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High-resolution seismic transects of the upper continental slope off southeastern Canada

D.J.W. Piper and R.A. Brunt

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Preface

This Open File Report presents information on the distribution of glacial till beneath the upper continental slope from a series of transects off southeastern Canada. The widespread occurrence of glacial till beneath the upper slope has important consequences for foundation and exploratory drilling conditions on the upper slope. The limit of till influences the steep morphology at the heads of submarine canyon, important in the routing of any pipelines from deep water to the continental shelf. The distribution of till is important for reconstructing the glacial history of the area.

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Appendix: Presentation of transects

Abstract

Hard unstratified sediment underlies the upper continental slope off Nova Scotia and Newfoundland and terminates seaward in "till tongues" imaged in high-resolution seismic-reflection profiles. Sparse piston cores confirm that these units consist of sandy diamict. Shear strength measurements indicate that the diamict is overconsolidated. Most piston cores fail to penetrate this lithology and the abundance of iceberg scour pits, rather than linear furrows, confirms the strength of this sediment. Some diamict deposits are less highly consolidated and may be melt-out tills from the buoyancy line.

Tills that reach beyond the shelf pass into downslope thinning wedge shaped bodies (till tongues) on the upper slope that interfinger with proglacial muddy sediment deposited from proglacial sediment plumes. The termination of the till tongue also passes laterally into stratified proglacial sediment, commonly with more abundant thin sands and local erosional channels. In many cases, shallow failure on the slope has retrogressed to the limit of till, thereby obscuring this transition. The limit of the till tongue is interpreted as corresponding approximately to the ice-sheet buoyancy line. Evidence for deposition of "flow tills" or glacigenic debris-flows downslope from the buoyancy line is limited to a few local areas - off Trinity Trough, off Laurentian Channel, and on the central Scotian Slope. We infer that most mass flows accelerated downslope and evolved into turbidity currents.

The morphology of upper slope till varies considerably along the southeastern Canadian margin. The till limit is at maximum water depths of 250 to 700 m below present sea level, with deeper limits found seaward of ice streams. The geometry of stacked till tongues is a consequence of the volume of glacial supply and the rate of subsidence of different parts of the margin, with strongly aggradational sequences in areas of subsidence due to active salt tectonics and strongly progradational sequences in stable areas with major glacial supply. The most recent till tongue stacks appear to be retrogressive up-slope. Chronology of stacked till tongue successions were interpreted by interpolation between regional seismic stratigraphic markers and comparison with dated sediment flux to distal offshore settings. On the Scotian Slope, the most recent till-tongue dates from between 18.5 and 20.3 ka; off Laurentian Channel there was a maximal ice advance at about 16.5 ka; whereas off the eastern and northern Grand Banks the maximum ice advance was at about 25 ka. Stacked till tongue successions appear to date back to MIS 12 at 0.45 Ma.

1 Introduction

The upper continental slope off southeastern Canada is underlain by glacial till (e.g. Bonifay and Piper 1988; Mosher et al. 1989; Piper and MacDonald 2002), but the distribution and character of this glacial till is not well understood. This lack of understanding is in part because the overconsolidated nature of the till and the overlying veneer of reworked sand and gravel makes it difficult to sample. It is also not well imaged by high-resolution Huntec DTS seismic systems.

Incoherent seismic units on the upper continental slope that wedge out seawards have previously been identified as "till tongues" (Mosher et al. 1989), although whether composed of lodgement till, melt-out till (aqua-till) at the buoyancy line, or some sort of "flow till" or debris-flow deposit (cf. Powell and Stravers 1997; King et al. 1998) has not been resolved. King et al. (1998) described the morphology and lithology of glacigenic debris flows on a transverse trough on the Norwegian margin, attributing the seismic continuity between till and debrite facies to an association between the debris flows and glacial ice at the shelf break. Piper et al. (2002) argued that lodgement till is present on the upper slope off southeastern Canada, because piston coring of the "till tongue" surface in water depths of 300-500 mbsl has been unsuccessful on the Scotian Slope, although in several cases, the corer appears to have penetrated stiff sediment, which inverted the core catcher and was not retained. Furthermore, highly consolidated tills have been locally sampled on the continental shelf (King and Fader 1986), although on Sable Island Bank they are principally sand rather than diamict (King 2001). Boulder ridges and outcrops of diamict have been observed from submersibles and ROVs on the upper slope (Piper and Campbell 2002). The presence of iceberg pits, rather than scours, in multibeam imagery of the upper slope (Pickrill et al. 2001) argued for a hard substrate.

Where accommodation due to salt tectonics has allowed "till tongues" to form an aggradational stack on the upper slope (e.g. Piper et al. 2005), the similarities in the morphology of successive till tongues suggests that overall morphology is controlled by the processes that formed the till tongue and the ability of the material to resist failure. In many places, the limit of "till tongues" appears to be the upslope limit of retrogressive failure (Mosher et al. 2004).

The character of upper slope till deposits is important in understanding the style of deposition in deeper water on the continental margin. The high rates of sedimentation on the continental slope and rise at times of glacial maxima (e.g. Hill, 1984; Piper and Skene 1998;

Skene and Piper 2003) indicates that much of the sedimentation on the deep-water margin is related to glacial supply of sediment to the upper slope. The presence of morainal ridges on the upper slope seaward of major ice streams (Piper and MacDonald 2002) suggest that ice streams extended to the shelf break, confirmed by the water depth to which iceberg scours are found on the upper Scotian Slope. The presence of relatively strong diamict on the upper slope has also been confirmed through ROV observations at a scarp face on the upper slope (Campbell and Piper 2002). Nevertheless, the style of deposition of diamict on the slope is not well constrained. This style of deposition of glacial diamict is likely a controlling factor of slope morphology and stability (Mosher et al. 2004). Furthermore, the record seen in places of stacked "till tongues" is important for understanding glacial history of the region (Mosher et al. 1989; Piper et al. 2002, 2005). Widespread occurrence of glacial till beneath the upper slope has important consequences for foundation and exploratory drilling conditions on the upper slope. The limit of till influences the steep morphology at the heads of submarine canyon, important in the routing of any pipelines from deep water to the continental shelf (Campbell and MacDonald 2005).

2 Purpose and content of this report

This report presents data and preliminary interpretation on the distribution of till beneath the upper slope on the Scotian Slope and off the Grand Banks of Newfoundland. Data are organised by seismic transects across the upper slope (Figure 1). A series of samples from possible tills collected in 2004 have been described and grain size and strength data are presented. Where possible, dated seismic reflectors have been used to comment on the age of till tongues exposed on the seabed. The following parameters have been interpreted from seismic profiles and are presented in Table 1:

- regional gradient
- water depth of the first prominent failure scarp downslope from likely till
- water depth of inflection points in bathymetric profiles that might relate to the position of a buoyancy line
- water depth of the deepest iceberg scour
- water depth of the downslope limit of a seismically-recognised "till tongue".

3 Methods and nomenclature

Transects across the upper slope were taken from conventional single-channel seismic (sleevegun and Generator Injector (GI) gun) and Huntec deep-towed sparker records from GSC(A) cruises from 1999 to 2005. Both analogue and digital records were used. For technical information regarding acquisition of seismic profiles refer to appropriate cruise reports.

Cores used in this study were processed onboard the ship according to the standard GSC(A) core procedures manual (Mudie et al. 1984). In many cases, upper slope diamicts were recovered only from the cutter and catcher of the piston core barrel. Standard procedures were followed on all samples; colour was measured on every sample with a Minolta spectrophotometer. Shear strength was measured with the shearvane and the pocket penetrometer in cases where the sediment was very stiff. Samples were described and grain-size sub-samples taken from sediment suspected to be till.

Grain-size sub-samples were sieved at 4ϕ (63μm), the fine fraction analysed in the Coulter Laser Analyser and the coarse fraction (> 1 mm) saved for petrological analysis. Grain size distribution for the mud and sand fractions is in 0.15 ϕ increments. Petrological analysis of the granule fraction was similar to that of Piper and de Wolfe (2003).

Previously dated seismic stratigraphies, where available, were used from the literature. In Orphan Basin and Trinity Trough (Fig. 1a) the shallowest horizon (blue – 35.5 ka) was based on Hiscott and Aksu (1995). On central Scotian Slope (Fig. 1d) the stratigraphic scheme of Campbell (2000) and Gauley (2001) was used.

We use the term outer shelf for water depths to 80-200 m beyond which there is a significant increase in gradient (the shelf break). Seaward of major transverse troughs, the shelf break occurs in deeper water - 380 m in Laurentian Channel and 340 m in Trinity Trough. We follow previous usage on the Scotian margin (Piper 2001) in defining the upper slope as that area from the shelf break to a zone of prominent headscarps of failures typically at 400-600 mbsl. The middle slope extends to about 1200 mbsl, where there is a decrease in gradient to the lower slope. The continental rise begins with a further decrease in gradient at about 2000 mbsl (Heezen et al., 1959).

For convenience, we use the term "till" for overconsolidated poorly sorted deposits beneath the upper slope that return incoherent reflections in high-resolution seismic systems. This usage reflects the conclusions of this study.

4 Previous work

4.1 Regional studies on the southeastern Canadian margin

The nature and pattern of deposition on the upper slope during glaciations and the effect on upper slope morphology has been documented by numerous investigations. Several studies have used airgun seismic profiles to identify stacked successions of acoustically incoherent wedges that pinch-out down slope. The first systematic study was by Mosher et al. (1989) on the central Scotian Slope. These authors argued that the till tongues were of glacigenic origin and could be correlated with major glacial advances in the mid to late Pleistocene. The youngest till tongue was correlated with the MIS 2 last-glacial maximum (LGM). Radiocarbon dating back to 36 ka (Campbell 2000) and the observation that MIS 4 ice was more extensive in Nova Scotia than MIS 3-2 ice (Stea et al. 1998) led Gauley (2001) to correlate the penultimate till-tongue with MIS 4 and a slightly deeper till tongue with MIS 6. Seaward of Emerald Basin, Piper (2000) identified five different acoustic facies from airgun profiles on the upper Scotian Slope, of which one is composed of till and proglacial sediments reaching a maximum water depth of 600 mbsl. Piper et al. (2002) examined till tongues just east of Dawson Canyon and made a speculative correlation with glacial events back to MIS 12, based in part on correlation with observations in a piston core that penetrates almost 1 Ma of pelagic sedimentation on the J-Anomaly Ridge south of the Grand Banks of Newfoundland. An analogous correlation was made on St Pierre Slope by Piper et al. (2005), loosely constrained by a 30 ka radiocarbon date and correlation with the terrigenous sedimentation record on Bermuda Rise (Giosan et al. 2002). The distribution of upper slope till in Flemish Pass was discussed by Piper and Normark (1989) and by Piper and Campbell (2005) and its distribution to the south in Salar basin was reported by Toews (2003).

There are fewer studies that have attempted to understand upper slope till from studies of ultra-high resolution seismic profiles and cores. Bonifay and Piper (1988) used V-fin sparker profiles from the shelf and upper slope off St Pierre Bank. There, an acoustically incoherent unit (Unit E) shows a "change in acoustic reflectivity passing downslope [which] probably represents a change from overconsolidated till at the shelf break to slumped diamicts and proglacial sediments on the upper slope to a more homogeneous debris flow on the mid slope".

Campbell (2000) showed that the horizons approximately corresponding to the limits of till tongues on the central Scotian Slope had a higher proportion of sand beds. Gauley (2001) showed that mass-transport deposits were common downslope at the approximate stratigraphic horizon of till tongues. Piper and Macdonald (2002) cored till dating to the last glacial maximum, which was exposed by failure on the continental slope above Laurentian Fan. The regular down-slope limit of the till was mapped for 6 km along the upper slope as well as an abrupt termination of the unit, suggesting a coherent package rather than a debris flow. Shear strengths in the lower part of the diamict are 90-105 kPa, compared with ~ 60 kPa in over- and under-lying sediment, which suggests some overconsolidation, likely produced by ice loading.

Piper and Gould (2004) studied tills on the upper slope of the South Whale Subbasin from Huntec sparker high-resolution seismic profiles, but lacked core control. Features identified as tills in this area terminate at 300 mbsl with deposits interpreted as glacigenic debris flows extending into deeper water.

Bouldery ridges have been observed at the sea floor on the upper Scotian Slope from submersible dives (*PISCES* 1051 and 1053) and from remotely-operated vehicles (ROV) (*ROPOS* dive R643) and on one ROV dive an outcropping diamict was observed (ROPOS dive R644) (Piper and Campbell 2002). Diamict was seen from submersible on upper Laurentian Fan (Hughes Clarke et al. 1989) and appeared to be a consolidated block of till. In Orphan basin, cores from the floor of Orphan basin (Tripsanas et al. 2005) contain a red-brown muddy diamict that has remarkably homogenous physical properties over thicknesses of many metres. This facies has low shear strength and on the basis of its geometry in high-resolution seismic-reflection profiles is interpreted as a glacigenic flow till, similar to those found on the Norwegian margin (e.g. King et al. 1998).

Elsewhere on the continental margin, where acoustically incoherent mass-transport deposits are interpreted downslope from till tongues, in their acoustic character and from cores they consist of rotated blocks of proglacial sediment or mud-clast conglomerate (Piper et al. 1985, 1999; Gauley 2001).

4.2 A conceptual model for upper slope glacial till

Using the premise that ice sheets did terminate at or just beyond the shelf break, a depositional model can be proposed based on literature descriptions of tidewater glaciers (e.g. Powell 1984). At the edge of the shelf, ice sheets, acting in a similar manner to warm based glaciers on land, deposited a poorly sorted sediment sub-glacially which was overconsolidated by the overlying weight of the glacier and by shear at the base of the glacier. Where the ice-margin lifted off at a buoyancy line, sediment would be released as ice proximal till, with a similar composition to that deposited subglacially, but lacking the high shear strength and density that is characteristic of subglacial till. Finer sediment entrained in meltwater is released in buoyant plume and sediment from that plume and from melting of icebergs will settle out in front of the ice sheet as stratified glaciomarine sediment. Some subglacial meltwater may have sufficient sediment in suspension to flow hyperpycnally (Normark and Piper 1991; Hesse et al. 2004) and thus be responsible for the cutting of channels downslope from the ice limit. Both stratified glaciomarine sediment and till at the buoyancy line may fail. Syn-depositional failure may evacuate all sediments deposited in front of the ice sheet leaving only overconsolidated till from grounded ice.

5 Observations

5.1 Cores

On cruise HU 2004024, a concerted effort was made to sample acoustically incoherent diamicts on the upper slope, using both a piston corer and an IKU grab. Both techniques commonly lead to considerable disturbance of diamict samples. Four criteria were used to identify diamict as being lodgement till, following Hillebrand et al. (2005) and references therein.

1. High shear strength (> 40 kPa), which results in poor penetration by the 1 tonne corer.
2. Poor sorting. In some cases, source material for tills on the upper slope is likely quite sandy, but the presence of a significant gravel or granule component and a mud component was taken as evidence for till.
3. Lack of indigenous microfossils.
4. Petrographic character of the granule-gravel fraction and colour of the bulk diamict that is consistent with inferred ice streams and ice domes (Shaw et al., 2006) and the petrographic character of tills on the adjacent continental shelf (e.g. Bonifay and Piper, 1988; Piper and deWolfe, 2003).

Samples of diamict that have high shear strengths and poor sorting were recovered in four transects (Fig. 2). In Transect A off Trinity Trough, brownish diamict was sampled in four cores: 2004024 76, 77 and 78 and 2005033B 12, that appear to have sampled a retrogressive set of till tongues terminating in low failure scarps (Transect A, fig. c). Measured shear strengths range from 20 to 100 kPa. These samples contain a granule assemblage of sandstones, carbonate rocks, metamorphic rocks and granites (Table 2) rather different from those characteristic of northern ice-rafted sources (e.g. as summarized by Piper and deWolfe 2003). These diamicts pass downslope into ice-margin stratified deposits in cores 2005033B 9, 10, and 11 (located in Transect A, fig. d). Farther down slope, cores 2004024 74 and 75 contain a red-brown muddy diamict similar to that interpreted as glacigenic flow till on the floor of Orphan basin (Tripsanas et al. 2005). Further information on Orphan basin cores is available in Tripsanas et al. (2006).

In Transect H, core 2004024-12 was collected from an apparent failure scarp that exposes a till that might have been buried as much as 80 ms below the sea floor. The sample recovered a sandy diamict with shear strength measurements between 180 and 220 kPa. A normally consolidated sediment buried to 70 m would be expected to have a shear strength of about 120 kPa (Mulder et al. 1997). The sample contained subequal abundances of granules of sandstone, granite and carbonate (Table 2) of uncertain provenance.

In Transect I off Haddock Channel, core 2004024-11 bottomed in brownish sandy till with shear strengths of < 50 kPa. The sample contained a similar assemblage of granules to core 2004024-12.

In Transect O off Banquereau, IKU grab sample 4 recovered a pinkish muddy diamict with shear strength of 70 kPa. The sample was obtained from an apparent failure scarp at 250-280 mbsl. The sample contained principally reddish and grey sandstone and siltstone, with lesser pink granite and low grade metamorphic rocks, in the granule fraction (Table 2).

5.2 Iceberg scours

Sediment responds differently to the impact of icebergs depending on its strength, with pits predominant in hard substrates (Fader and Miller, 1986; Pickrill et al. 2001) and deeper longer furrows in softer sediment, such as unconsolidated till near the buoyancy line and glaciomarine sediment. A transition from shallower scours in shallow water, where overconsolidated till is suggested by higher reflectivity in Huntec sparker profiles, to deeper scours in more transparent proglacial sediments is seen in a number of transects and is best illustrated in transect C.

5.3 Glacial till marking the upslope limit of retrogressive failure

Multibeam bathymetric imagery from the central Scotian Slope (Pickrill et al. 2001; Mosher et al. 2004) shows that in many areas, retrogressive failures appear to terminate on the upper slope near the limit of till inferred from seismic-reflection profiles. Similarly, in other transects, till identified from seismic sections appears to terminate downslope against a failure surface (e.g., Transects C, E, I). In some cases, the limit of failure is marked by an inflection point in the bathymetry and a corresponding change in gradient in underlying reflections (e.g., Transects G, O). Elsewhere, there is an inflection point, but underlying reflections that parallel the gentler gradient upslope from the inflection point are truncated (e.g. Transects A, H), implying that the inflection point is a result of failure.

5.4 The nature of the till to proglacial sediment transition in unfailed areas

Evidence for failure of proglacial sediment may be found in areas where failure of the ice proximal and distal sediments has not occurred, such as in the western section of the Scotian slope where acoustically incoherent bodies (till tongues) interfinger with stratified sediment, believed to be stratified proglacial sediments (transects K, L, N, R, S). The transition is gradual. As noted by Bonifay and Piper (1988), till tongues on the outer shelf and uppermost slope tend to be quite highly reflective, suggesting strong impedance contrasts between surficial sediment and overconsolidated till. Passing downslope, reflectivity becomes less (e.g. Transect C) and discontinuous stratification may appear within the till tongue (e.g. Transects L, N, R). In some cases, the transition from incoherent to stratified sediment takes place by lateral facies change (e.g. Transect N), whereas in other cases the till tongue appears to pinch out (e.g., Transect R). In strike lines close to the till tongue limit, channels are visible in some seismic sections (e.g., Fig. 8 of Piper et al. 2005).

6 Discussion

6.1 The nature of till tongues

Hard unstratified sediment underlies the upper continental slope off Nova Scotia and Newfoundland and terminates seawards in "till tongues" imaged in high-resolution seismic-reflection profiles. Sparse piston cores confirm that these units consist of sandy diamict and shear strength measurements indicate that the diamict is overconsolidated. Most piston cores fail to penetrate this lithology and the abundance of iceberg scour pits, rather than linear furrows, supports the interpreted strength of this sediment. Some diamict deposits are less highly consolidated and represent tills deposited at or near the buoyancy line of the ice sheet. Near the buoyancy line, the thickness of till decreases, it is acoustically less reflective, and interstratified sediment appears more important. The termination of the till tongue passes laterally into stratified proglacial sediment, commonly with more abundant thin sands and local erosional channels. In many cases, shallow failure on the slope has retrogressed to the limit of till, thereby obscuring this transition. The limit of the till tongue is therefore interpreted as corresponding approximately to the buoyancy line.

6.2 Glacigenic debris-flows beyond the buoyancy line

Evidence for deposition of "flow tills" or glacigenic debris-flows downslope from the buoyancy line is limited to a few local areas - off Trinity Trough, off Laurentian Channel, and on the central Scotian Slope. Off Trinity Trough, the glacigenic debris-flow deposits closely resemble upper slope till in their colour and petrography (Tripsanas et al. 2005). Sedimentologically, they resemble glacigenic debris-flow deposits described from the North Sea fan as flowing directly from upper slope tills (King et al. 1998). As on the North Sea fan, the regional slope gradient is low at 1.7°.

Off Laurentian Channel, upper slope acoustically incoherent units terminate at a consistent water depth of about 700 mbsl, overlying and passing downslope into a gullied erosion surface (Piper and MacDonald 2002). The only deep-water diamict appears to be blocks of overconsolidated till, such as illustrated by Hughes Clarke et al. (1989, their Fig. 5.6) from about 1950 mbsl, which could have been transported by sediment failure on the steep slope, such as discussed for Transect O below.

The evidence from Trinity Trough and the Norwegian margin suggests that glacigenic debris-flows may be fed by rapid delivery of glacial till to the upper slope by the deforming bed beneath an ice stream (Alley 1991). The presence of such deposits on low gradients such as the western Orphan Basin slope and the North Sea fan, but their absence on steeper and dissected slopes such as that above Laurentian fan suggests that debris flows may transform to turbidity currents where gradients are sufficient to create a hydraulic jump (Weirich 1989; Piper et al. 1999).

Clear evidence for glacigenic debris-flow deposits on continental slopes between ice streams is lacking. It is uncertain whether this is because they do not form, because the rate of till delivery to the ice margin is too low, or because those that form accelerate down steep slopes and evacuate the region.

6.3 Failure near the till limit

In several transect, there is evidence from Huntec seismic-reflection profiles that bodies of till from near the buoyancy line have failed along weaker underlying stratified sediments, presumably muds with thin silt beds. In Transect A, an uppermost till has a prominent terminal scarp at 0.66 s (TWTT) and has a very thin stratified interval above a deeper till tongue that extends downslope to 0.78 s, suggesting that not only stratified glaciomarine sediment related to the till tongue, but some of the till itself has failed. In Transect B (Figure b), a deeper till also terminates in a scarp which passes downslope into a mass-transport deposit that has not been cored. As argued above, the lack of stratification and the high shear strength of the till samples in Transect H also suggests that till has failed here. In transect O, till with a shear-strength of 70 kPa is exposed on a scarp and appears to have evacuated above a surface that has very deep iceberg scours, suggesting the presence of weak glaciomarine sediment.

Several previous studies have documented the timing of failure on the continental margin and have argued that most failures, occurring in multiple drainage systems, are the result of earthquake triggering (Mosher et al. 1994; Piper et al. 2003). Many failures are demonstrably retrogressive (Piper et al. 1999; Mosher et al. 2004) and many are initiated in deep water. We conclude that when such retrogression reaches the upper slope, it may result in failure of low-strength till deposited close to the buoyancy line, particularly where it is underlain by weak layers of glaciomarine sediment (Campbell 2000). We also conclude that the lack of failure farther up the slope is because the till is stronger and interbedded weak layers are lacking.

The products of such retrogressive failures are either blocky slump deposits (e.g. Piper et al. 1985, 1999; Mosher et al. 1994) or are mass-transport deposits consisting principally of mud-clast conglomerate, where the mud clasts comprise proglacial muddy sediment. Clasts of till are not seen in such deposits, but the mud-clast conglomerate in some cases is overlain by either gravelly diamict or sorted gravel to coarse sand (Jenner et al. 2006; Tripsanas et al. submitted), which may have been sourced by the break-up of low-strength till.

It is not known whether all till failure takes place as a result of rare earthquake-triggered events, or whether some failure is a result of depositional oversteepening. The record of deep-water turbidites might provide an answer to this question, but suitable and sufficient samples are not available.

6.4. The relationship between till tongues, inflection points and ice margins

Many of the transects examined clearly show in Huntec seismic-reflection profiles that the general form of the most recent till deposits is retrogressive, with progressively younger till deposits terminating in progressively shallower water (e.g. Transects A, B, O). Chronology from cores downslope in both Orphan Basin (Tripsanas et al. 2005) and on St Pierre Slope (Piper et al. 2005) shows that these groups of tills all date approximately from MIS 2.

In areas such as the central Scotian Slope and St Pierre Slope, where there is good core control on the age of till tongues, there is a thick proglacial stratified succession both underlying and overlying the prominent till-tongue horizon, suggesting that the deposition of the till tongue took place over only a short period of time compared with the total time of glaciomarine sedimentation.

Thus the significance of a till tongue termination, particularly one imaged by airgun seismic-reflection profiles, is that it represents only the maximum extent of the ice sheet and may have been of quite short duration. In shallower water on the upper slope, there is evidence for progressively longer and longer periods of till deposition (Transect A, O). The prominent inflection points in many slope profiles, clearly seen in Transects B and C, appear to be constructional features of till and represent points of prolonged stillstand of the ice margin.

6.5 Regional variation in the depth of ice-margin positions

Variations in the maximum water depth of ice margin positions are tabulated in Table 1. There appears to be no simple pattern of maximum water depth, at least in part because till tongues of different ages have been imaged. The limit generally lies between 400 and 600 mbsl.

6.6 Timing of the most recent till-tongue maximum

Few new insights were gained from this study as to the timing of the most recent till-tongue maximum on the continental slope. On the central Scotian Slope, the most recent till-tongue dates from between 18.5 and 20.3 ka (Gauley 2001). Off Laurentian Channel, there was a maximal ice advance at about 16.5 ka (Piper and MacDonald 2002). On the St Pierre Slope, McCall (2006) dated till tongues at 12.5 ka (following Bonifay and Piper, 1988) and just before 30 ka (Piper et al. 2005). Off the eastern and northern Grand Banks, the maximum ice advance appears to have been at about 25 ka (Piper and Campbell 2005), although there is no direct dating of till tongues in this area. Off Trinity Trough, the glacigenic debris-flow deposits appear to date between Heinrich event 1 and 2 (Tripsanas et al. 2005), thus likely corresponding to the classic Last Glacial Maximum in MIS 2.

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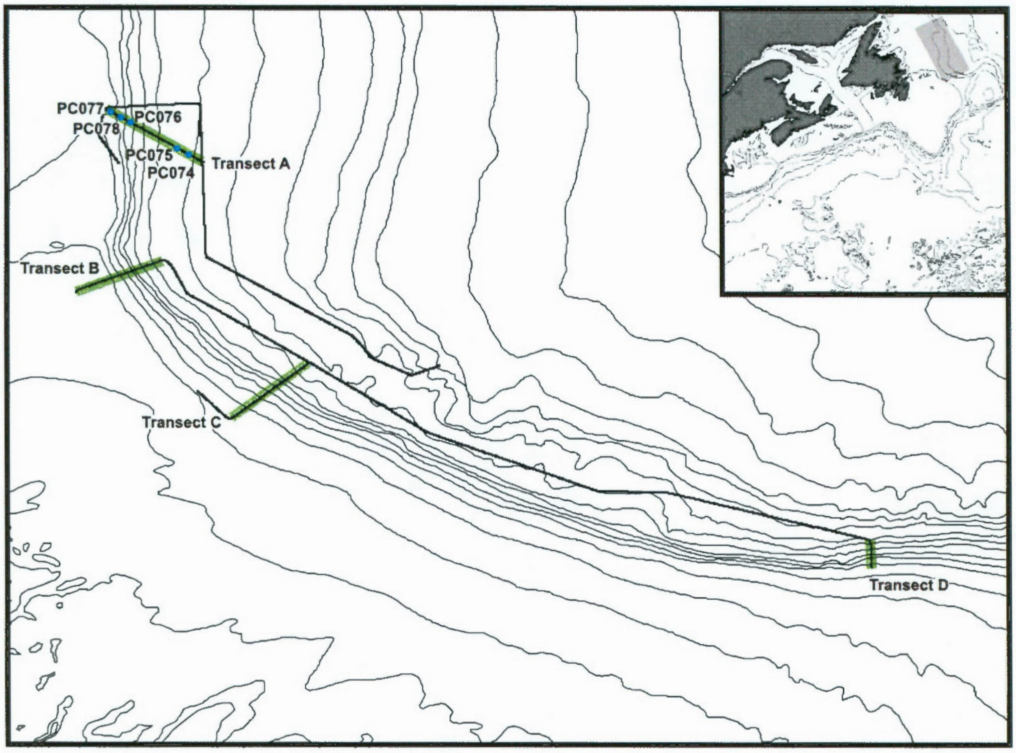
a)



b)

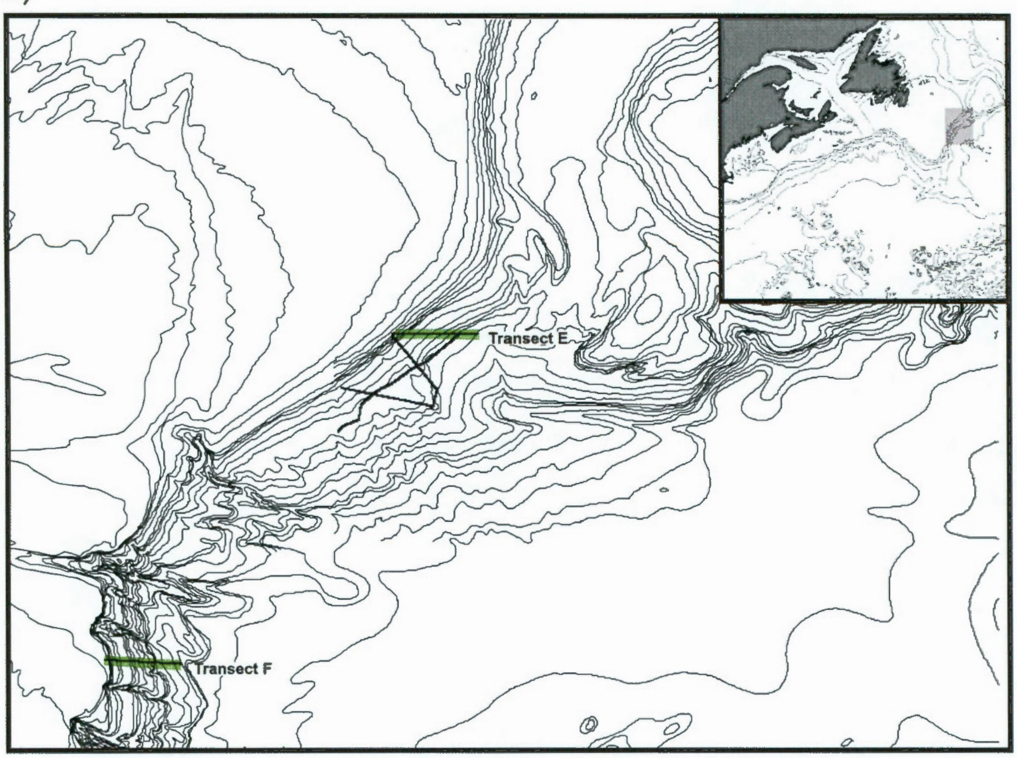
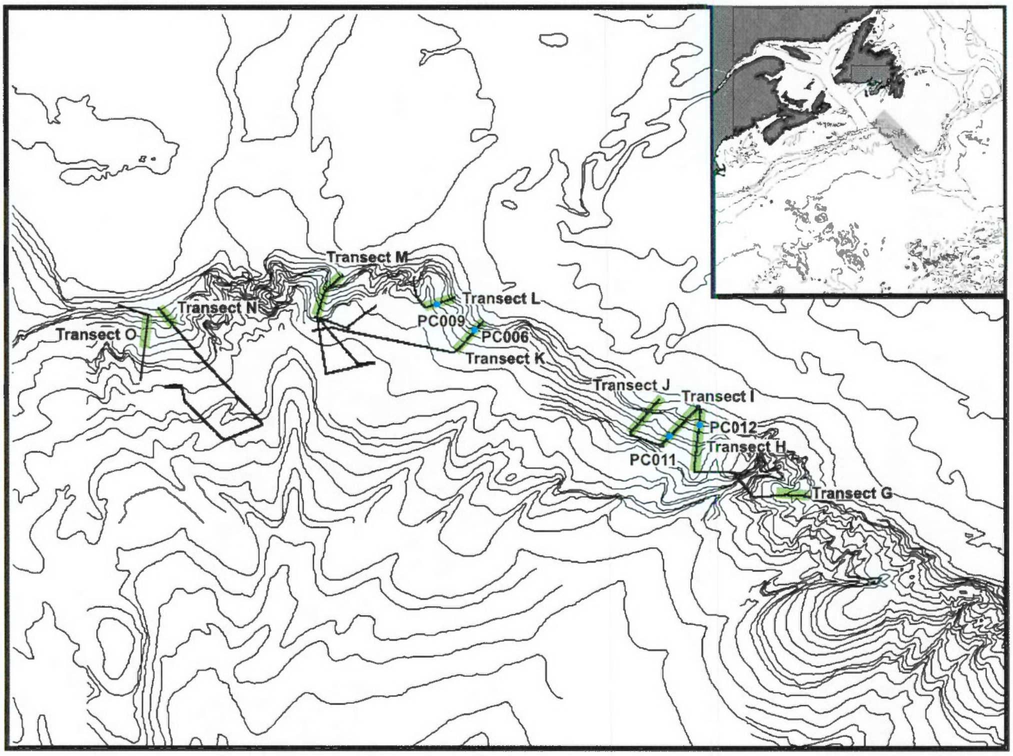
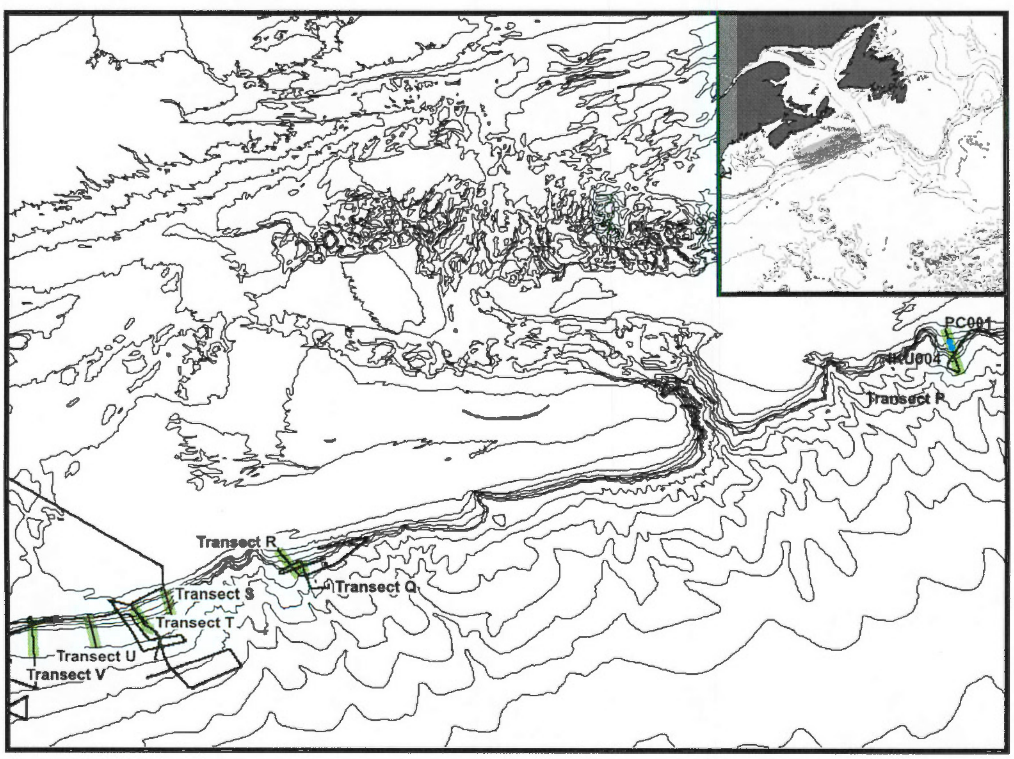


Figure 1 a to d: Location of slope transects and samples used in this study. a) Orphan Basin and Trinity Trough b) Grand Banks c) St. Pierre Slope and Narwhal area d) Scotian Slope.

c)


Transect M
Transect L
Transect N
Transect O
PC009
PC006
Transect K
Transect J
Transect I
PC012
PC011
Transect H
Transect G

d)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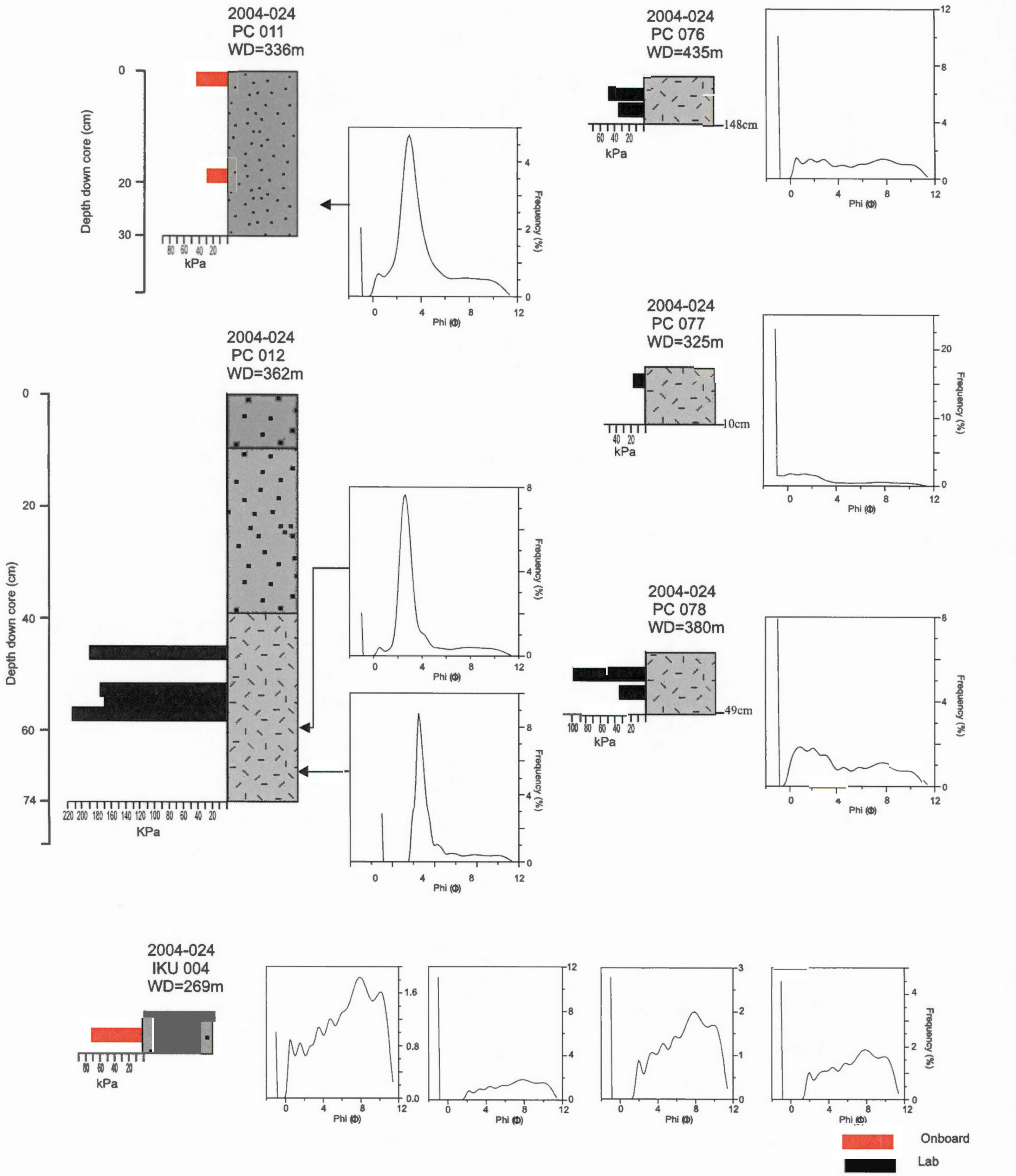


Figure 2: Description of diamict samples used in this study and results of grainsize analysis performed on sub-samples collected as part of this study (location of cores in figure 1).

Table 1: Summary of key features in each transect.

Transect					Features							
					scarp(s)				inflection point			
Map number	Cruise #	start	end	Regional slope angle (degrees)	daytime	water depth	latitude	longitude	daytime	water depth	latitude	longitude
S	2002046	2282255	2290044	3	none				none			
R	99036	2452155	2452315	2.5	none				none			
Q	81044	3461215	3461406	5								
P	2001048a	2450520	2450545	5	2450534	400.00	43.238548	-60.922791	2450546	325.00	43.250019	-60.92844
O	2003033	1672312	1680057	3.5	1680001-1680002	no arcview bathymetry	44.270908	-57.822652	1680001			
N	99036	2322145	2322230	2	2322245	610.82	44.813150	-55.626840	none			
M	2002-046	2470014	2470213	5	2470125-2470130	411.48-453.54	44.968760	-54.980650	2470140	292.61	45.001080	-54.943340
L	2003033	1710635	1710745	3.9	1710701-1710703	479.15-524.87	44.920817	-54.477402	1710647 (airgun)	309.07	44.929920	-54.451240
K	2003033	1710242	1710407	2.8	1710318	587.04	44.763712	-54.378643	1710343	294.44	44.800332	-54.346005
J	2001-043	2270726	2270921	4.5	2270835	336.536	44.45328	-53.61013	2270835	336.536	44.45328	-53.61013
I	2001-043	2270330	2270550	4	2270430	448.105	44.410610	-53.459450	2270410	257.89	44.433680	-53.436270
H	2001-043	2270010	2270335	2.1	2270255	279.837	44.435920	-53.392720	2270255	279.84	44.435920	-53.436280
G	2004-024	1722028	1722122	3.5	1722111	523.04	44.094421	-52.921661	1722120	358.44	44.093151	-53.436280
F	2004-024	1732228	1740136	6					1732329	314.55	44.431702	-53.436280
E	2001-043	2242244	2250157	4	2250130	532.239	46.000010	-47.657090	none			
D	2003-033	1770940	1771054	6	1771010	546.87	48.094667	-47.901835	1771021	459.08	48.077273	-47.901173
C	2003-033	1760548	1760756	3	1760705	358.48	48.569892	-49.703523	1760739	281.67	48.528483	-49.761845
B	2003-033	1752328	1760131	2.2	1760050	438.96	48.939257	-50.089640	1760015	267.03	48.913913	-50.162250
A	2004024	1890600	1891000	1.7	1890848-1890851	548.64-574.24	49.33939-49.336311	-50.030010	1890743	325	49.404572	-50.150101

Transect					Features							
					deepest iceberg scour				Limit of till			
Map number	Cruise #	start	end	Regional slope angle (degrees)	daytime	water depth	latitude	longitude	Daytime	Water depth	latitude	longitude
S	2002046	2282255	2290044	3	2282335	650	42.880870	-62.208230	2282311		42.91183	-62.21024
R	99036	2452155	2452315	2.5	2452243	565.1	42.949040	-61.675490	2452245	565.1	42.94904	-61.67549
Q	81044	3461215	3461406	5								
P	2001048a	2450520	2450545	5	2450521	600.00	43.224701	-60.917759	2450526	500.00	43.230141	-60.91964
O	2003033	1672312	1680057	3.5	1680020	no arcview bathymetry	44.235877	-57.810370	1680022			
N	99036	2322145	2322230	2	2322240	552.3	44.819060	-55.631860	2322228	713.23	44.79516	-55.61109
M	2002-046	2470014	2470213	5	2470103	610	44.936130	-54.994390	2470134	411.48	48.98009	-54.96751
L	2003033	1710635	1710745	3.9	1710700	479.15	44.921440	-54.475520	1710704	524.87	44.91844	-54.48505
K	2003033	1710242	1710407	2.8	1710300	731.52	44.736898	-54.402375	1710317	587.04	44.75932	-54.38269
J	2001-043	2270726	2270921	4.5					2270842	290.81	44.45968	-53.44206
I	2001-043	2270330	2270550	4	2270520	1444.91	44.352800	-53.517300	2270434	557.85	44.40516	-53.46499
H	2001-043	2270010	2270335	2.1	2270145	636.492	44.338320	-53.404000	2270225	446.28	44.39444	-53.39753
G	2004-024	1722028	1722122	3.5	1722045	596.19	44.098579	-52.976372				
F	2004-024	1732228	1740136	6	1732343	570	44.430168	-48.968761	1732305	160.93	44.43426	-49.04445
E	2001-043	2242244	2250157	4	2252348	396.893	46.00026 (actually from day 224)	-47.427170	2250129	532.239	46.00000	-47.65709
D	2003-033	1770940	1771054	6	1771005	623.69	48.102633	-47.902287	1771005	623.69	48.10263	-47.90228
C	2003-033	1760548	1760756	3	1760625	581.62	48.616128	-49.638348	1760740	281.67	48.52725	-49.76357
B	2003-033	1752328	1760131	2.2	1760130	618.2	48.966217	-50.012823	1760015	267.03	48.91767	-50.15216
A	2004024	1890600	1891000	1.7	1890915	665.68	49.308800	-49.973579	1890827	471.83	49.36031	-50.06854

Table 2. Granule petrology of diamicts

Cruise	Core	Depth (cm)	No of granules counted	Percentage by grouped lithologies																	
				Hematite-stained quartz	Frosted quartz	Other quartz	Feldspar	Black-and-white granite	Pink granite	Rhyolite, basalt, diabase	White carbonate	Grey Carbonate	Other Carbonate	Pink, red, brown sandstone and siltstone	Grey, green, black sandstone and siltstone	Quartz sandstone	Carbonate-rich Sandstone	Well lithified sandstone	Meta-sediment	Amphibolite	Other
				Number of lithologies included in group																	
				3	1	4	2	2	2	4	1	2	4	7	11	3	1	2	9	1	3
2004-024	PC011	4-7	20	5	10	0	0	20	5	10	5	5	10	0	15	0	0	5	10	0	0
2004-024	PC012	62-64	24	0	0	17	0	13	0	4	4	17	8	0	17	0	0	0	17	4	0
2004-024	PC012	70-73	23	0	0	22	0	13	0	0	4	26	4	4	0	4	0	9	9	0	4
2004-024	PC061	593-597	16	6	0	0	0	6	0	0	0	6	0	6	6	25	0	13	19	6	6
2004-024	PC061	655-657	14	14	0	0	0	0	0	14	0	7	7	14	7	7	7	7	7	7	0
2004-024	PC076	cutter	40	5	0	3	0	0	10	8	5	8	0	5	13	5	0	23	8	8	3
2004-024	PC077	0-3	59	5	7	5	0	12	3	3	0	2	2	10	27	2	0	7	14	0	2
2004-024	PC078	3-7	85	5	7	0	1	4	2	6	4	0	5	5	21	13	0	12	14	0	2
2004-024	0041K4	Sample 1	11	0	9	0	0	9	18	0	0	9	9	9	27	0	0	0	9	0	0
2004-024	0041K4	Sample 3	14	0	0	0	0	21	7	0	7	7	21	0	14	14	0	0	0	0	0
2004-024	0041K4	Sample 8	15	7	0	0	0	7	13	0	13	33	0	7	7	0	0	7	0	7	0
2004-024	0041K4	Sample 12	35	6	3	3	0	3	3	3	9	20	20	11	3	6	0	6	6	0	0

Transect A			
cruise #	start	end	regional slope angle (degrees)
2004024	1890735	1891010	1.7

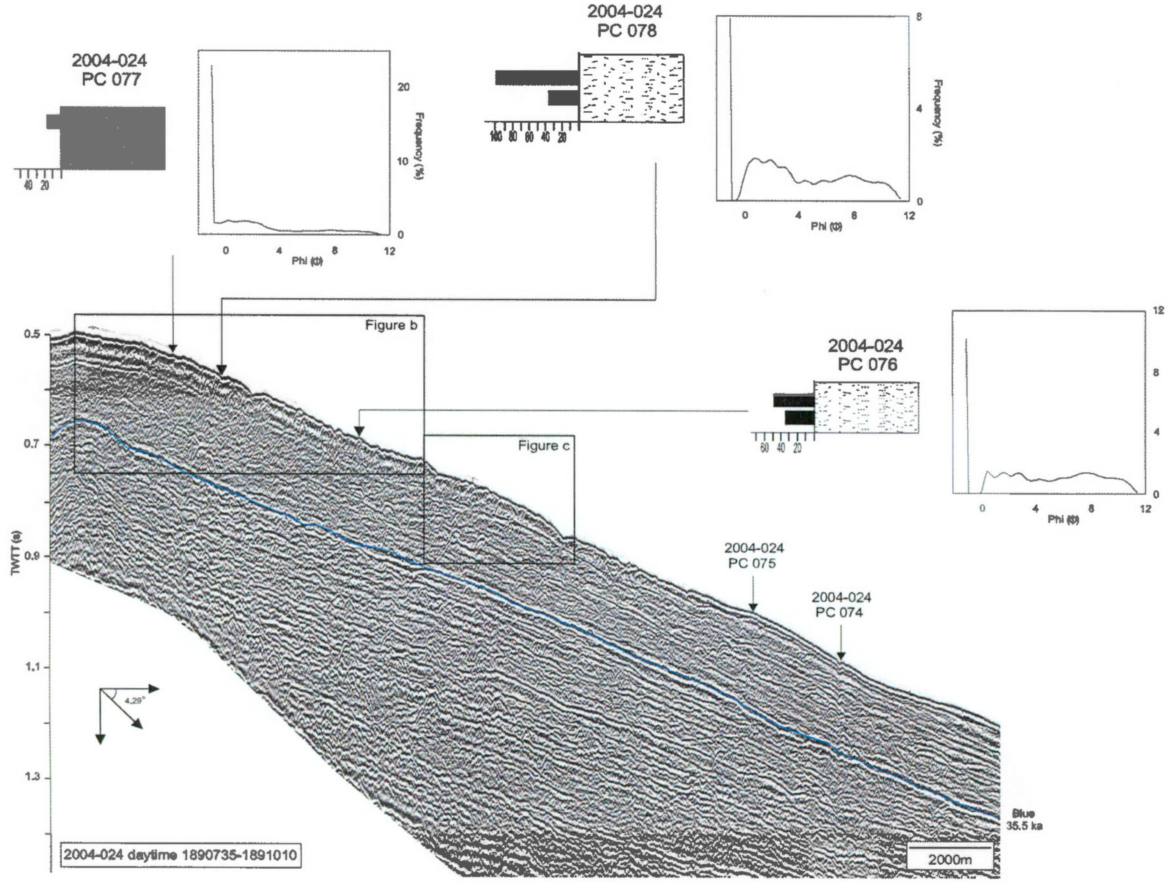
scarp			
daytime	water depth (m)	latitude	longitude
1890848-1890851	548.64-574.24	49.33939-49.336311	-50.030010

inflection point			
daytime	water depth (m)	latitude	longitude
1890743	325	49.404572	-50.150101

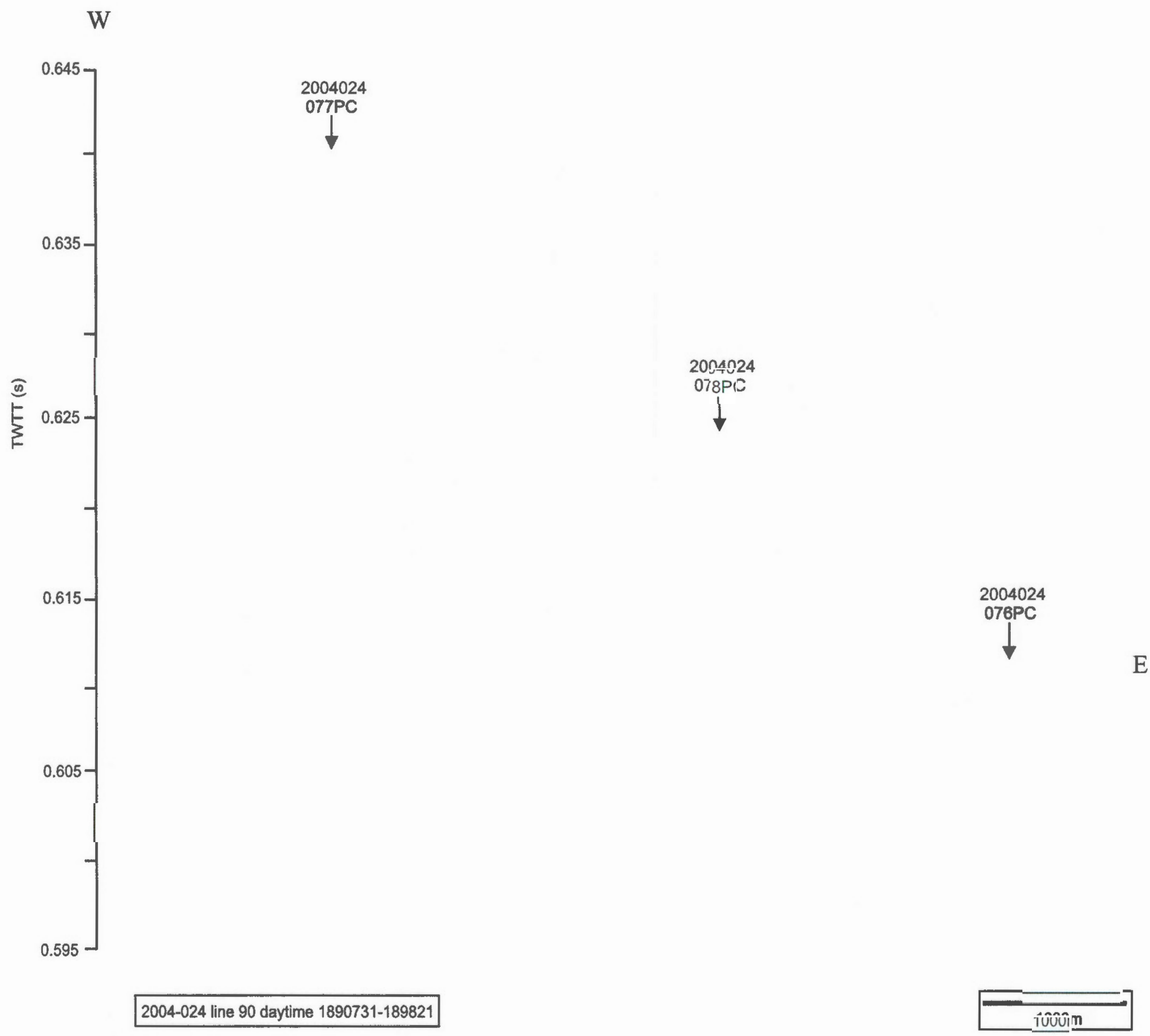
deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
1890915	665.68	49.308800	-49.973579

limit of till			
daytime	water depth (m)	latitude	longitude
1890827	471.83	49.36031	-50.06854

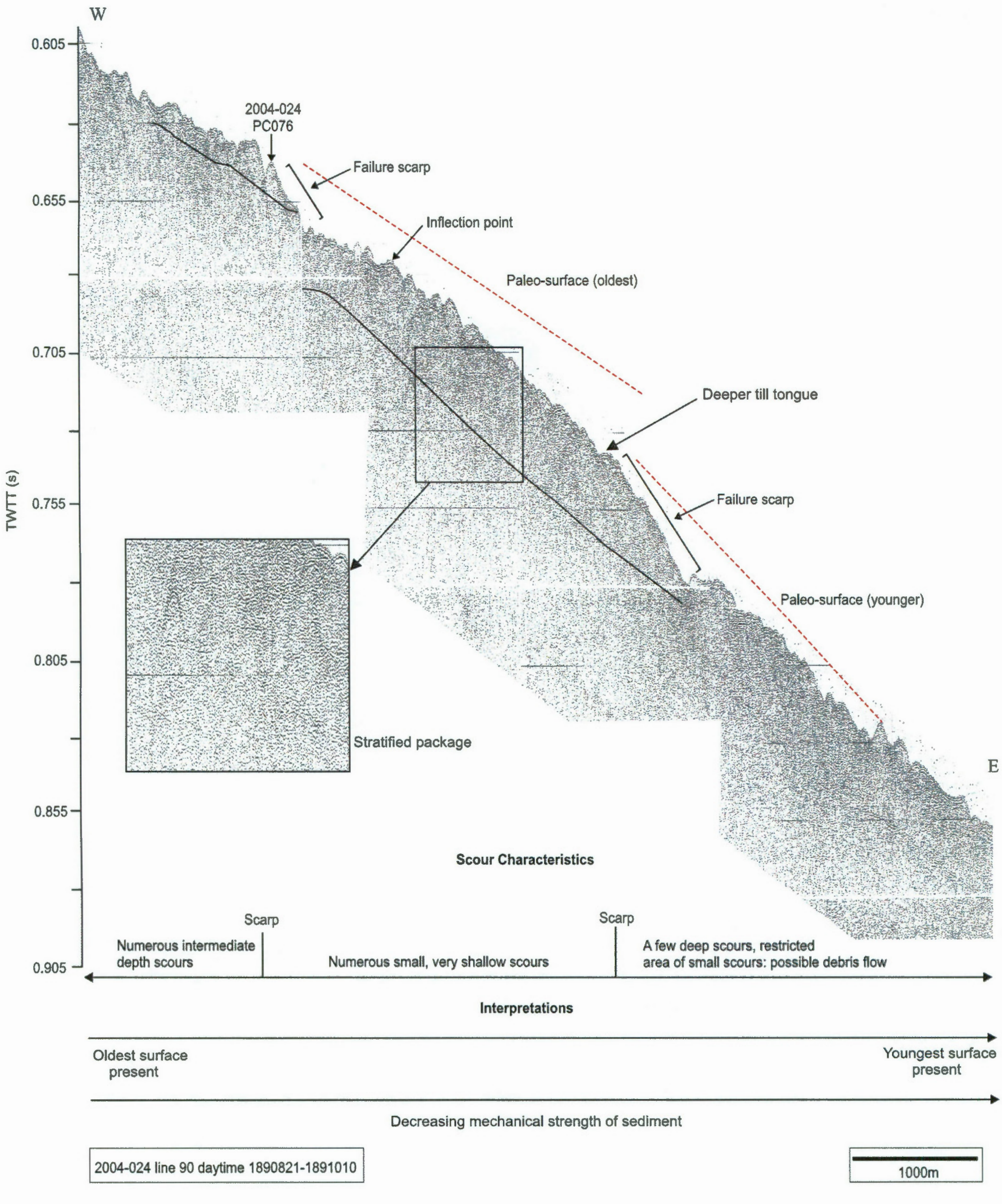
Region: Orphan Basin (Trinity Trough)
Previous work: Hiscott and Aksu (1996); Tripsanas et al. (2006).
Notes: line contains core sites 74 to 78, and additional cores from 2005-033B (Fig. d).
Style: till cut off at failure scarp – no facies transition to stratified proglacial sediment because it has failed
Age: 35.5ka blue reflector (Hiscott and Aksu, 1996) – correlated from Orphan Basin.
Interpretation: At least two failure surfaces. May be stepping till tongues.
Down slope mass transport deposit – may be flow till or failed proglacial sediment.
Huntec shows position of failure scarps and inferred, pre-failure paleo-surfaces. Change in scour characteristics associated with failure scarps are displayed along the bottom, showing a change from numerous intermediate depth scours to numerous small, shallow scours to rare, deep scours.



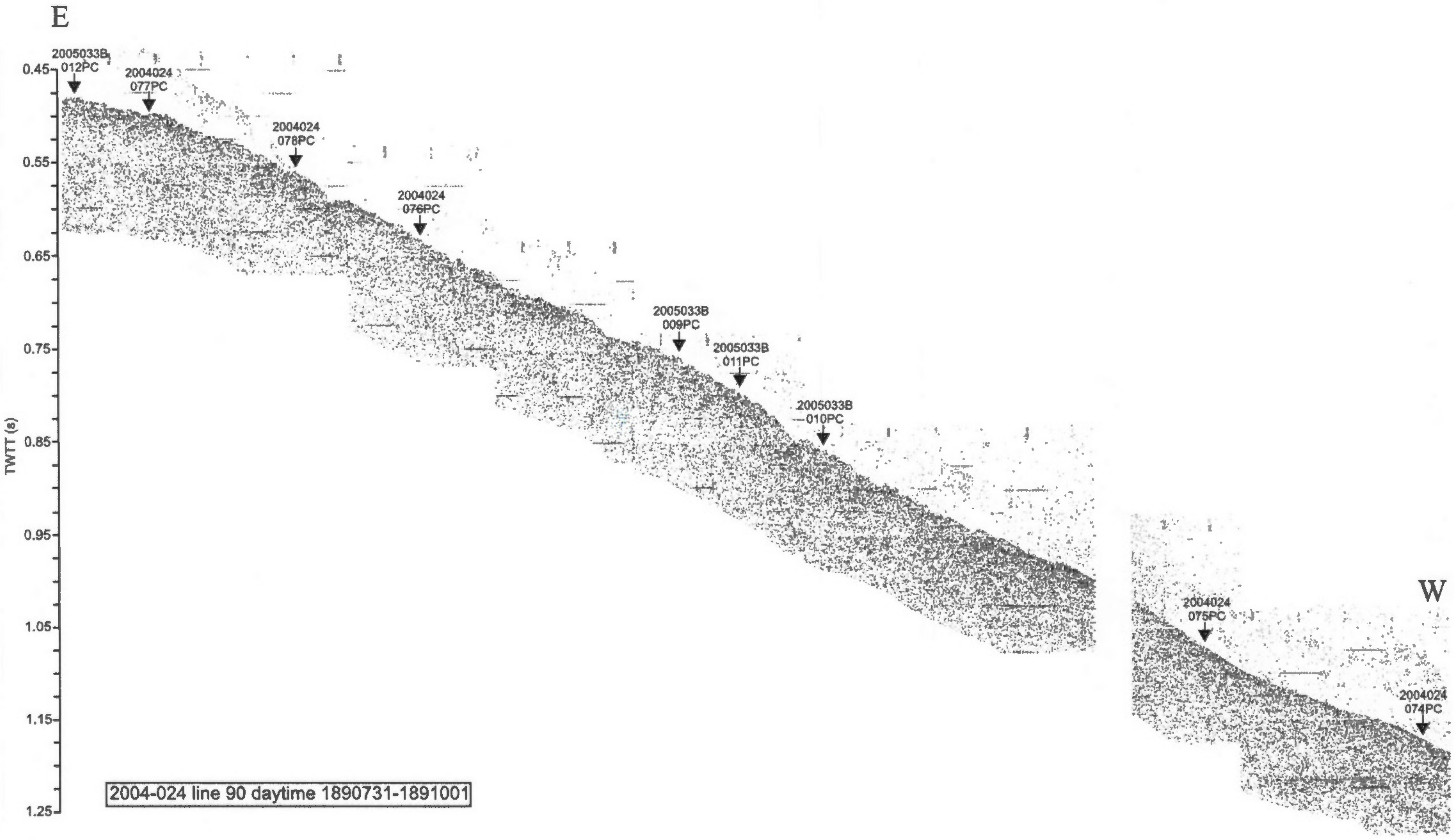
Transect A, figure a



Transect A, figure b: Huntec profile on upper slope. Location in figure (a).



Transect A, figure c: Huntec profile on middle slope. Located in figure (a).



Transect A, figure d: Huntec profile corresponding to figure (a) showing 2004 and 2005 cores.

Transect B			
cruise #	start	end	regional slope angle (degrees)
2003-033	1752328	1760131	2.2

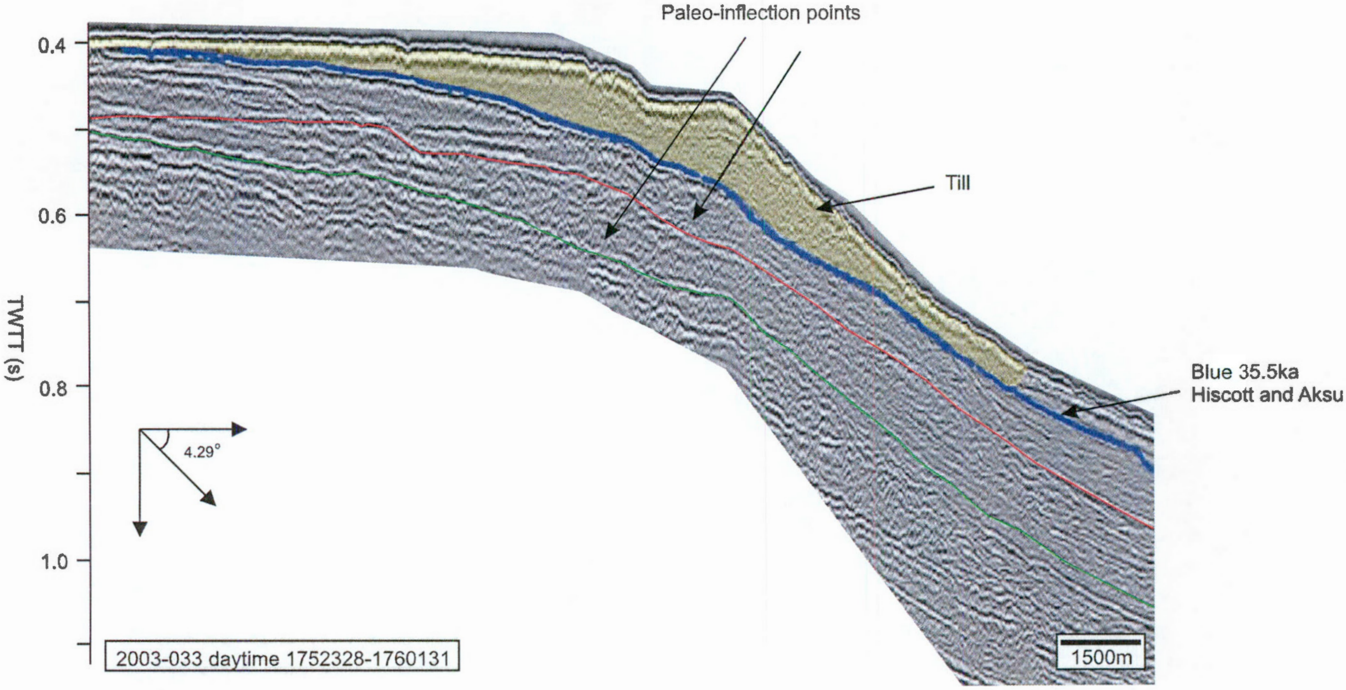
scarp			
daytime	water depth (m)	latitude	longitude
1760050	438.96	48.939257	-50.089640

inflection point			
daytime	water depth (m)	latitude	longitude
1760015	267.03	48.913913	-50.162250

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
1760130	618.2	48.966217	-50.012823

limit of till			
daytime	water depth (m)	latitude	longitude
1760015	267.03	48.91767	-50.15216

Region: Orphan Basin (Just south of Trinity Trough)
Previous work: Tripsanas and Piper (2006).
Notes: Till tongue complex. Buried inflection points visible
Age: Youngest horizon is blue at 35.5ka (Hiscott and Aksu, 1996).
Interpretation: Paleo inflection points suggest a subsiding margin



Transect B, Figure a: Airgun profile, showing prograding and aggrading inflection points.

Transect C			
cruise #	start	end	regional slope angle (degrees)
2003-033	1760548	1760756	3

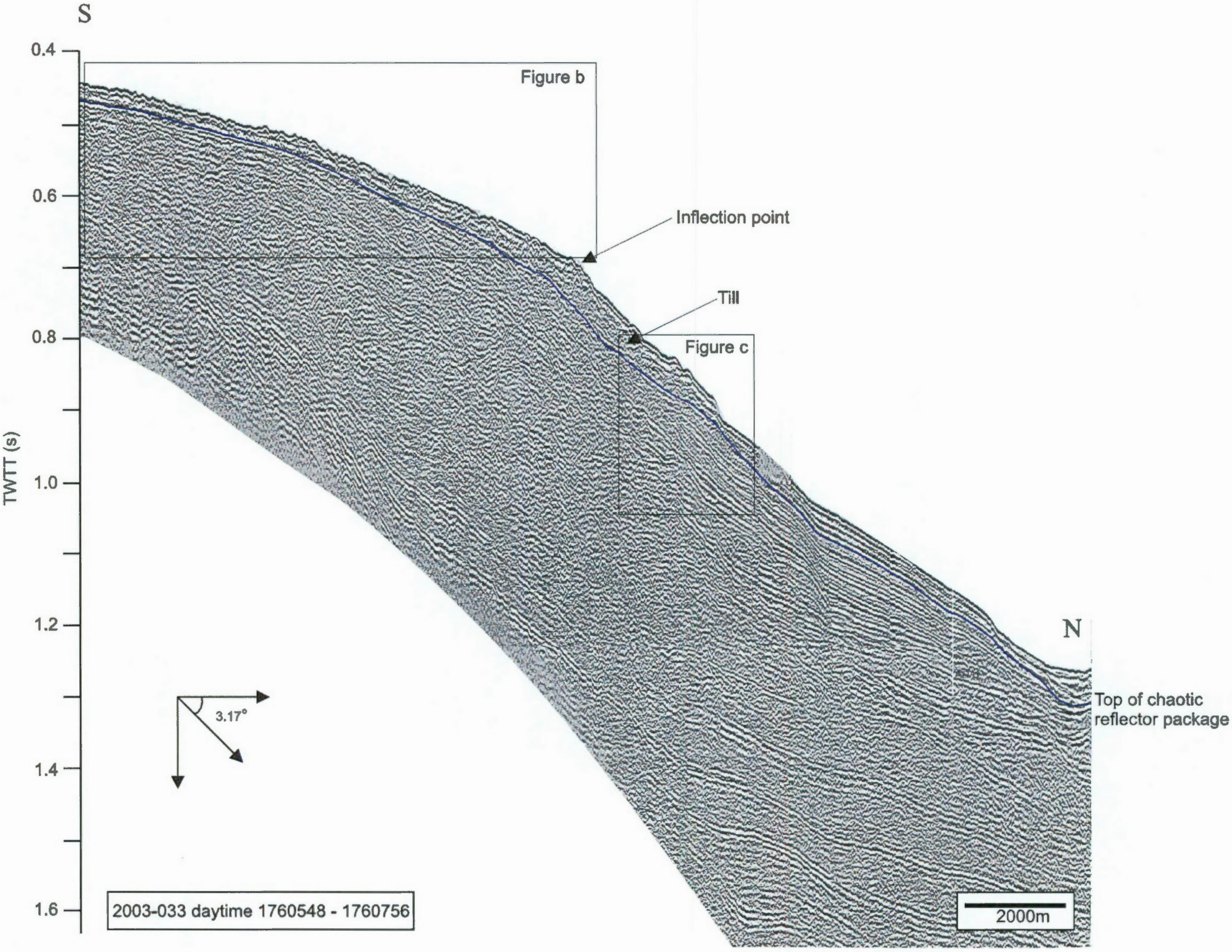
scarp			
daytime	water depth (m)	latitude	longitude
1760705	358.48	48.569892	-49.703523

inflection point			
daytime	water depth (m)	latitude	longitude
1760739	281.67	48.528483	-49.761845

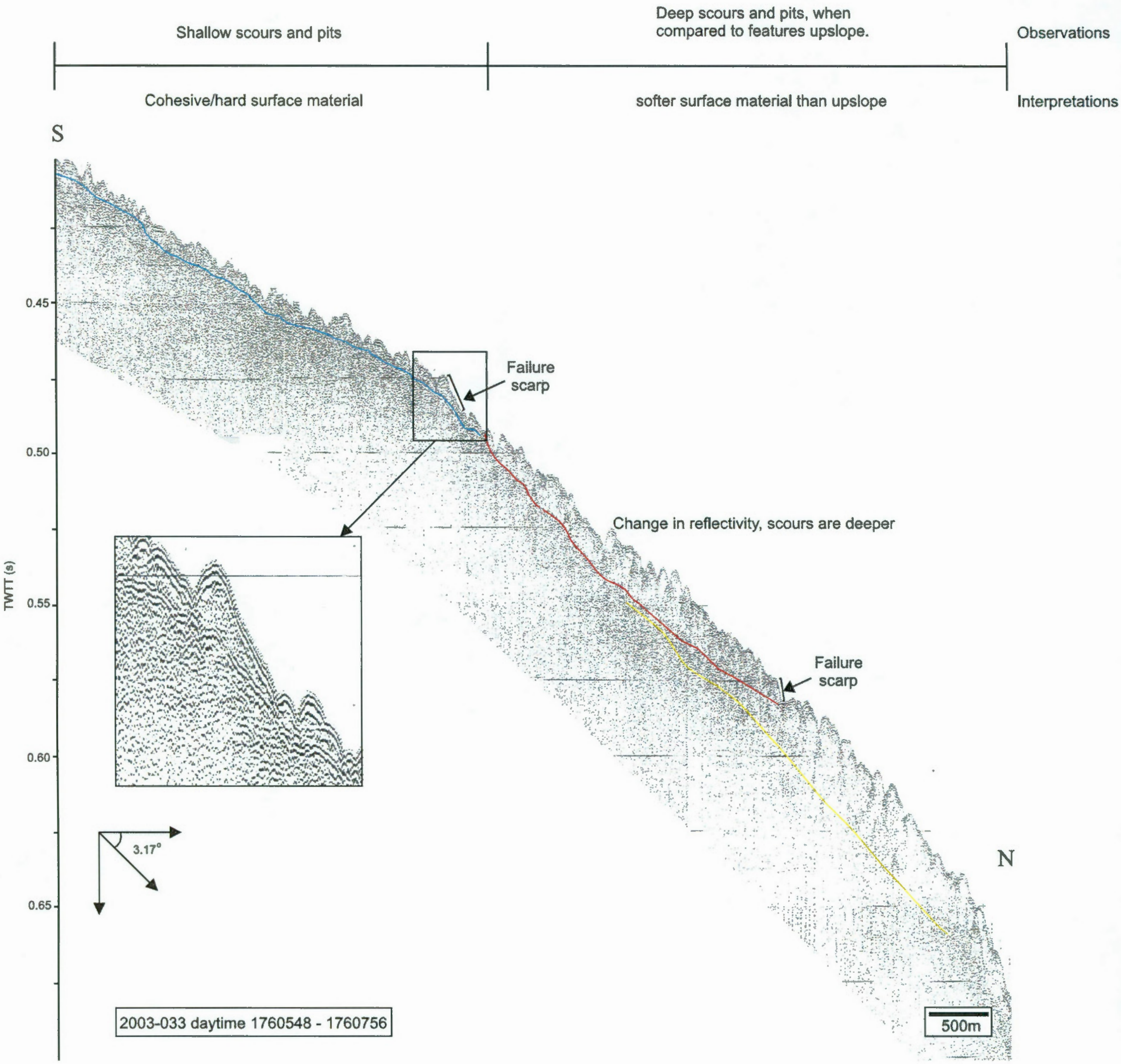
deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
1760625	581.62	48.616128	-49.638348

limit of till			
daytime	water depth (m)	latitude	longitude
1760740	281.67	48.52725	-49.76357

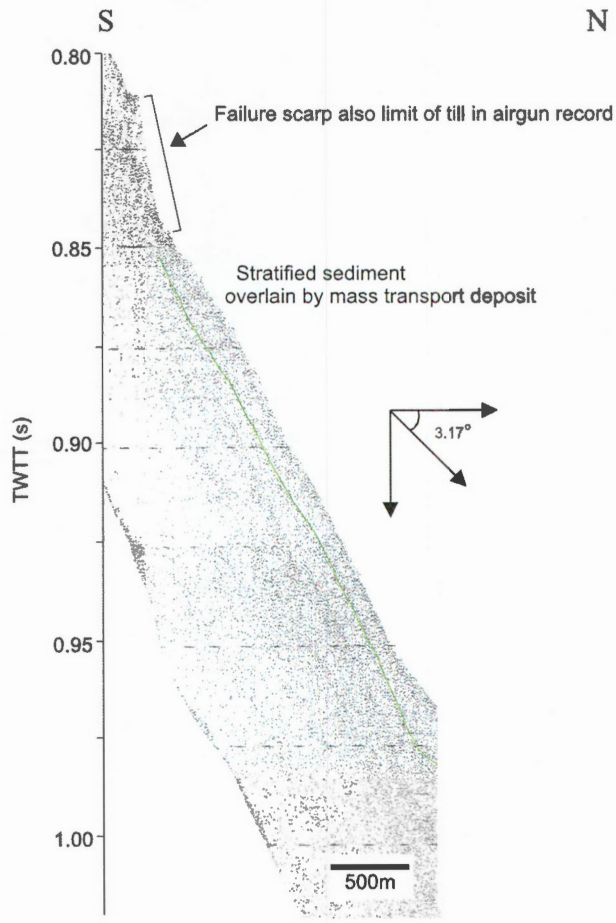
Region: SW Orphan Basin
Previous work: Tripsanas and Piper (2006).
Notes: Upper slope scours are smaller & more numerous than downslope scours. Poorly defined till tongue pinching out beneath iceberg turbated till (very transparent).
Style: Pockets of material at the surface? No defined till tongue except at the surface in fig a.
Age: Blue horizon at 35.5ka (Hiscott and Aksu, 1996) correlated from Orphan Basin.
Interpretation: Thin till at the surface probably pinches out at the failure scarp. No obvious intervals of stratified sediment or till tongue pinch out. Proglacial material has failed back to the till (fig b). MTD farther down slope may be composed of failed proglacial sediment. 2 inflection points (fig a and b) (inherited or constructed?). Also a failure scarp lower down the slope, may be failure of a stratigraphically lower till tongue or secondary failure of an earlier MTD.



Transect C, figure a: Airgun profile showing pinch-out of till above blue horizon.



Transect C, figure b: Huntec profile retrogressive till bodies above main till unit in figure (a).



Transect C, figure c: Huntec profile showing limit of till body imaged in figure (a).

Transect D			
cruise #	start	end	regional slope angle (degrees)
2003-033	1770940	1771054	6

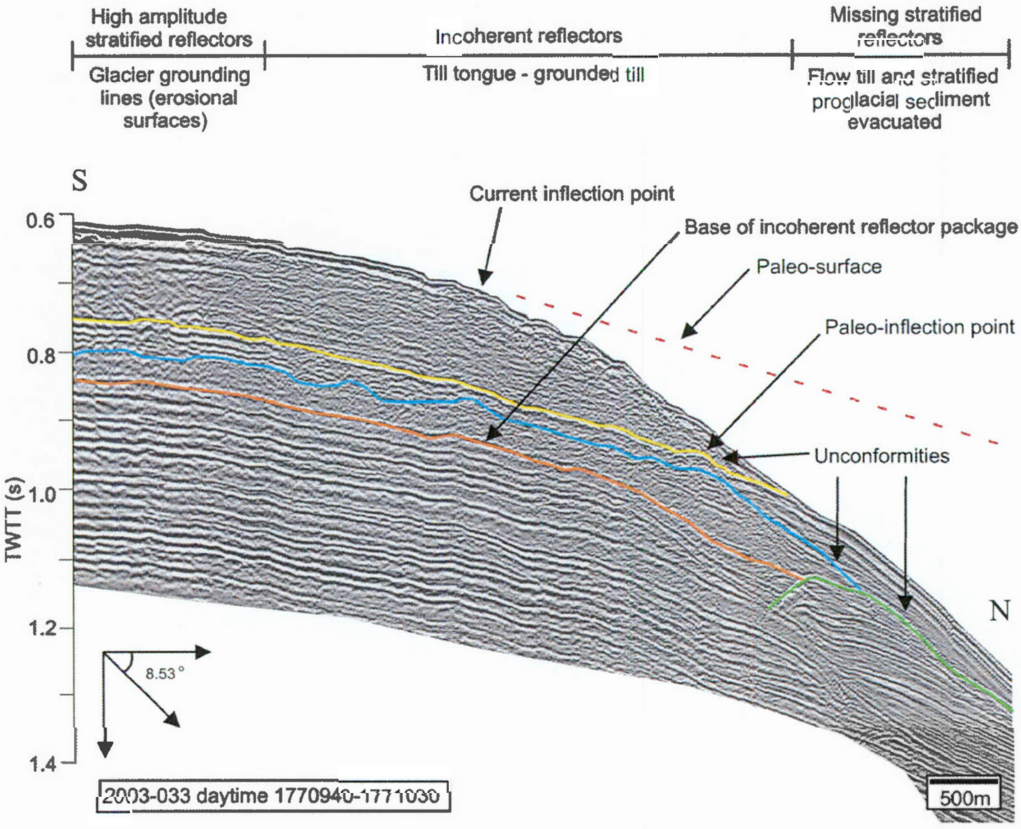
scarp			
daytime	water depth (m)	latitude	longitude
1771010	546.87	48.094667	-47.901835

inflection point			
daytime	water depth (m)	latitude	longitude
1771021	459.08	48.077273	-47.901173

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
1771005	623.69	48.102633	-47.902287

limit of till			
daytime	water depth (m)	latitude	longitude
1771005	623.69	48.10263	-47.90228

Region: Southern margin of Orphan Basin (near Sackville Spur)
Previous work: Hiscott and Aksu, (1996) to the west and Mackie (2006) to the east
Notes: Upper slope- many small scours, lower slope - few large scours. Scarp at 1771010 maybe a scour
Style: No failure surface visible.
Age: Hiscott and Aksu (1996) stratigraphy cannot be brought into this area.
Interpretation: Possible till at the surface (above the yellow marker) Some evidence of the lateral facies transition from high amplitude reflectors on the shelf to chaotic/incoherent reflectors on the upper slope (scattered stratified packets).



Transect D, figure a: Airgun profile showing aggradation of till on outer shelf.

Transect E			
cruise #	start	end	regional slope angle (degrees)
2001-043	2242244	2250157	4

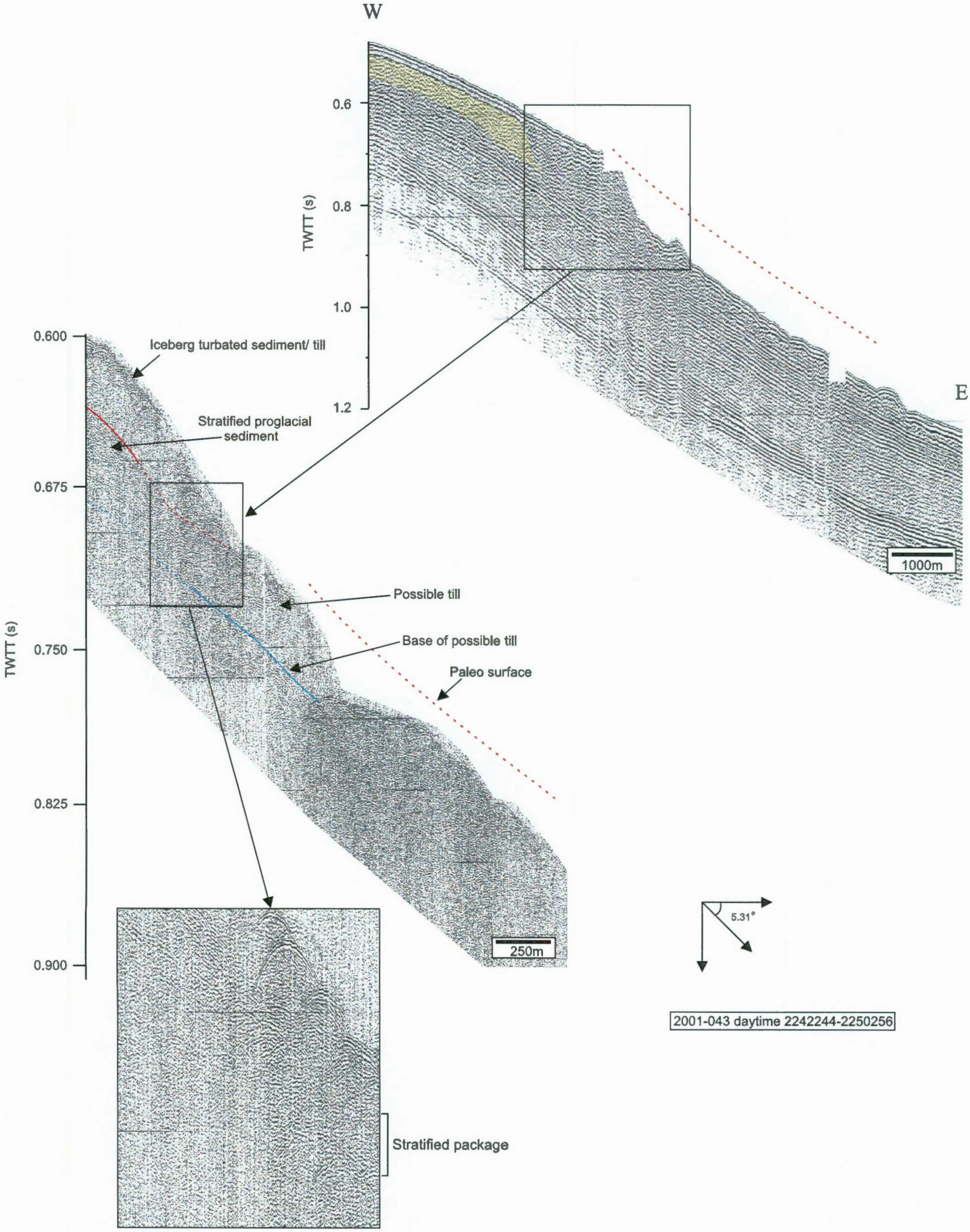
scarp			
daytime	water depth (m)	latitude	longitude
2250130	532.239	46.000010	-47.657090

inflection point			
daytime	water depth (m)	latitude	longitude
2250130	532	45.657090	-46.000000

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2252348	396.893	46.00026	-47.427170

limit of till			
daytime	water depth (m)	latitude	longitude
2250129	532.239	46.00000	-47.65709

Region: Salar Basin
Notes: Extent of till taken from Toews (2003), his figure 19.
Previous work: Toews (2003)
Style: Lateral facies transition (stratified upper slope to incoherent tongue to stratified proglacial material). Constructed inflection point
Age: Some stratigraphy from Toews (2003) but not well constrained.
Interpretation: At surface difficult to distinguish whether there is till or iceberg turbated sediment. Retrogression of scarps through proglacial till/iceberg turbate. Upslope transition from proglacial sediment to poorly defined and incoherent till tongues. Transition from possible flow till to grounded till marked by the appearance, upslope, of strong coherent reflectors.



Transect E, figure a: Airgun profile (above) and Huntec profile (below) showing detail of downslope facies transitions.

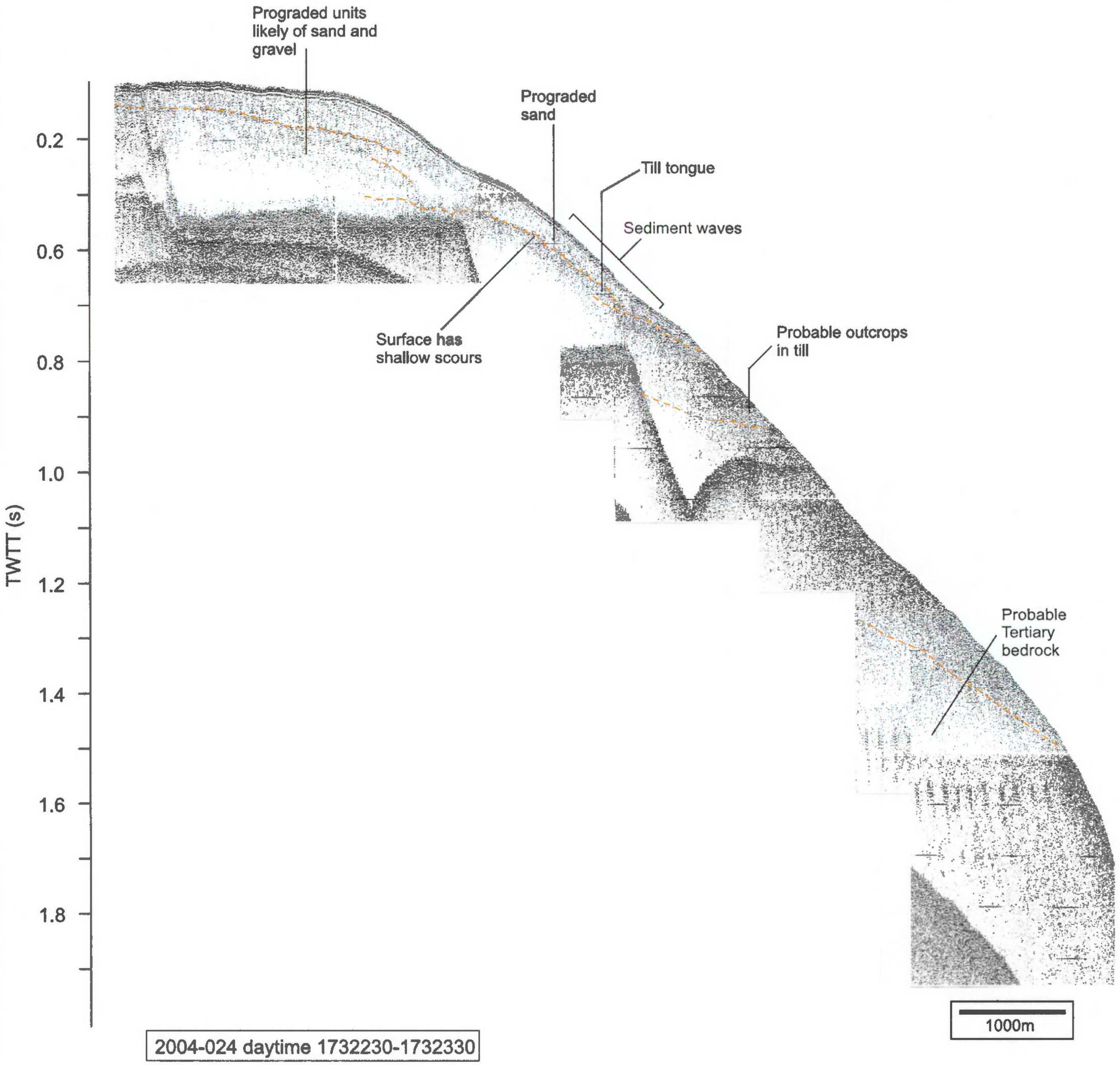
Transect F			
cruise #	start	end	regional slope angle (degrees)
2004-024	1732228	1740136	6

inflection point			
daytime	water depth	latitude	longitude
1732329	314.55	44.431702	-53.436280

deepest iceberg scour			
daytime	water depth	latitude	longitude
1732343	570	44.430168	-48.968761

limit of till			
Daytime	water depth	latitude	longitude
1732305	160.93	44.43426	-49.04445

Region: Southeastern Grand Banks
Previous work: none
Notes:
Style: erosional margin, needs core control to confirm interpretation
Age:
Interpretation:



Transect F, figure a: Huntec profile showing old till deposits overlain by prograded sand and gravel unit.

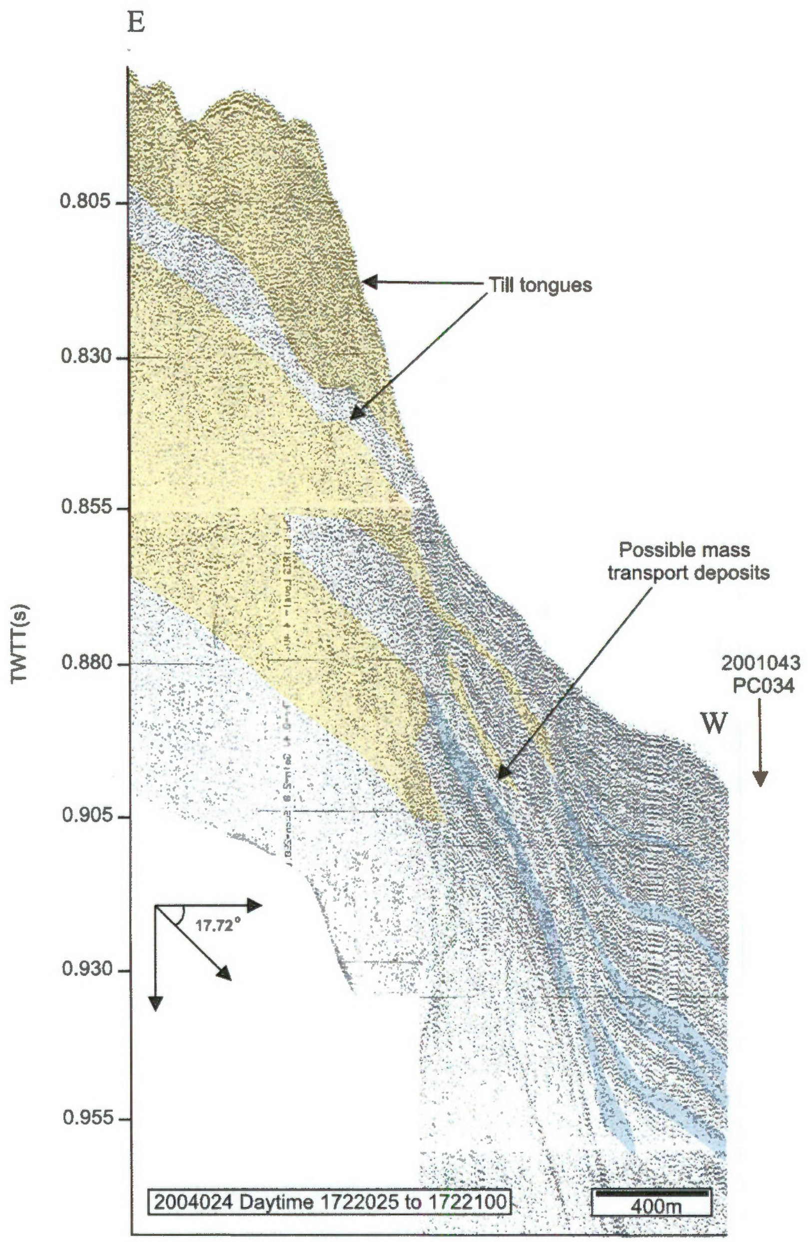
Transect G			
cruise #	start	end	regional slope angle (degrees)
2004-024	1722028	1722122	3.5

scarp(s)			
daytime	water depth	latitude	longitude
1722111	523.04	44.094421	-52.921661

inflection point			
daytime	water depth	latitude	longitude
1722120	358.44	44.093151	-53.436280

deepest iceberg scour			
daytime	water depth	latitude	longitude
1722045	596.19	44.098579	-52.976372

Region: Southwest Grand Banks, south of Debarres Canyon
Previous work: Piper and Gould (2004)
Notes: Figure 5 of Piper and Gould (2004)
Style:
Age:
Interpretation:



Transect G, figure a: Huntec profile showing limit of till tongues.

Transect H			
cruise #	start	end	regional slope angle (degrees)
2001-043	2270010	2270335	2.1

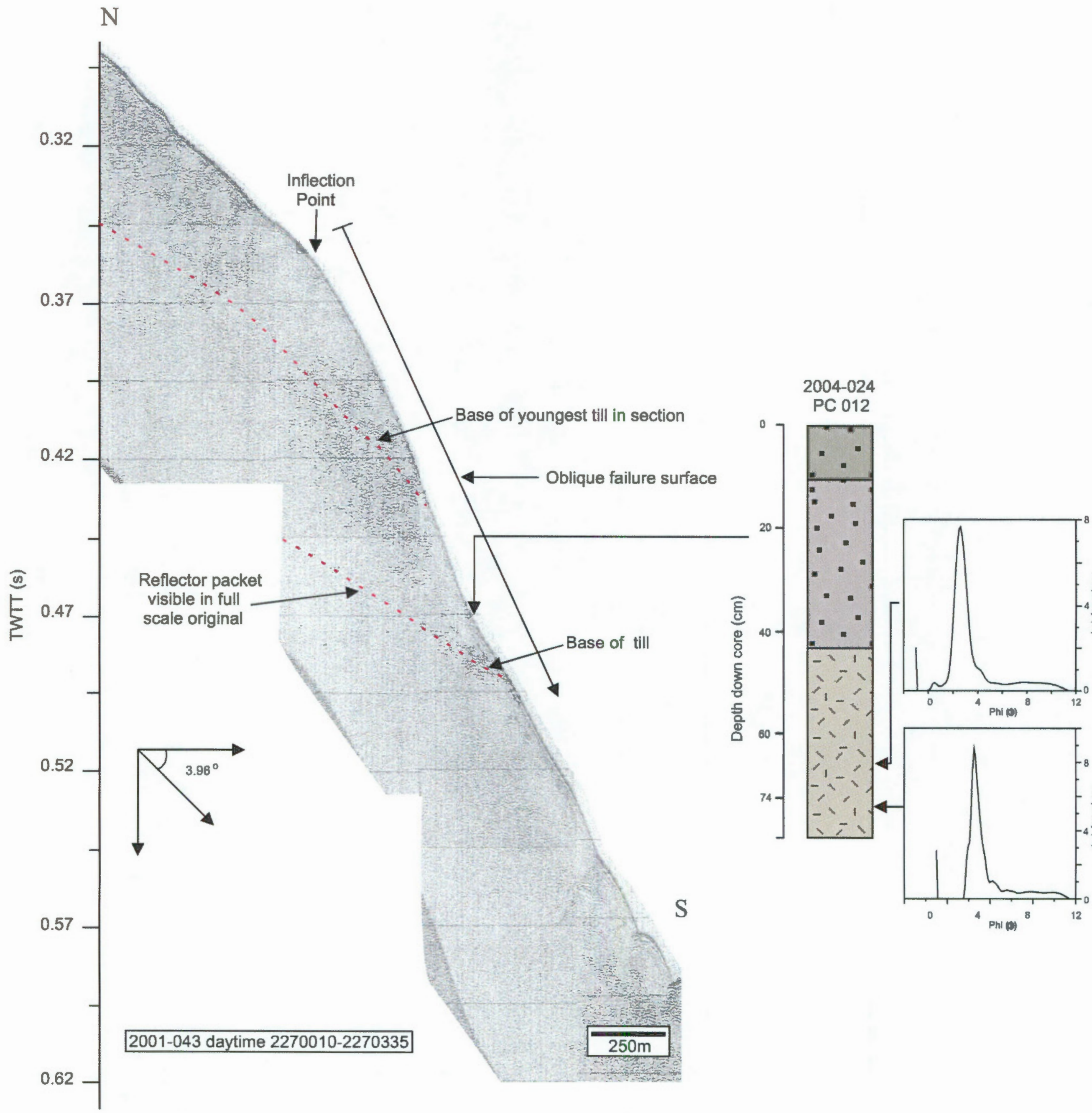
scarp			
daytime	water depth (m)	latitude	longitude
2270255	279.837	44.435920	-53.392720

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2270145	636.492	44.338320	-53.404000

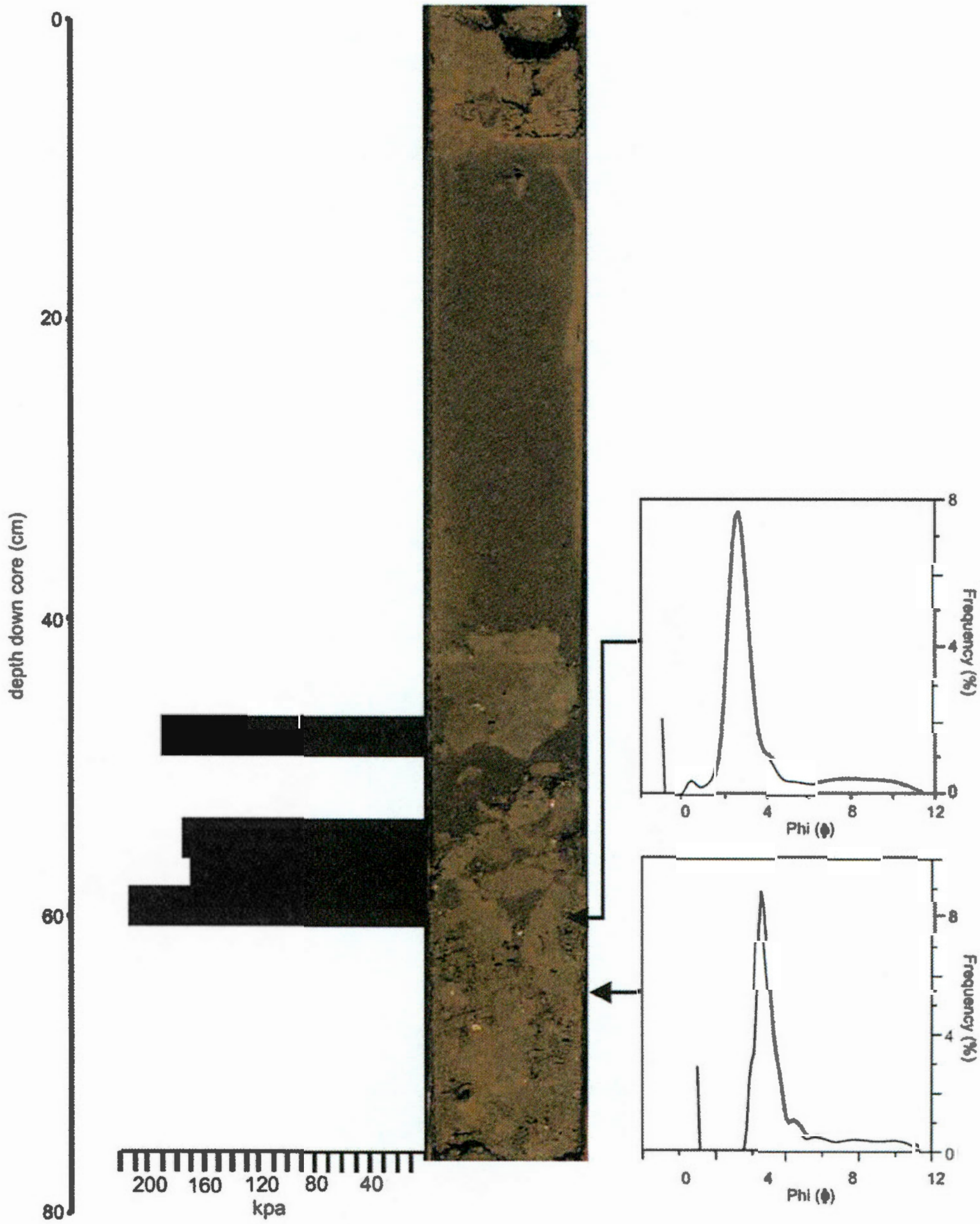
inflection point			
daytime	water depth (m)	latitude	longitude
2270255	279.84	44.435920	53.392720

limit of till			
daytime	water depth (m)	latitude	longitude
2270225	446.28	44.39444	-53.39753

Region: Southwest Grand Banks near Narwhal F-99 well.
Notes: Includes core 12, which contains till
Previous work: Piper and Gould (2004) - same line as their figures 2 and 3
Age: Piper and Gould (2004)
Interpretation: Two till tongues pinching out, near surface, down slope. Shows possible position of the base of the youngest till present in the section and the position of core 012. Core 012 may be on a scarp and therefore may be representative of an older till.



Transect H, figure a: Huntec profile showing detail of till limit.



Transect H, figure b: Detail of core 2004-024-PC012.

Transect I			
cruise #	start	end	regional slope angle (degrees)
2001-043	2270330	2270550	4

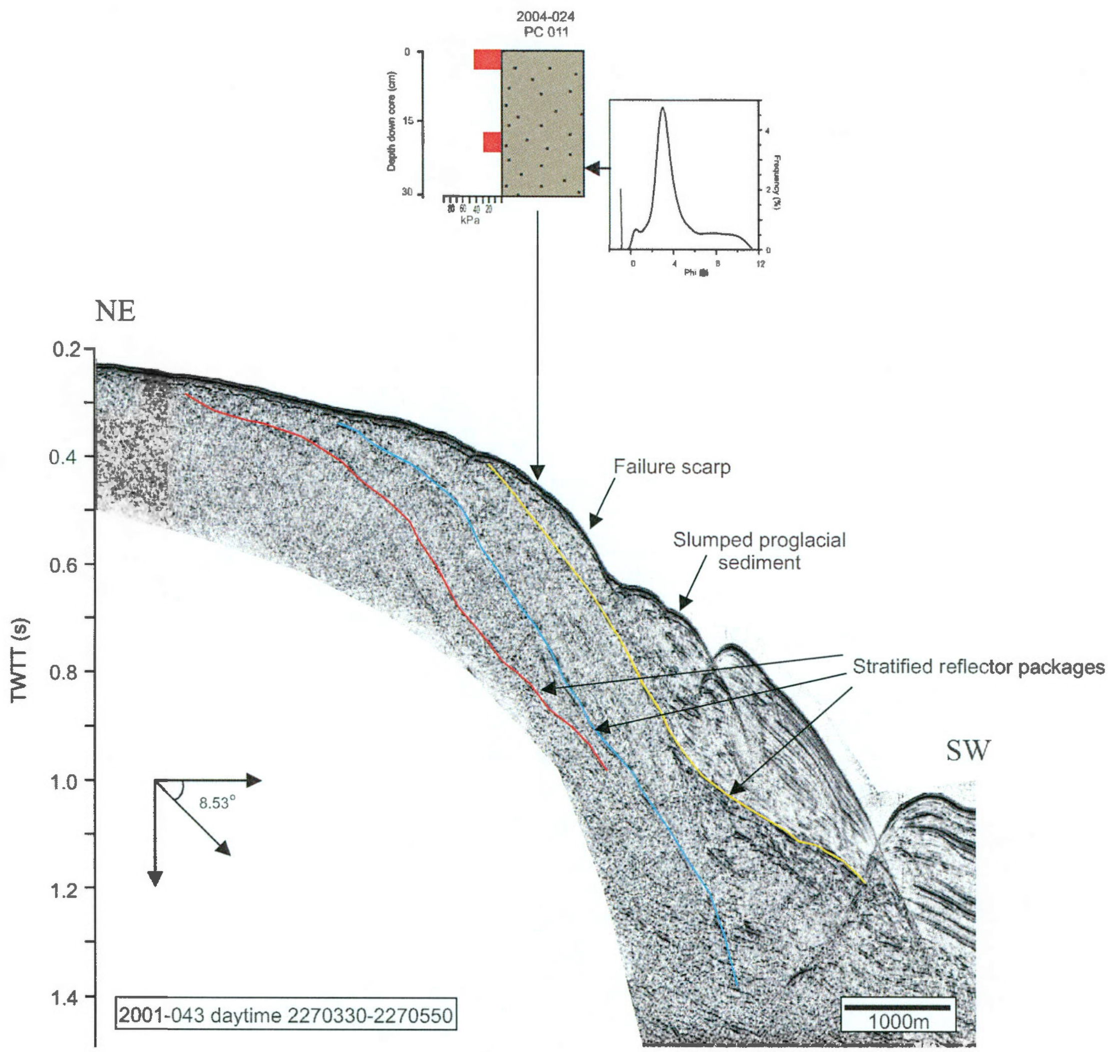
scarp			
daytime	water depth (m)	latitude	longitude
2270430	448.105	44.410610	-53.459450

inflection point			
daytime	water depth (m)	latitude	longitude
2270410	257.89	44.433680	-53.436270

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2270520	1444.91	44.352800	-53.517300

limit of till			
daytime	water depth (m)	latitude	longitude
2270434	557.85	44.40516	-53.46499

Region: Southwest Grand Banks near Narwhal F-99 well
Notes: Includes core 2004-024 11
Previous work: Piper and Gould (2004) their figure 2.
Age: Piper and Gould (2004)
Interpretation: Does not contain definable till tongues but incoherent sediment suggests till maybe exposed at the surface. Incoherent shelf sediment (somewhat stratified in the paper record) and upper slope packages pass into stratified sediment on the mid to lower slope.



Transect I, figure a: Airgun profile showing shelf-edge progradation.

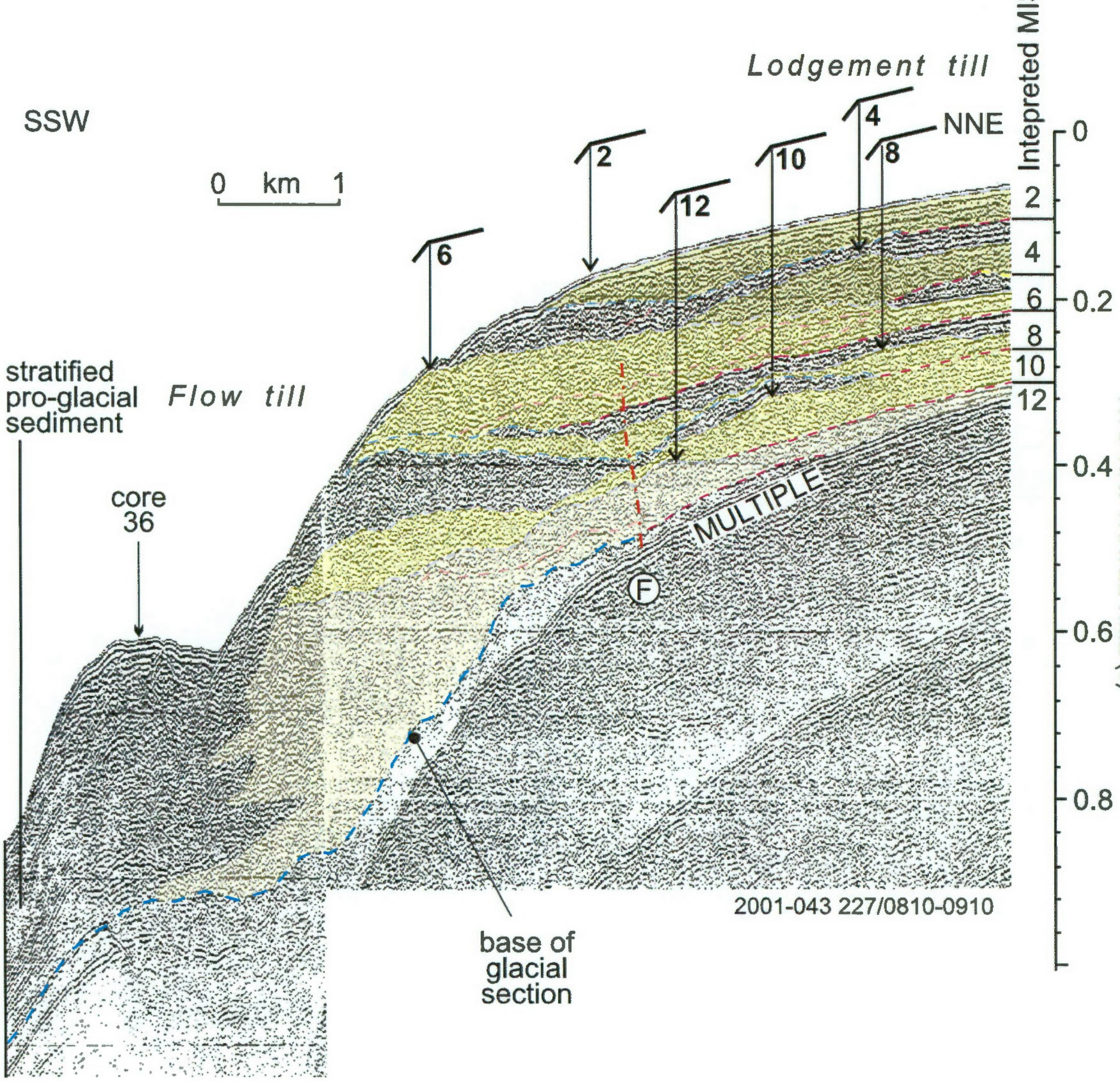
Transect J			
cruise #	start	end	regional slope angle (degrees)
2001-043	2270726	2270921	4.5

scarp(s)			
daytime	water depth (m)	latitude	longitude
2270835	336.536	44.45328	-53.61013

inflection point			
daytime	water depth (m)	latitude	longitude
2270835	336.536	44.45328	-53.61013

limit of till			
daytime	water depth (m)	latitude	longitude
2270842	290.81	44.45968	-53.44206

Region: Southwest Grand Banks near Narwhal F-99 well.
Previous work: Piper and Gould (2004), their figure 3.
Style: Stacked till tongues on subsiding continental margin.
Age: Piper and Gould (2004).



Transect J, figure a: Airgun profile from Piper and Gould (2004) showing interpretation of stacked till bodies.

Transect K			
cruise #	start	end	regional slope angle (degrees)
2003033	1710242	1710335	2.8

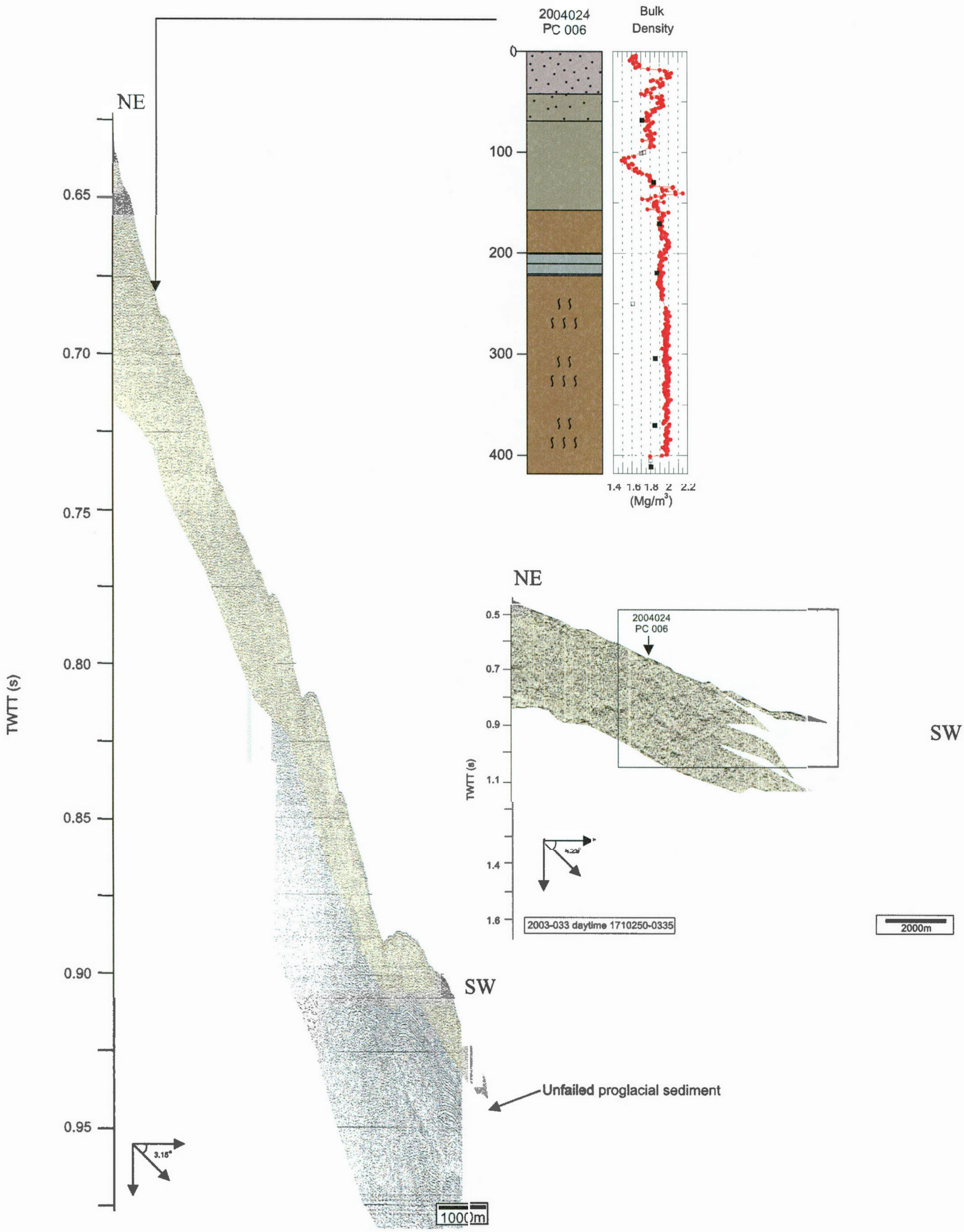
scarp(s)			
daytime	water depth (m)	latitude	longitude
1710318	587.04	44.763712	-54.378643

inflection point			
daytime	water depth (m)	latitude	longitude
1710343	294.44	44.800332	-54.346005

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
1710300	731.52	44.736898	-54.402375

limit of till			
daytime	water depth (m)	latitude	longitude
1710317	587.04	44.75932	-54.38269

Region: Northwesterm Grand Banks
Previous work: Ledger-Piercey & Piper (in prep.), Pass et al. (2000).
Notes: Includes core site 2004024-PC006.
Style:
Age: Pass et al. (2000) stratigraphy has base of glacial section, however is difficult to correlate to the upper slope.
Interpretation: Un-failed slope showing lateral facies transition from chaotic till to stratified proglacial sediment



Transect K, figure a: Huntec profile near limit of surface till. Inset shows location on airgun profile.

Transect L			
cruise #	start	end	regional slope angle (degrees)
2003033	1710635	1710745	3.9

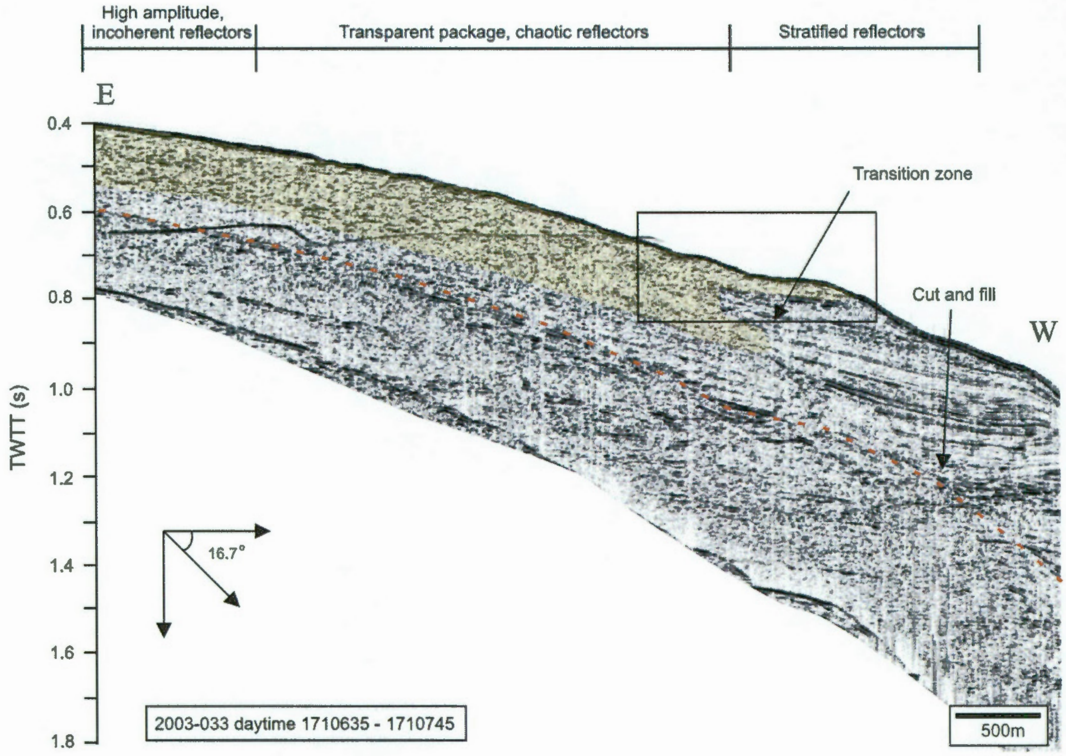
scarp(s)			
daytime	water depth	latitude	longitude
1710701-1710703	479.15-524.87	44.920817	-54.477402

inflection point			
daytime	water depth	latitude	longitude
1710647 (airgun)	309.07	44.929920	-54.451240

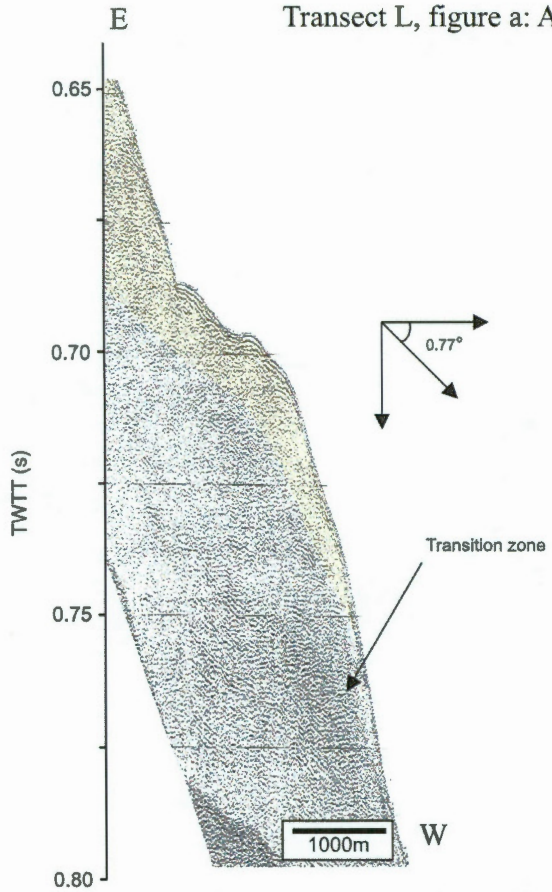
deepest iceberg scour			
daytime	water depth	latitude	longitude
1710700	479.15	44.921440	-54.475520

limit of till			
daytime	water depth	latitude	longitude
1710704	524.87	44.91844	-54.48505

Region: Slope off Haddock Channel
Previous work: Ledger-Piercey and Piper (in prep.) and Pass et al. (2000)
Age: Uncertain
Interpretation: Till at surface overlies stratified proglacial sediment. In airgun section package shows lateral facies transition from high amplitude stratified reflectors on the shelf to an incoherent package on the upper slope which then terminates against stratified reflectors.



Transect L, figure a: Airgun profile showing distribution of till.



Transect L, figure b: Huntec profile showing detail of limit of till tongue.

Transect M			
cruise #	start	end	regional slope angle (degrees)
2002-046	2470014	2470213	5

scarp(s)			
daytime	water depth (m)	latitude	longitude
2470125	411.48	44.968760	-54.980650

inflection point			
daytime	water depth (m)	latitude	longitude
2470140	292.61	45.001080	-54.943340

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2470103	610	44.936130	-54.994390

limit of till			
daytime	water depth (m)	latitude	longitude
2470134	411.48	48.98009	-54.96751

Region: Slope off Green Bank
Previous work: none
Notes: No figure – Huntec is poor quality

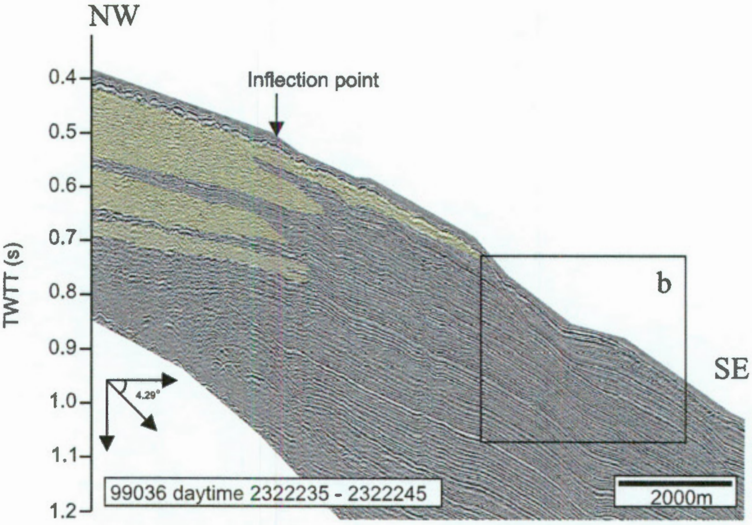
Transect N			
cruise #	start	end	regional slope angle (degrees)
99036	2322145	2322230	2

scarp			
daytime	water depth (m)	latitude	longitude
2322245	610.82	44.813150	-55.626840

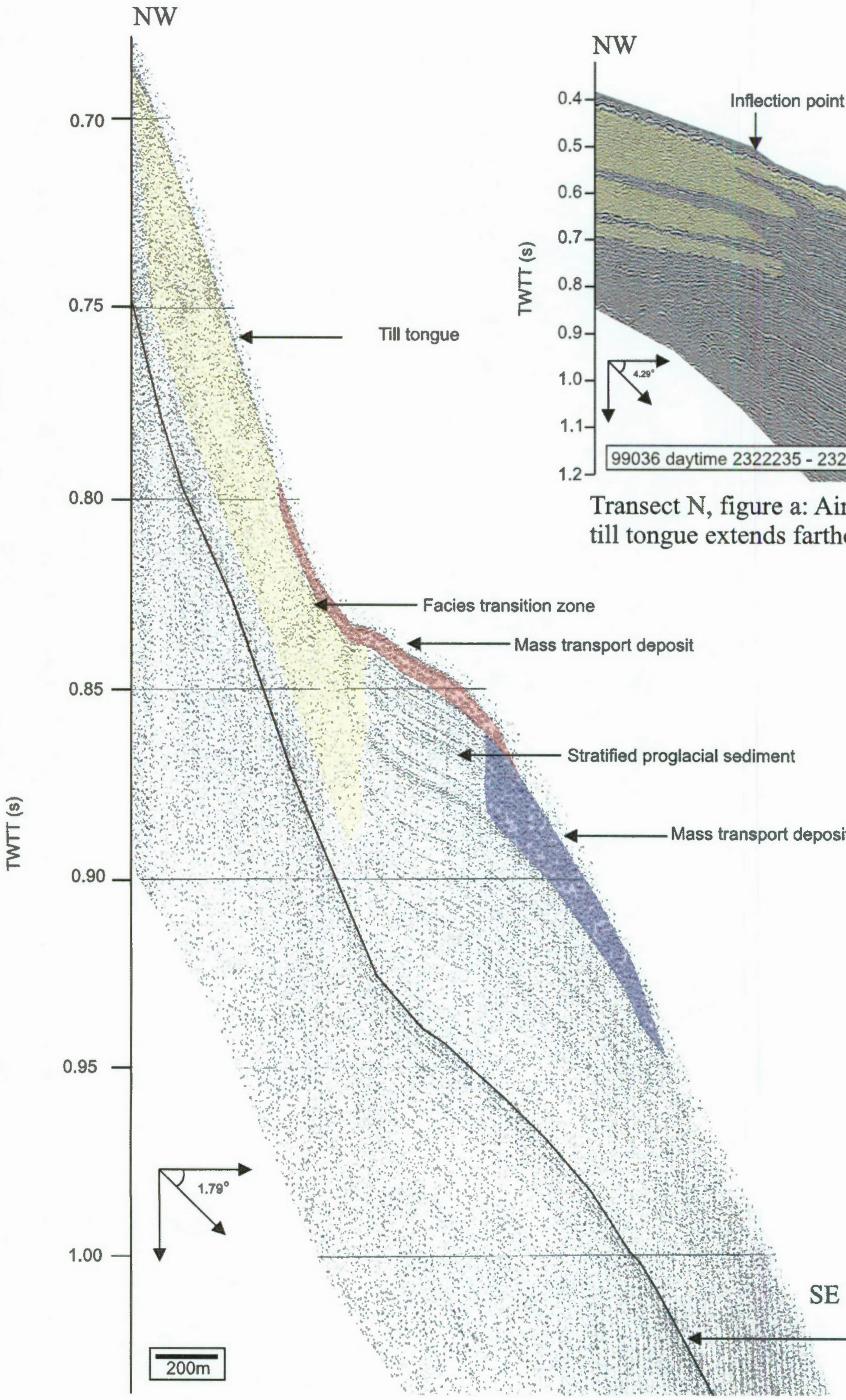
deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2322240	552.3	44.819060	-55.631860

limit of till			
daytime	water depth (m)	latitude	longitude
2322228	713.23	44.79516	-55.61109

Region: St Pierre Slope
Previous work: Macdonald (1999); Piper et al. (2005); McCall et al. (2004); McCall (2006).
Style: Huntec captures the tip of the youngest tongue which does not "pinch out" but has a vertical termination not seen in airgun records
Age: contains McCall (in prep.) stratigraphy but no ages as of yet
Interpretation: Uppermost till extends much farther seaward than underlying stacked till tongues seen in figure (a). Huntec profile (b) shows apparent lateral facies change. Till is steeper than stratified sediment. May be evidence for slow creep of till downslope and for no ice but viscous flow. Clear transition from incoherent to coherent packages, probably the flow till-proglacial sediment boundary.



Transect N, figure a: Airgun profile showing that upper till tongue extends farther seaward than below till tongues.



Transect N, figure b: Huntec profile showing facies transition from upper til tongue to stratified sediment.

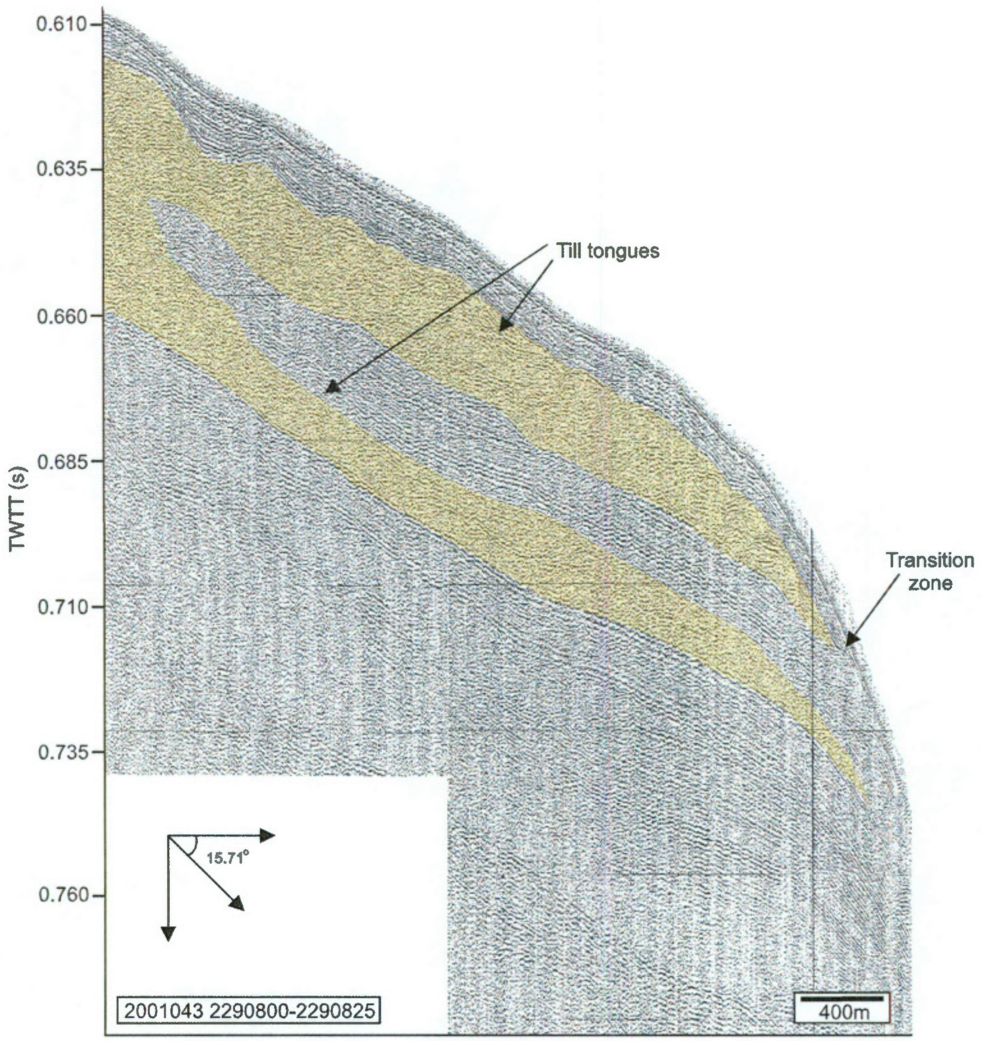
Transect O			
cruise #	start	end	regional slope angle (degrees)
2001-043	2290800	2290900	

inflection point			
daytime	water depth	latitude	longitude

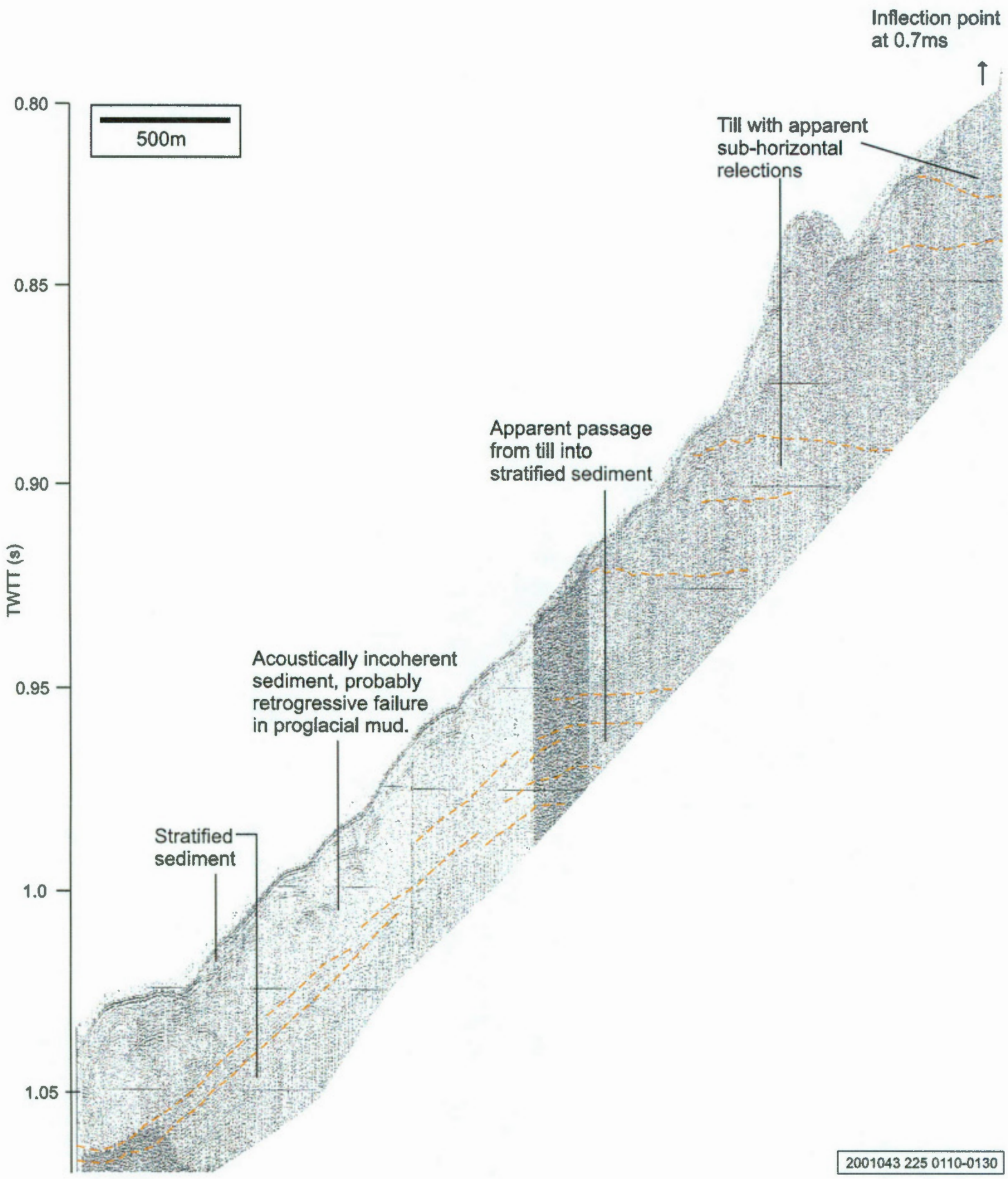
deepest iceberg scour			
daytime	water depth	latitude	longitude

limit of till			
Daytime	water depth	latitude	longitude

Region: St Pierre Slope
Previous work: Macdonald (1999); Piper et al. (2005); McCall et al. (2004); McCall (2006).
Age: McCall (2006); Piper et al. (2005).
Interpretation: Till tongues terminating at stratified proglacial sediment, common termination positions.



Transect O, figure a: Huntec profile showing stacked upper slope till tongues, Stratigraphy for Piper et al. (2005) and McCall (2006).



Transect O, figure b: Huntec profile showing highly reflective till outcropping below inflection point and passing into stratified sediment with retrogressive failure.

Transect P			
cruise #	start	end	regional slope angle (degrees)
2003033	1672312	1680057	3.5

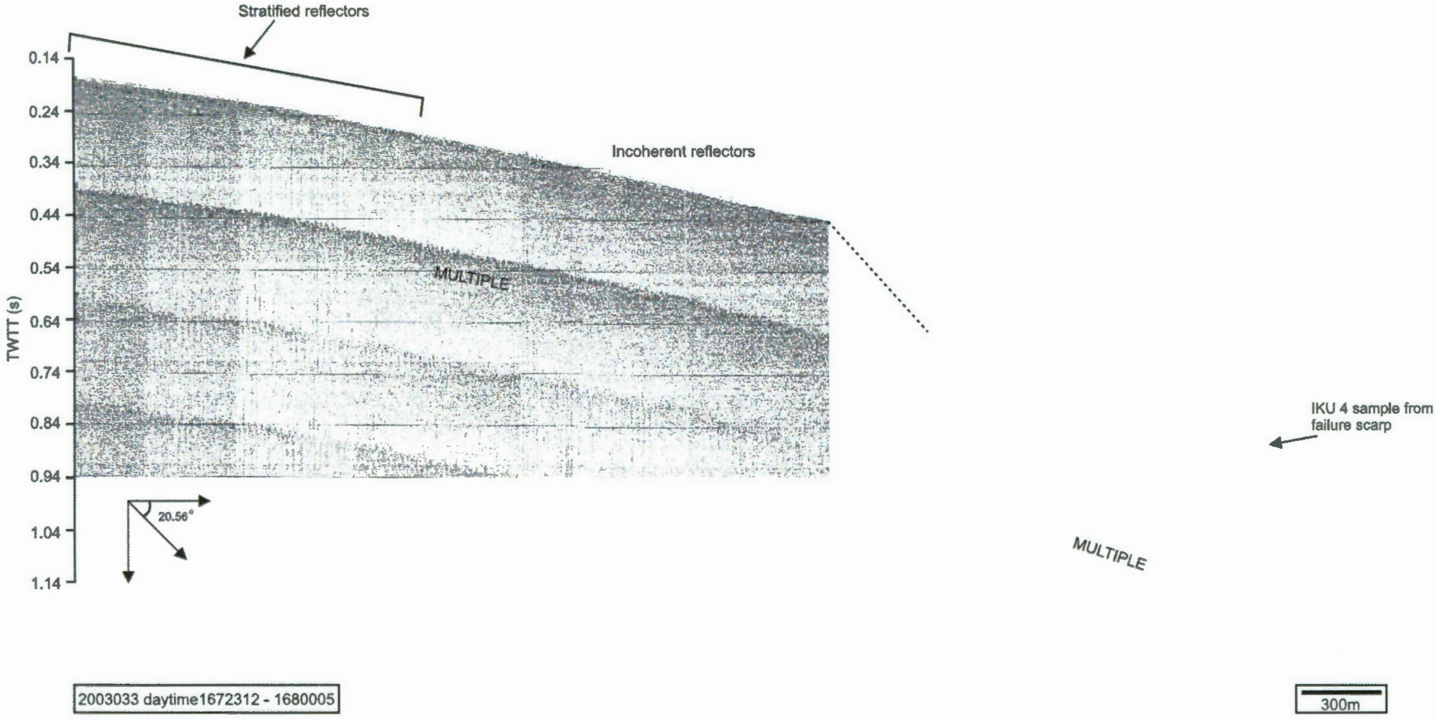
scarp(s)			
daytime	water depth (m)	latitude	longitude
1680001-1680002		44.270908	-57.822652

inflection point			
daytime	water depth (m)	latitude	longitude
1680001			

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
1680020		44.235877	-57.810370

limit of till			
daytime	water depth (m)	latitude	longitude
1680022			

Region: North Eastern Scotian Slope off Banquereau
Previous work: Piper (2001)
Notes: Contains IKU site.



Transect P, Figure a: Prominent failure scarp at limit of shallowest till tongue.

Transect Q			
cruise #	start	end	regional slope angle (degrees)
2001048a	2450520	2450545	5

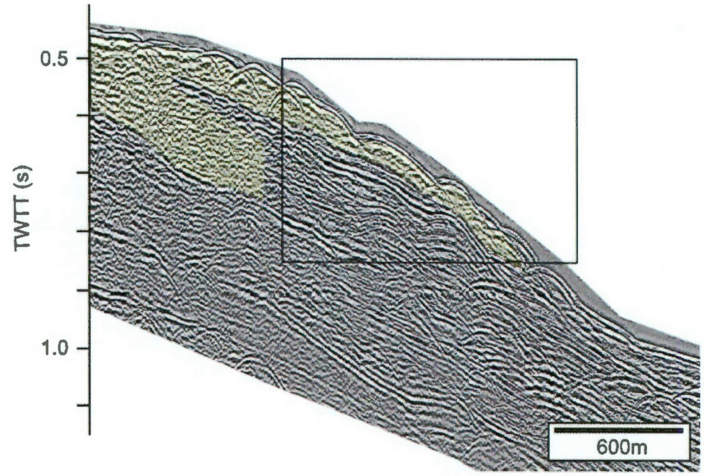
scarp(s)			
daytime	water depth (m)	latitude	longitude
2450534	400.00	43.238548	-60.922791

inflection point			
daytime	water depth (m)	latitude	longitude
2450546	325.00	43.250019	-60.92844

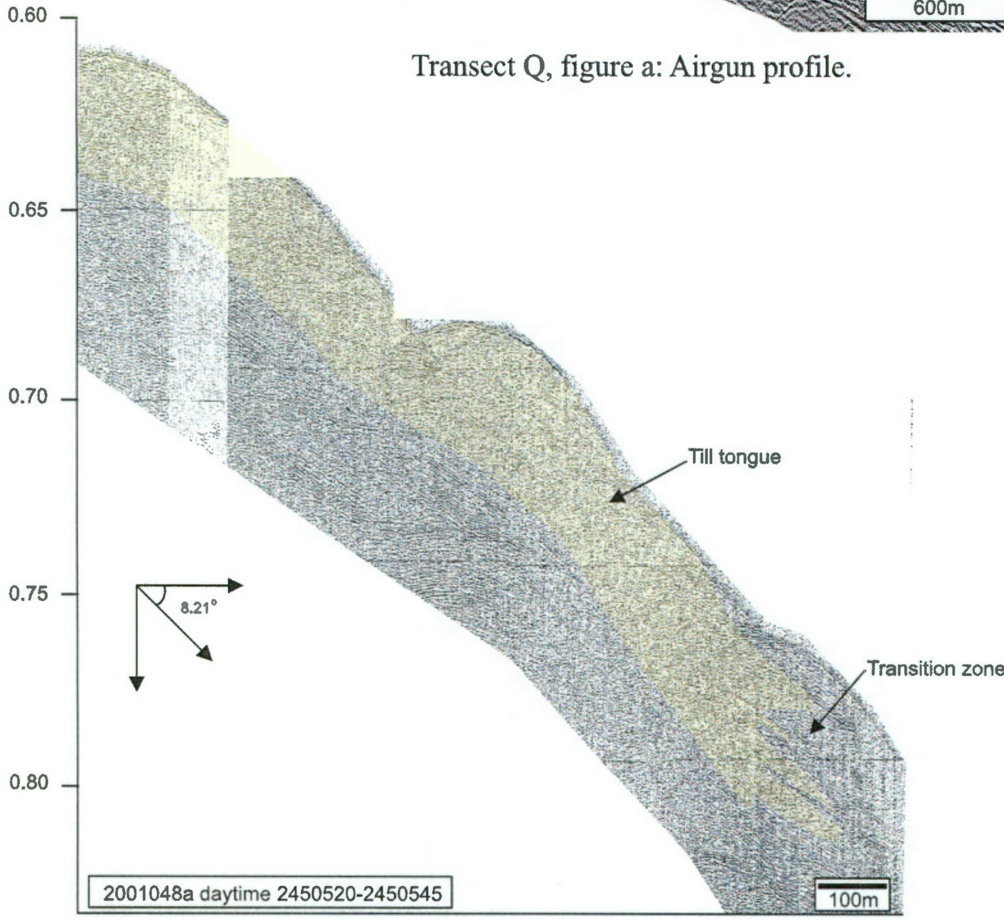
deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2450521	600.00	43.224701	-60.917759

limit of till			
daytime	water depth (m)	latitude	longitude
2450526	500.00	43.2301	-60.91964

Region: Scotian Slope – East of Dawson Canyon
Previous work: Piper et al. (2002); Chubbs (2003)
Notes:
Style:
Age: see Piper et al. (2002).
Interpretation: No clear facies transition. May only show approximate location of tongue.



Transect Q, figure a: Airgun profile.



Transect Q, figure b: Huntec profile.

Transect R			
Cruise #	start	end	Regional slope angle (degrees)
81044	3461215	3461406	5

Region: Scotian Slope – East of Dawson Canyon
Previous work: Piper et al. (2002); Chubbs (2003)
Notes: illustrated in Piper et al. (2002)
Style:
Age: see Piper et al. (2002)
Interpretation:

Transect S			
cruise #	start	end	regional slope angle (degrees)
85001	0800354	0800520	

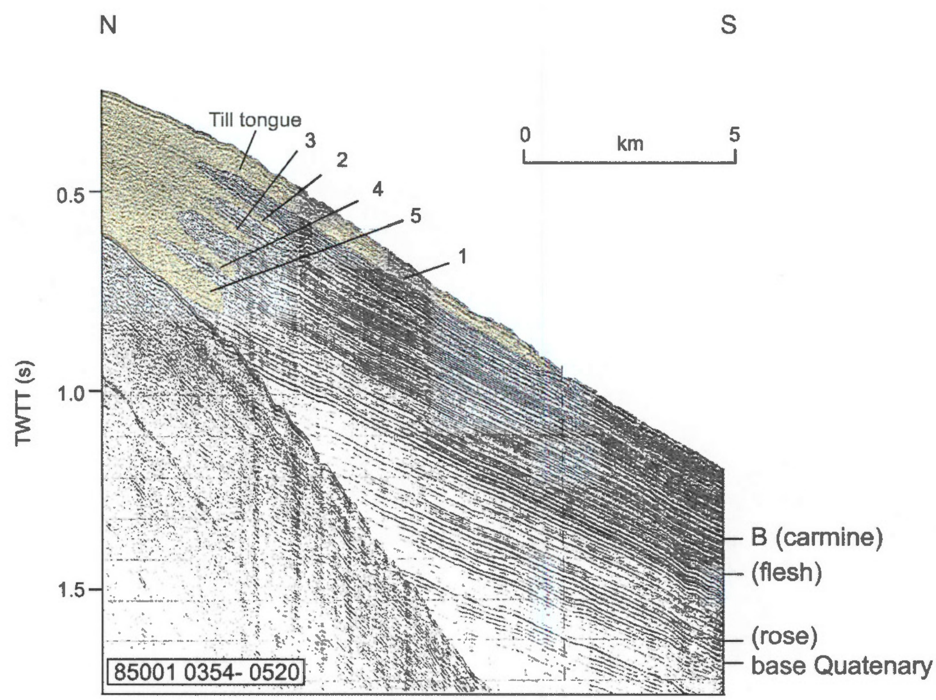
Scarp			
daytime	water depth (m)	latitude	longitude

inflection point			
daytime	water depth (m)	latitude	longitude

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude

limit of till			
daytime	water depth (m)	latitude	longitude

Region: Scotian Slope, west of Verill Canyon.
Previous work: Piper (2001), Newton (2003)
Style:
Age: Regional chronology from Piper (2001), correlated by Newton (2003).
Interpretation: stacked till tongues, progradational morphology.



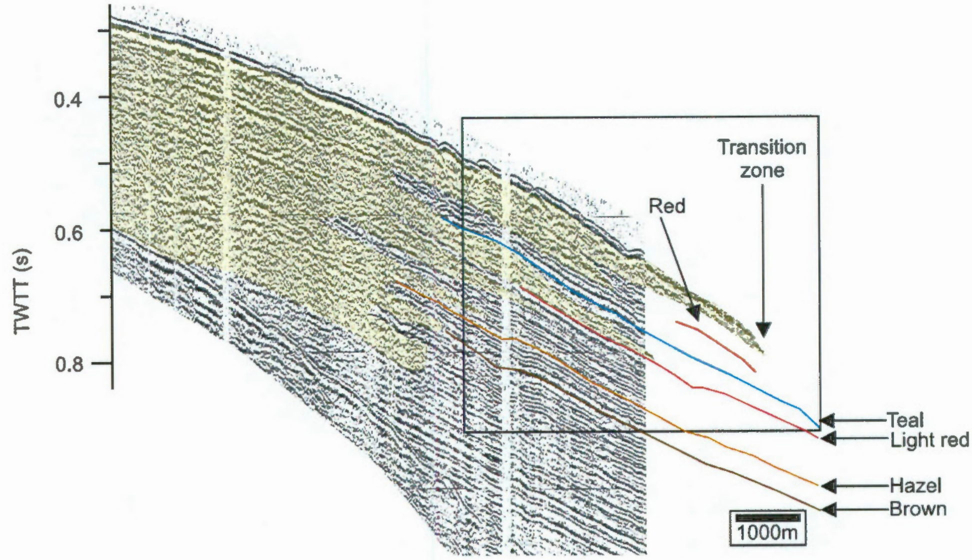
Transect S, figure a: Airgun profile showing stacked till tongues.

Transect T			
cruise #	start	end	regional slope angle (degrees)
99036	2452155	2452315	2.5

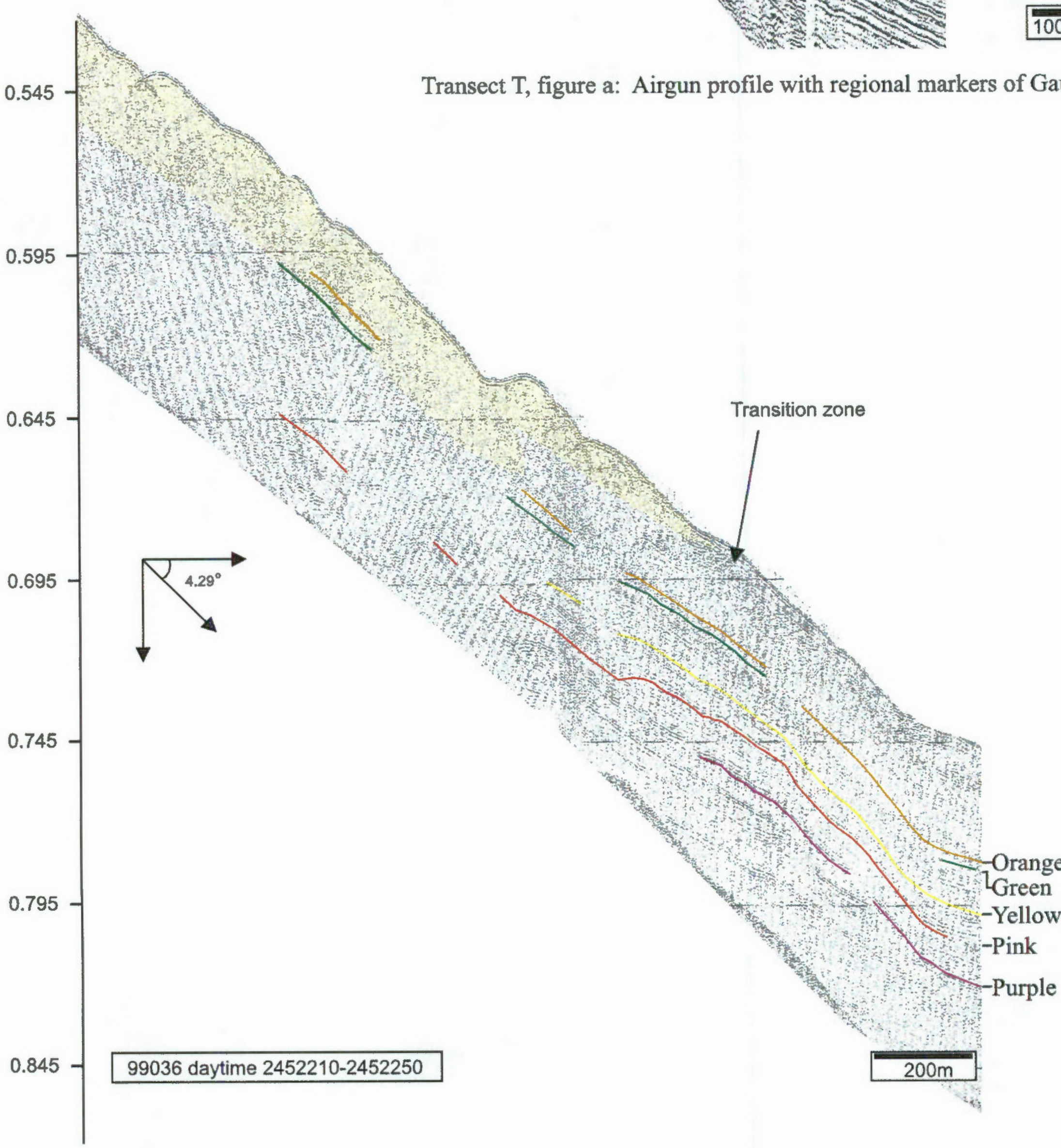
deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2452243	565.1	42.949040	-61.675490

limit of till			
daytime	water depth (m)	latitude	longitude
2452245	565.1	42.94904	-61.67549

Region: Scotian Slope – West of Verrill Canyon
Previous Work: Gauley (2001); Mosher et al. (1994); Piper et al. (1985); Campbell (2000); Newton (2003).
Style: Typical pinch out (thinning) against proglacial stratified sediment
Age: Sequence shows continuous stratigraphy (Gauley's (2001) orange, green, yellow, red and purple) but lacks 14ka (brown) reflector.
Interpretation: No failure present.Till tongue at surface is from most recent glaciation (inferred from Gauley's (2001) chronology). Airgun record suggests the presence of multiple till tongues. Huntec record illustrates the internal divisions in a single till tongue suggesting multiple minor retreats and advances. Internal structure is formed by interlayered till and stratified proglacial sediment.



Transect T, figure a: Airgun profile with regional markers of Gauley (2001).



Transect T, figure b: Huntect profile with regional markers of Gauley (2001).

Transect U			
cruise #	start	end	regional slope angle (degrees)
99036	2471940	2472150	

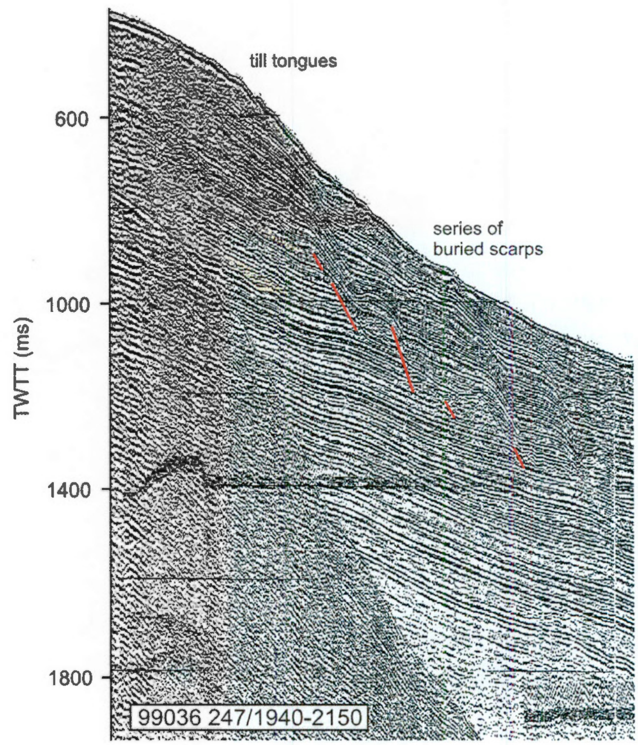
scarp			
daytime	water depth (m)	latitude	longitude

inflection point			
daytime	water depth (m)	latitude	longitude

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude

limit of till			
daytime	water depth (m)	latitude	longitude

Region: Scotian Slope, west of Verill Canyon.
Previous work: Piper (2001)
Age: Reflectors from Piper (2001)
Interpretation: Till tongues pinch out at the inflection point. Till tongue terminations characterized by an abrupt transition from chaotic reflectors to stratified reflectors. Multiple buried failure scarps are located downslope from the till tongues.



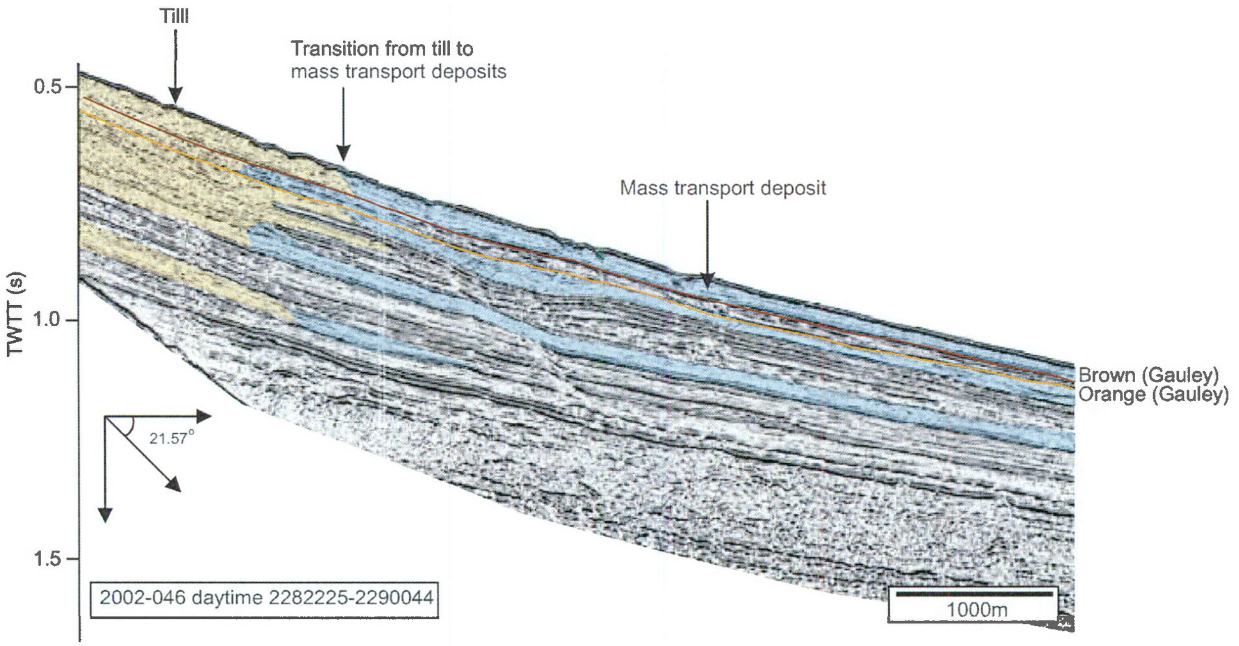
Transect U, figure a: Airgun profile showing stacked till tongues.

Transect V			
Cruise #	start	end	Regional slope angle (degrees)
2002046	2282255	2290044	3

deepest iceberg scour			
daytime	water depth (m)	latitude	longitude
2282335	650	42.880870	-62.208230

limit of till			
daytime	water depth (m)	latitude	longitude
2282311	over 500m	42.91183	-62.21024

Region: Scotian slope, between Mohican Channel and Acadia Valley
Notes: Dip line through Gauley (2001) strike lines, East of Mohican Channel. Reflectors pulled through from cross lines. Huntec poor quality and lacks the section where till pinches out.
Previous work: Gauley (2001), White (2005).
Style: hard to determine without Huntec. Till pinches out at a constant depth/slope angle. Terminations are not well defined on airgun. Stratified proglacial material lies between till tongues.
Age: Gauley's (2001) brown is older than 14 ka and orange is older than 18.3 ka.
Interpretation: Uninterrupted/unfailed section showing the lateral facies change between incoherent/chaotic till to stratified proglacial sediment. If brown is correct then the till exposed at the surface is also the most recent. Slope of 3° is similar in areas that contain failures.



Transect V, figure a: Airgun profile showing transition from upper slopt till to mass-transport deposits.