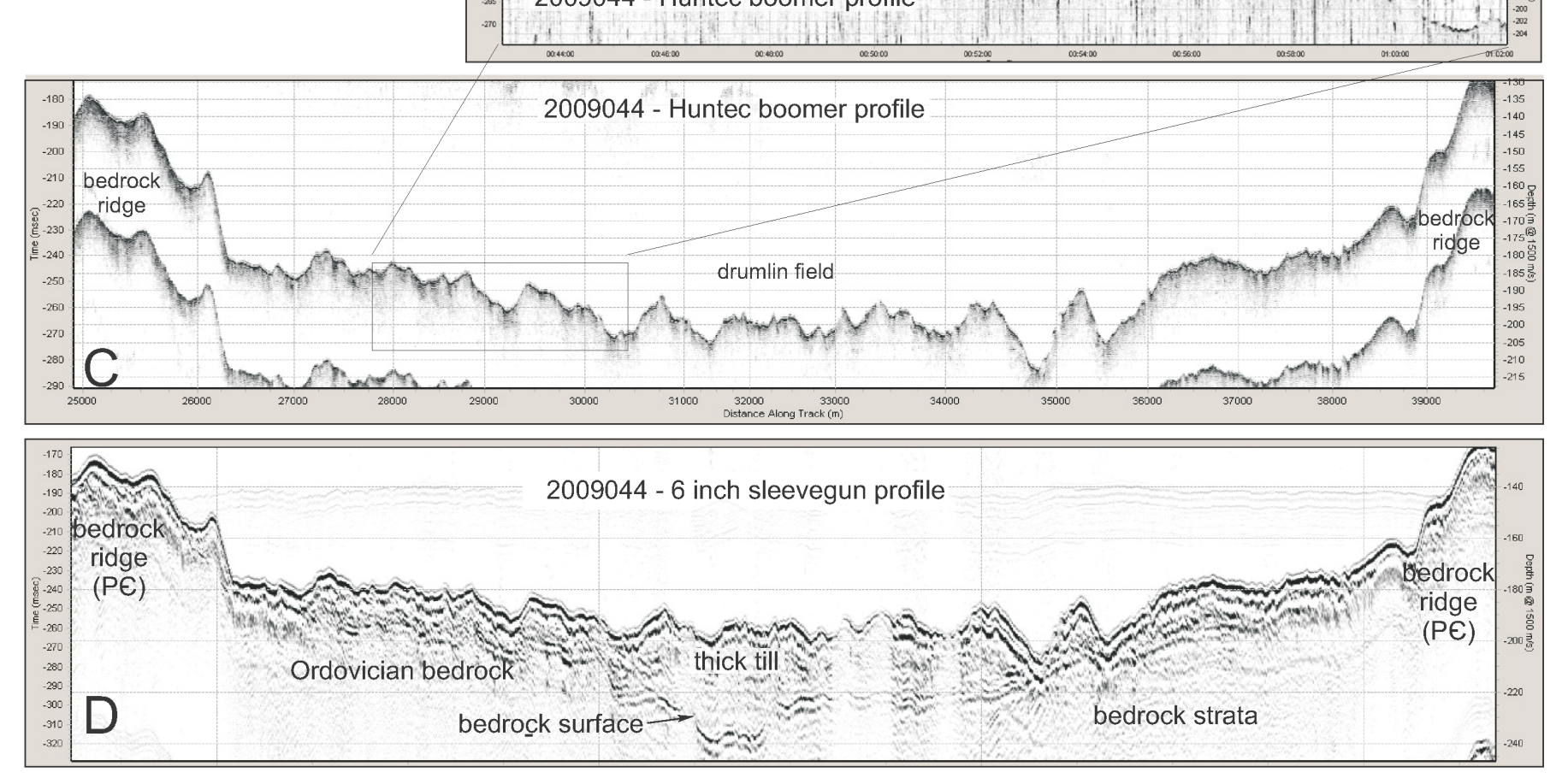






Bathymetric DEM from CHS spot depths with superimposed 2009044 sidescan and position of seismic profiles





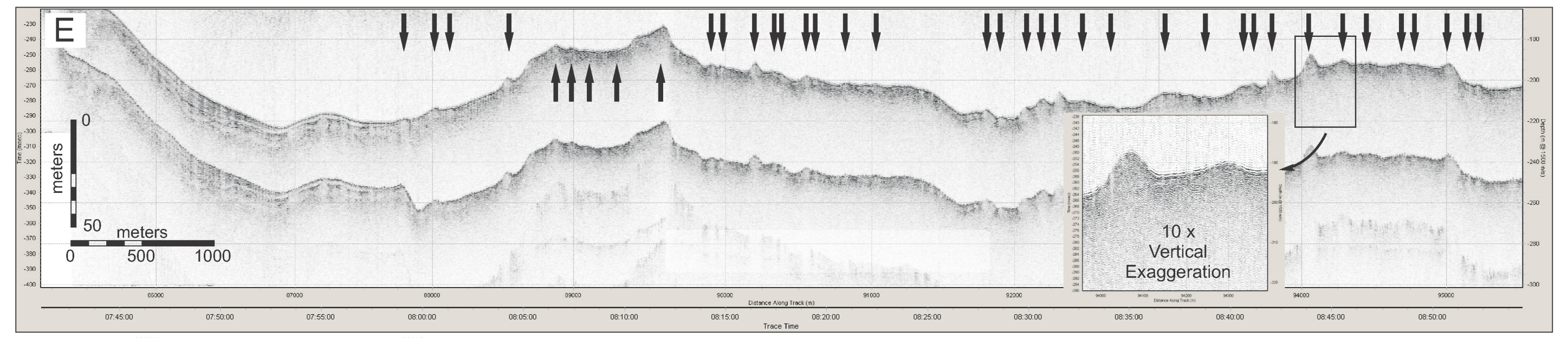
Drumlins and Moraines and ...*Iceberg Scours*?

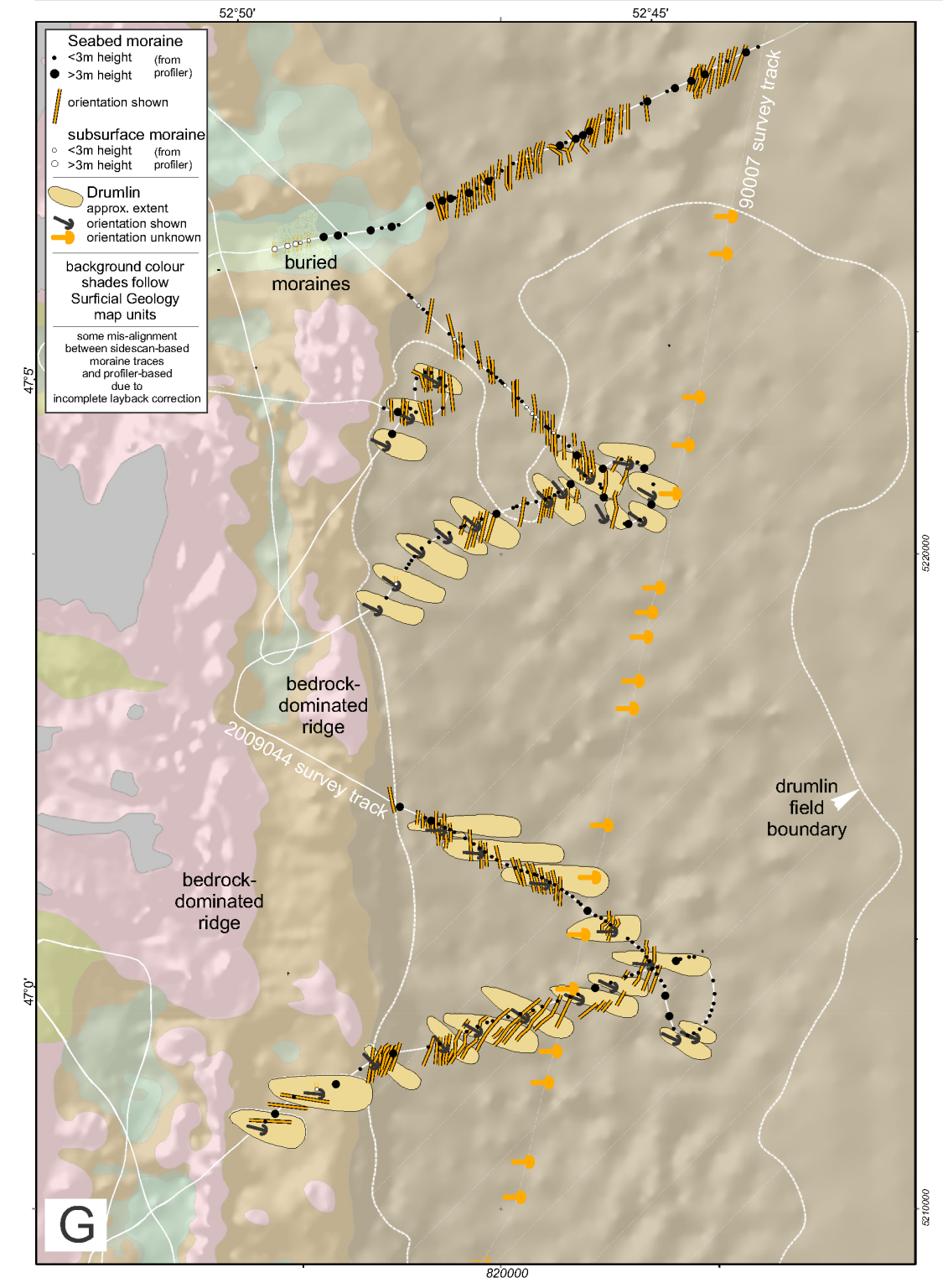
Box A shows the bathymetric digital elevation mode, DEM, with a superimposed geo-referenced sidescan image. Location of the Box B sidescan image is shown. Seismic profiler cross-sections located along the red line in Box A are shown in Boxes C (Huntec, high-resolution boomer) and D (Sleevegun). The sidescan (B) reveals near-orthogonal lineations which are also imaged in both the DEM and the seismic profiler data. The black rectangle in Box C shows the location of the corresponding sidescan image in Box B. The sleevegun (D) shows a thick till cover over Ordovician (stratified) bedrock which has a relatively low-relief surface character.

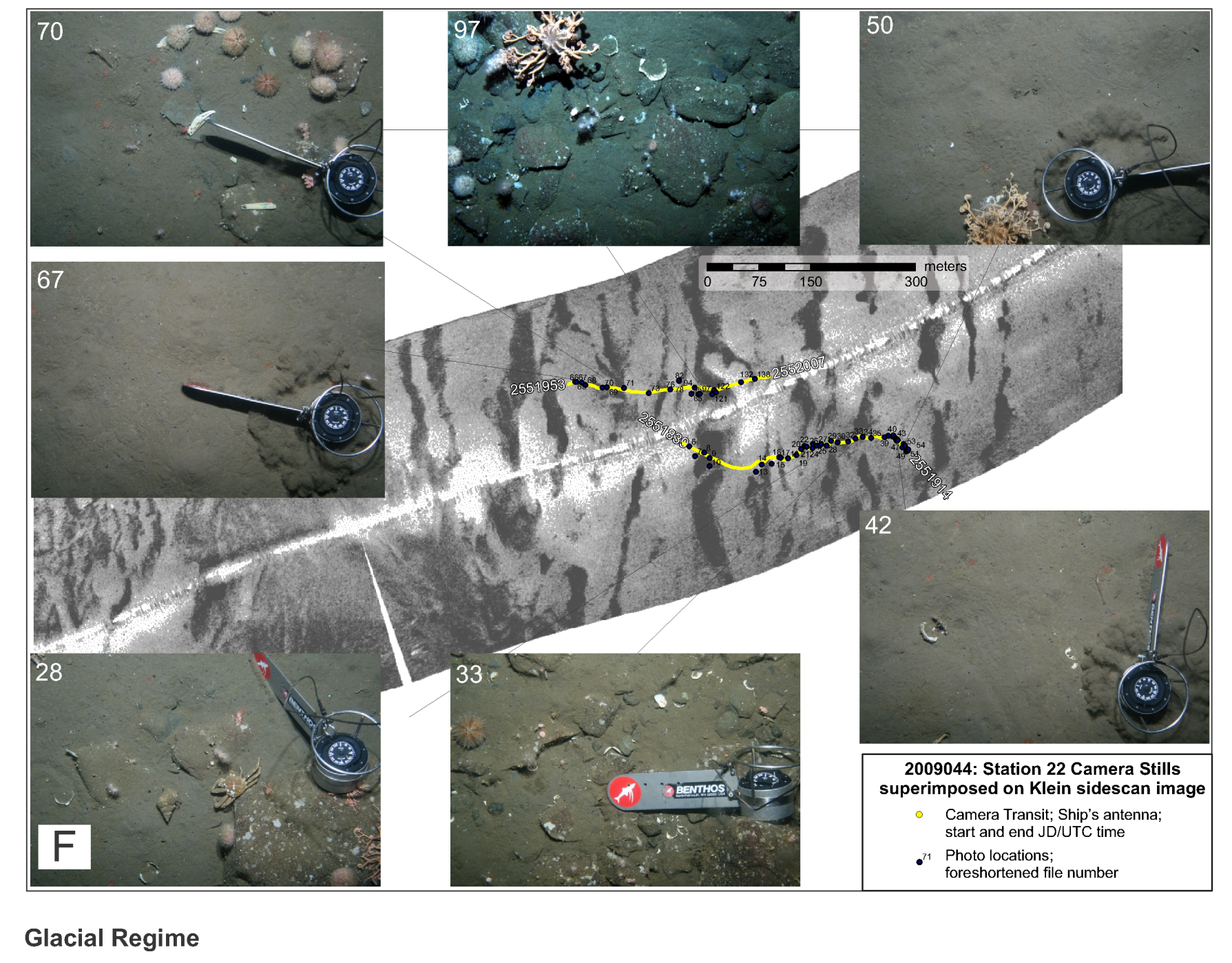
Although corresponding relief is imaged on the bathymetric DEM (A) and the seismic profiles, the spot depths are too widely spaced in the DEM to allow a confident sense of their orientation. The boomer profiler (Box C) shows the series of ridges and troughs in the till at higher resolution. A matching of features between the sidescan lineations and the coincident boomer (C) shows that the broader and larger relief ridges/troughs (red arrows) are subtle ESE-WNW oriented lineations on the sidescan and interpreted as fluting or drumlinization. The DEM clearly demonstrates the lack of linear continuity so these must be drumlins.

The smaller, superimposed ridges on the boomer profile (C) are marked by blue arrows and correspond to the ribbed moraines on the sidescan. They are up to 5 m relief and typically ~50 to 75 m across with spacings of 75 to 150 m. The largest ridge is 200 m across and asymmetric in profile. A larger field of the features is situated in a sub-basin of the Avalon Channel, Box E, each highlighted with an arrow. They also occur in the basin to the left, beneath the glacimarine sediment, marking the top of till. Box F shows selected seabed photographs from a transect across several ridges as identified from sidescan. They are cobble and gravel-topped with a thin sand cover on the till and possibly limited glacimarine ponded between the ridges. They are interpreted as ribbed (transverse) moraines (similar to Rogen or deGeer moraines). Box G shows their distribution.

While these moraines have similar profile relief as large iceberg scours, the sidescan confirms that they are not. This introduces the possibility that the "megafurrow" (iceberg scour) located NE of Cape Race (Fader 1985; no sidescan coverage) could instead be a set of two such parallel moraines. The significance is that mistakenly identifying a 10 m relief feature as an iceberg scour suggests that paleo-conditions *could* produce such an anomalously large scour. This large "end member" would have engineering implications in terms of iceberg size, strength and force to displace this till, all of which might be over-estimated were they glacially, not iceberg-formed.







Drumlin and Moraine Configuration

Relief in the DEM is too sparse to show drumlin orientation but the geophysical data combined with the DEM spot elevations allow determination of their approximate boundaries but only along the survey tracks. The white hatch outlines the field. Moraines, as traced from sidescan images show a dominant N-S orientation, normal to the drumlins.

Glacial Regime

Both the drumlins and subsequently-formed moraines indicate that at least the latest glacial ice imprint on the seabed flowed from the Avalon Cap and not along the Avalon Channel. This glacier must have been quite rigerous as drumlins are generally associated with streaming ice. The swing in moraine orientation (partly schematic yellow lines, box A) generally follows the contour trend of a bathymetrically-defined lobate body. This indicates that the glacier was thin enough for this subtle sub-glacial form to affect local flow direction and a lobate (slightly radially flowing) ice tongue developed during deglaciation. As no stratigraphic differentiation is visible in the thick till it is not possible to deduce any regional evolution in flow direction. The Avalon Channel, a large geomorphic feature, may have formed entirely through flow-transverse erosion (overdeepening). The pre-Cambrian rock clasts at it's sole are harder than the offshore bedrock, affording a mechanism for preferential erosion at and down-ice from the bedrock contact.

Acknowledgments

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