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Géographie physique et Quaternaire

# Timing and position of Late Wisconsinan ice-margins on the upper slope seaward of Laurentian Channel

# Chronologie et emplacement des marges glaciaires sur le talus supérieur au large du Chenal laurentien

# Cronología y localización del margen glaciar durante el periodo wisconsiniano tardío de la vertiente costera superior del canal del san lorenzo

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Résumé de l'article

Au cours du dernier maximum glaciaire, le principal exutoire à travers le Chenal laurentien se terminait sur le talus continental supérieur. Une surface de 10 km$^2$ sur le talus supérieur a été étudiée en détail, à l'aide de profils résultant de l'utilisation de divers instruments de sismique rélexion. Le glissement pendant le tremblement de terre de 1929 au Grand Banc a causé la mise à nu sur le fond marin de sédiments du dernier maximum glaciaire, normalement enfouis sous des dizaines de mètres de nouvelles couches. Les lithofaciès et faciès acoustiques ont été interprétés à l'aide de critères mis au point sur la plate-forme continentale et la chronologie a été fournie par les datations SMA faites sur des coquillages de mollusques *in situ*. Les données sismiques font ressortir une crête morainique à 500 m snm (sous le niveau actuel de la mer) correspondant à la ligne d'ancrage au dernier maximum glaciaire. Un changement dans le régime thermique de la glace ou une éruption d'eau de fusion sousglacaire à 16,5 ± 0,15 ka (âge corrigé à -0,4 ka, compte tenu de l'effet de réservoir) a causé la libération d'eau de fusion enfouie qui a creusé des ravins sur le talus continental. Cette surface d'érosion a immédiatement été recouverte par un important diamicton pierreux jusqu'à 700 m snm, qui semble être un till déposé au cours d'une crue glaciaire. La marge glaciaire s'est par la suite retirée vers l'amont vers 16,3 ka, à l'emplacement de l'importante moraine située à 380 m snm, sur le bord du chenal Laurentien. Des indices tirés des boues de turbidites sur l'éventail Laurentien laissent croire que cette position de la marge glaciaire a été maintenue jusque vers 14,2 ka. La glace s'est ensuite rapidement retirée vers le nord le long du chenal Laurentien, vers 14 ka (Épisode de Heinrich 1/*Heinrich Event* 1). Des sédiments proglaciaires plus récents se sont effondrés vers 12 ka, probablement en raison d'une surcharge causée par une récurrence glaciaire tardive à travers le banc de Saint-Pierre.

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# TIMING AND POSITION OF LATE WISCONSINAN ICE-MARGINS ON THE UPPER SLOPE SEAWARD OF LAURENTIAN CHANNEL*

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ABSTRACT At the last glacial maximum, the major ice outlet through Laurentian Channel terminated on the upper continental slope. A 10 km square area of the upper slope has been investigated in detail, using airgun and boomer seismic reflection profiles and piston cores. Sediment failure during the 1929 Grand Banks earthquake resulted in exposure at the seabed of Last Glacial Maximum sediments that are normally buried beneath tens of metres of younger strata. Ice-margin acoustic and lithofacies are interpreted using criteria developed on the continental shelf and chronology is provided by AMS radiocarbon dates on *in situ* mollusc shells. Seismic data show a morainal ridge at 500 mbsl (mbsl = metres below (present) sea level) corresponding to the Last Glacial Maximum ice grounding line. A change in thermal regime of the ice or a subglacial meltwater outburst, at 16.5 ± 0.15 ka (radiocarbon years, -0.4 ka marine reservoir correction applied), resulted in release of sediment-laden meltwater that eroded gullies on the continental slope. This erosion surface is immediately overlain by a prominent stony diamict that extends to about 700 mbsl and may represent till deposition from a glacial surge. The ice margin then retreated upslope by 16.3 ka, probably to the prominent moraine at 380 mbsl at the lip of the Laurentian Channel. Evidence from mud turbidites on Laurentian Fan suggests that this ice marginal position may have persisted until about 14.2 ka. Ice then retreated rapidly northwards up Laurentian Channel, synchronous with Heinrich Event 1 at about 14 ka. Younger proglacial sediment on the upper continental slope slumped at about 12 ka, probably as a result of loading by a late-ice advance across St. Pierre Bank.

RÉSUMÉ *Chronologie et emplacement des marges glaciaires sur le talus supérieur au large du Chenal laurentien.* Au cours du dernier maximum glaciaire, le principal exutoire à travers le Chenal laurentien se terminait sur le talus continental supérieur. Une surface de 10 km$^2$ sur le talus supérieur a été étudiée en détail, à l'aide de profils résultant de l'utilisation de divers instruments de sismique rélexion. Le glissement pendant le tremblement de terre de 1929 au Grand Banc a causé la mise à nu sur le fond marin de sédiments du dernier maximum glaciaire, normalement enfouis sous des dizaines de mètres de nouvelles couches. Les lithofaciès et faciès acoustiques ont été interprétés à l'aide de critères mis au point sur la plate-forme continentale et la chronologie a été fournie par les datations SMA faites sur des coquillages de mollusques *in situ*. Les données sismiques font ressortir une crête morainique à 500 m snm (sous le niveau actuel de la mer) correspondant à la ligne d'ancrage au dermier maximum glaciaire. Un changement dans le régime thermique de la glace ou une éruption d'eau de fusion sousglacaire à 16,5 ± 0,15 ka (âge corrigé à -0,4 ka, compte tenu de l'effet de réservoir) a causé la libération d'eau de fusion enfouie qui a creusé des ravins sur le talus continental. Cette surface d'érosion a immédiatement été recouverte par un important diamicton pierreux jusqu'à 700 m snm, qui semble être un till déposé au cours d'une crue glaciaire. La marge glaciaire s'est par la suite retirée vers l'amont vers 16,3 ka, à l'emplacement de l'importante moraine située à 380 m snm, sur le bord du chenal Laurentien. Des indices tirés des boues de turbidites sur l'éventail Laurentien laissent croire que cette position de la marge glaciaire a été maintenue jusque vers 14,2 ka. La glace s'est ensuite rapidement retirée vers le nord le long du chenal Laurentien, vers 14 ka (Épisode de Heinrich 1/*Heinrich Event 1*). Des sédiments proglaciaires plus récents se sont effondrés vers 12 ka, probablement en raison d'une surcharge causée par une récurrence glaciaire tardive à travers le banc de Saint-Pierre.

RESUMEN *Cronología y localización del margen glaciar durante el periodo wisconsiniano tardío de la vertiente costera superior del canal del san lorenzo* Durante el clímax de la ultima glaciación, el mayor avance del hielo dentro del canal lorensiano se encontraba en la vertiente continental superior. Con la ayuda de diversos métodos de perfiles de reflexión sísmica , un área de 10 km$^2$ de la vertiente superior a sido investigada en detalle. En 1929 el terremoto acaecido en *Grand Banks*, puso al descubierto el lecho marino compuesto por sedimentos del periodo clímax de la ultima glaciación, dichos sedimentos generalmente se encuentran sepultados a decenas de metros de los estratos mas recientes. La interpretación del margen acústico del hielo y las litofacias fue establecida con base a criterios desarrollados en la zona continental, la edad de las formaciones fue proporcionada por la datación(AMS) de isótopos de carbono radioactivo *in situ* sobre conchas de moluscos. Los datos sísmicos indican una cima morainica a 500m bnm (bnm= metros bajo el nivel del mar) correspondiendo a la línea de anclaje durante el clímax de la ultima glaciación. Un cambio en el régimen térmico del hielo o una erupción subglaciar que genero la fusión del agua a 16,5+- 0,15 ka (años de radiocarbono, -0,4 ka considerando la corrección debida al efecto de «recipiente» marino) dio por resultado la liberación de sedimentos asociados al agua de fusión, y que genero las barrancas de la vertiente continental. Dicha erosión superficial fue inmediatamente recubierta por una capa rocosa de diamicton que se extendió hasta 700m snm y que podría representar el depósito de tillitas resultante de la oleada glacial. El margen del hielo retrocedió de la vertiente hacia 16,3 ka, probablemente hasta la moraina situada a 380m snm al borde del canal lorensiano. Ciertos índices obtenidos a partir de la turbidez del fango en el cono de deyección lorensiano permiten suponer que la posición marginal del hielo puede haberse mantenido hasta hace unos 14,2 ka. Mas tarde los hielos de retiraron rápidamente hacia el norte del canal lorensiano al mismo tiempo que el Evento 1 de Heinrich, aproximadamente 14 ka. Algunos sedimentos proglaciares mas recientes en la parte superior de la vertiente continental se hundieron hace unos 12 ka, probablemente como resultado de una progresión tardía del glaciar hacia el banco de *St. Pierre* .

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## INTRODUCTION

The Laurentian Channel (Fig. 1) was the major ice outlet of the Appalachian Ice Complex and the southeastern portion of the Laurentide Ice Sheet (Grant 1989). When glacial ice extended to the top of the continental slope, it played an important role in supplying sediment to Laurentian Fan (Uchupi and Austin, 1979; Skene, 1998), the largest Pleistocene sediment depocentre off southeastern Canada. Calving of icebergs from this ice margin was an important source of ice-rafted detritus to the North Atlantic Ocean (Bond and Lotti, 1995). The deglacial history of the ice outlet in the Gulf of St. Lawrence since about 14 ka has recently been documented by Josenhans and Lehman (1999). In this paper, we attempt to define the glacial history of the ice outlet around the Last Glacial Maximum (LGM).

## METHODS

The principal data set for this study is a detailed seismic survey in August 1999 using a Huntec Deep-Tow Seismic boomer system and one piston core (99036-01) located on the

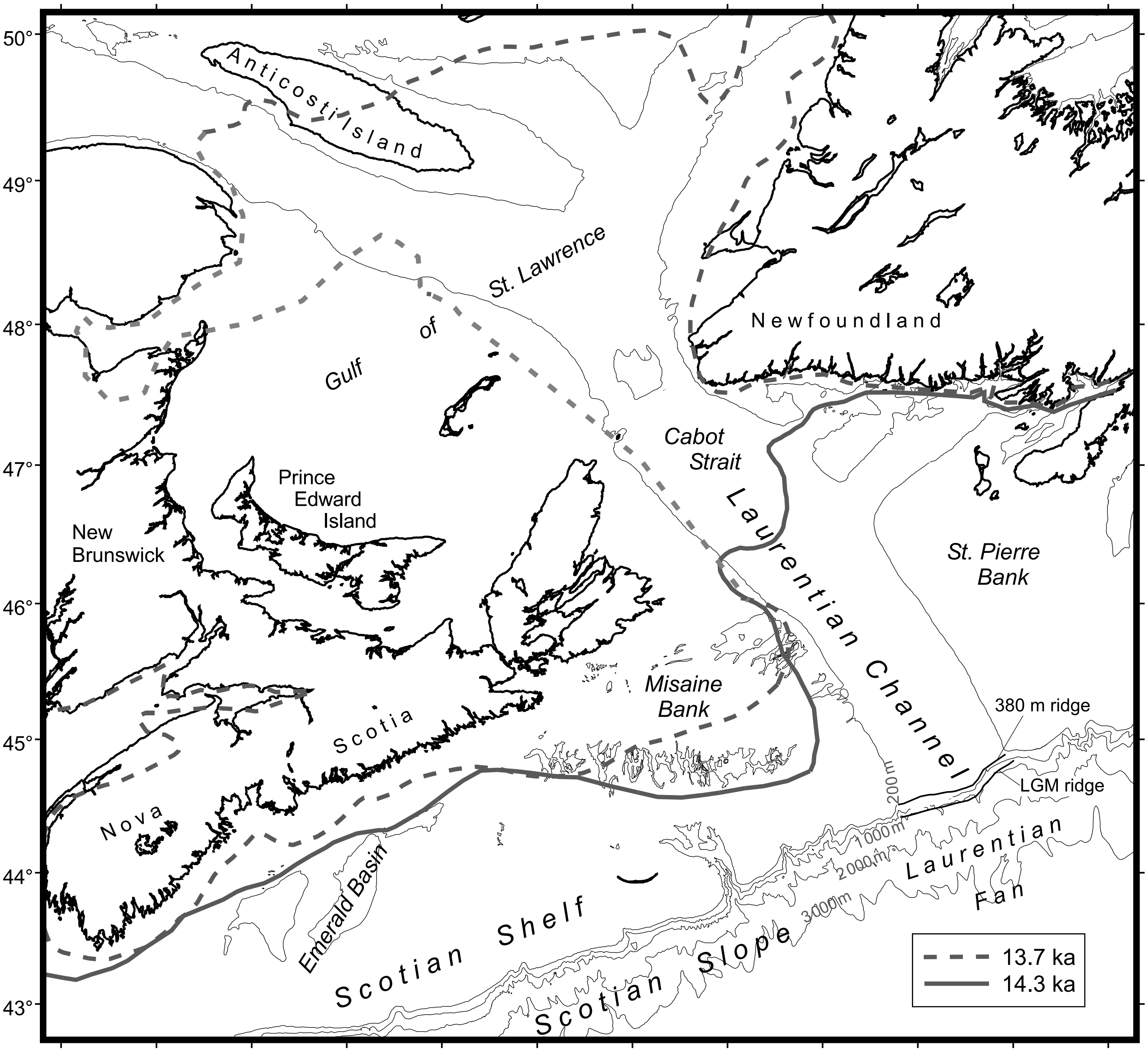


FIGURE 1. Regional setting of outer Laurentian Channel, showing rapid Late Wisconsinan ice retreat between 14.3 and 13.7 ka (largely from Josenhans and Lehman, 1999; some information from Stea *et al.,* 1998 and Piper and Skene,1998). Also shows schematically the grounding line ridges discussed in text.

*Emplacement du chenal Laurentien externe, illustrant le retrait rapide de la glace au Wisconsinien supérieur entre 14,3 et 13,7 ka (en grande partie de Josenhans et Lehman, 1999 ; quelques données de Stea* et al.*, 1998 et de Piper and Skene,1998). Sont aussi illustrées les crêtes de limite d'ancrage dont on parle dans le texte.*

basis on this survey (Fig. 2a). Previous data from the area include high-resolution sparker seismic-reflection profiles, run along strike, that were interpreted by Bonifay and Piper (1988) and a 1-km swath deep-water sidescan survey and coincident airgun seismic reflection profiles, interpreted by Piper *et al.* (1999). Several piston cores have been collected from the area on previous cruises. Navigation for cruises since 1990 has been by GPS; earlier cruises used Loran C. All AMS radiocarbon ages (Table I) are reported in radiocarbon years with a -400 year reservoir correction.

## SEISMIC STRATIGRAPHY

Regional seismic stratigraphy is known from multichannel seismic profiles STP-1 and STP-5 illustrated by MacLean and Wade (1992). These show that the modern shelf break approximately corresponds to the shelf break at the base of the Tertiary and that a series of basin-dipping normal faults underlie the outer shelf and upper slope.

Regional airgun single-channel seismic reflection profiles (Fig. 2a) show that the outermost part of Laurentian Channel

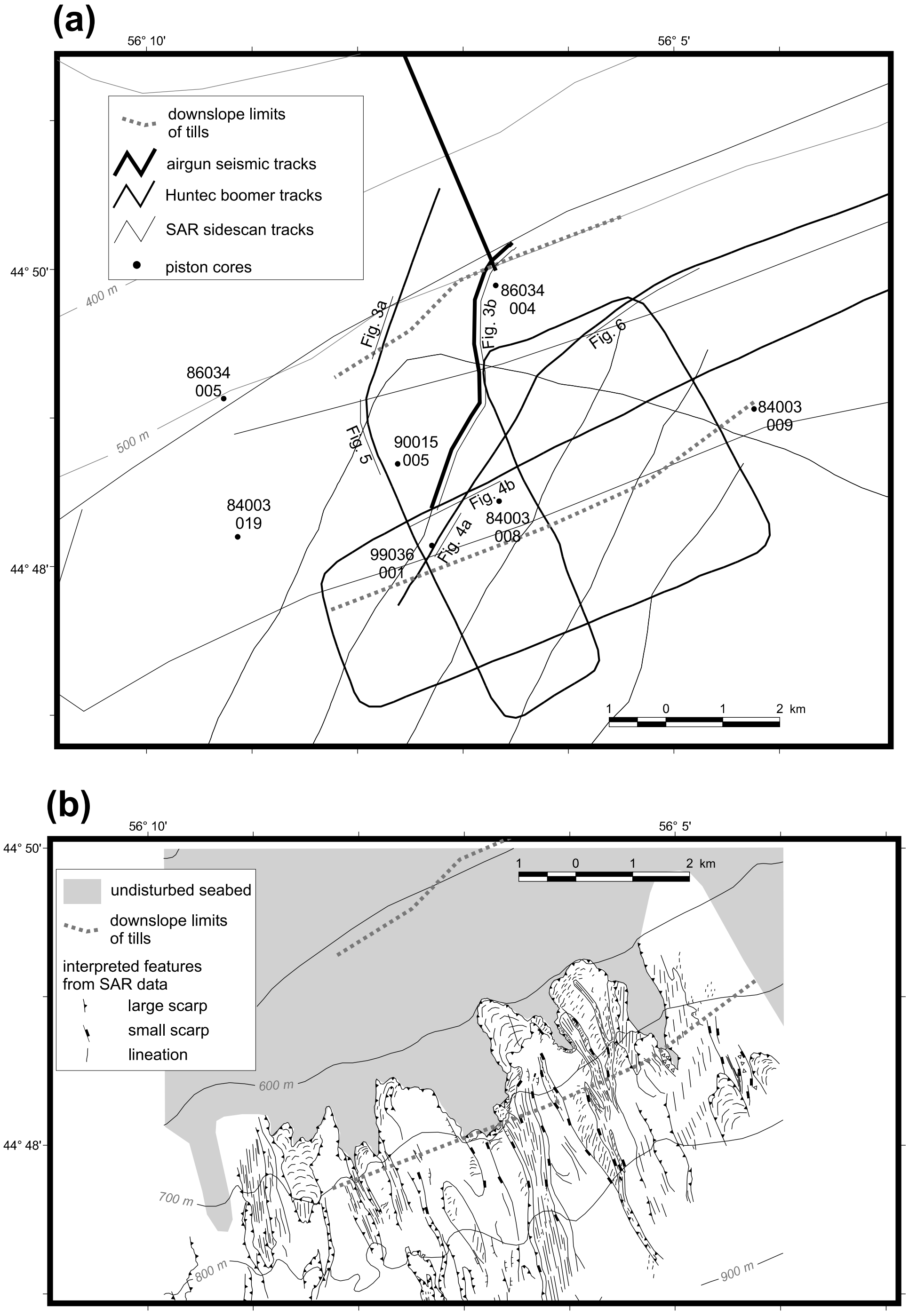


FIGURE 2. Detailed map of study area showing (a) location of seismic reflection profiles and cores and (b) interpreted sidescan sonar imagery (Piper *et al.,* 1999).

*Carte détaillée de la région à l'étude montrant (a) la localisation des profils et des carottes de sismique réflexion et (b) les tracés de l'imagerie de sonar latéral (Piper* et al.*, 1999).*

TABLE I

*New AMS radiocarbon ages*

| Core | Depth in core | Material | Age[1] | Lab No |
|---|---|---|---|---|
| 84003-9 | 100 | *Yoldia myalis valve* | 10 340 ± 240 | Beta-17871 |
| 90015-005TWC | 59 | *Astarte crenata frags* | 8 240 ± 80 | TO-4264 |
| 90015-005 | 4 | *Macoma calcarea frags* | 10 560 ± 90 | TO-4255 |
| 90015-005 | 49 | *N. pernana and Megayoldia frags* | 10 090 ± 80 | TO-4263 |
| 90015-005 | 95 | *Nuculana pernana frags* | 10 470 ± 80 | TO-4262 |
| 90015-005 | 157 | *Nuculana pernana frags* | 10 460 ± 90 | TO-4261 |
| 90015-005 | 245 | *Nuculana pernana valve* | 10 750 ± 110 | TO-4260 |
| 99036-001 | 116 | *single valve of bivalve mollusc* | 16 370 ± 50 | Beta-139257 |
| 99036-001 | 224 | *bivalve fragments* | 16 530 ± 110 | TO-8772 |
| 99036-001 | 338 | *bivalve fragments* | 16 550 ± 150 | Beta-149804 |

1. All ages expressed in radiocarbon years with a –400 year marine reservoir correction

is underlain by material with incoherent seismic reflections identified as till (King and Fader, 1986). This inferred till, corresponding to the Lower Till of Josenhans and Lehman (1999), occurs as a morainal ridge with several tens of metres of seabed relief at the outermost edge of Laurentian Channel (Fig. 1). King and Fader (1990) showed that this till stratigraphically underlies a series of three till-tongues off St. Pierre Bank and one off Misaine Bank, the latter interpreted as dating from about 13.5 ka by Stea *et al.* (1998). In both airgun and Huntec DTS profiles, this Lower Till can be traced downslope to approximately the 500 m isobath, where there is a low ridge and the acoustically incoherent strata pass downslope into well-stratified sediment (Fig. 3), in the manner of till tongues described by various authors (*e.g.*, King *et al.*, 1991). Similar relationships are found in several areas along the upper Scotian Slope and are interpreted as representing the transition from a long-lived grounding line into stratified proglacial sediment (Mosher *et al.,* 1989; Piper, 2000).

In water depths of 500-700 mbsl, the following sequence of acoustic facies is readily recognisable:

a) an upper unit, typically 5-10 ms (~5 m) thick, that is well stratified, particularly near its base where three reflections can be correlated with reflections a, b and c defined by Bonifay and Piper (1988) on northwestern St. Pierre Slope (Fig. 4). This unit correlates with the LaHave Clay Formation on the continental shelf.

b) an acoustically more transparent unit that is stratified in deeper water (Figs. 4 and 5) but higher on the slope appears acoustically incoherent, with an irregular upper surface (Fig. 6). This unit is 5-10 ms thick on the lower slope but thickens upslope to locally more than 25 ms (~20 m).

c) a well stratified unit, capped by a prominent reflector “orange”, with reflector amplitude decreasing stratigraphically downward. This unit is 10-15 ms (~10 m) thick, and thickens upslope. This unit drapes pre-existing topography, as do the stratified portions of the overlying two units.

d) an acoustically incoherent but strongly reflective unit with an irregular upper surface (Fig. 4). This unit has the acoustic character of tills that have been sampled on the continental shelf (*cf.* King and Fader, 1986). The distribution of this unit is patchy, but it is generally about 5 ms (~4 m) thick. The unit conformably (Fig. 5) overlies older acoustically stratified sediment in places, but elsewhere there is a pronounced unconformity (Fig. 6) that in places is marked by deep gullies (Fig. 4b). The downslope limit of the diamict unit appears to be at about 700 mbsl (Fig. 2b).

e) a lower unit of acoustically stratified sediment underlies the diamict unit. This unit is at least 15 m thick and passes upslope into an inferred morainal ridge at about 500 mbsl (Figs. 2b and 3a).

Widespread slumping during the 1929 “Grand Banks” earthquake (Piper *et al.*, 1999) resulted in prominent headscarps forming in water depths of 500-700 mbsl (Fig. 2b). These failures removed the entire sediment sequence above the diamict horizon (d above) (Fig. 4).

## PISTON CORE CONTROL AND RADIOCARBON CHRONOLOGY

The uppermost stratified unit has been sampled by several piston cores, including 90015-05 (Fig. 4), for which a series of radiocarbon dates is available. The Holocene section comprises ~1 m of sandy silt with scattered mollusc shells. It overlies 2.5 m of alternating olive grey bioturbated mud and laminated sandy silt beds, with radiocarbon ages[2] between 10.55 and 10.75 ka. Beneath this, a 4.6 m long interval of bioturbated muds corresponds to the acoustically transparent unit. Upslope, where the acoustically transparent unit is incoherent and has surface relief, core 86034-04 retrieved 20 cm of Holocene sandy silt overlying 2 m of alternating bioturbated mud and sandy silt beds, resting on a mud clast conglomerate of highly contorted blocks of a variety of types of mud. Such mud clast conglomerates are typical of rotational slumps and debris flows found elsewhere on the Scotian Slope (Piper *et al.* 1985; Shor and Piper, 1989).

2. In radiocarbon years with a –400 year reservoir correction

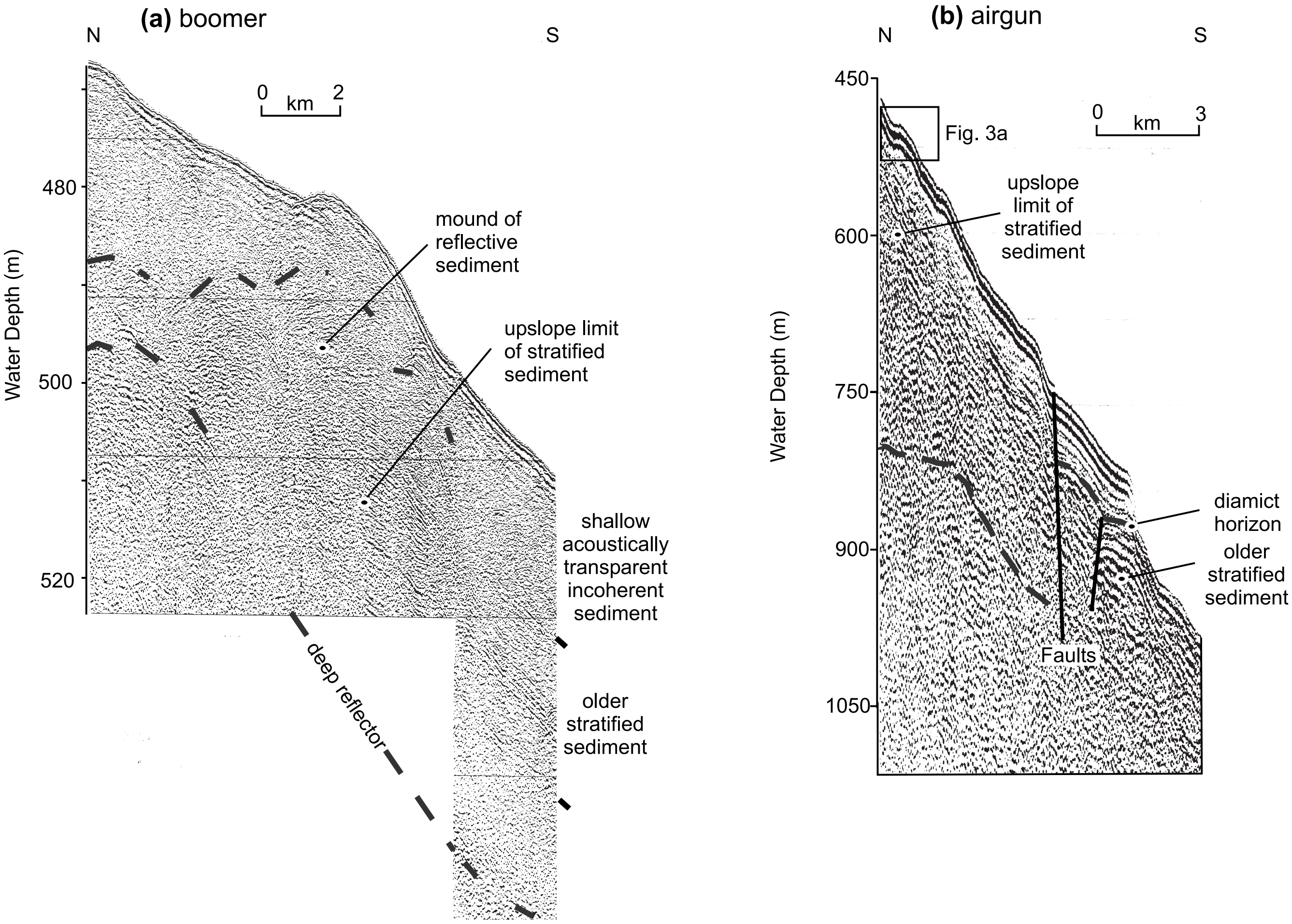


FIGURE 3. Seismic profiles across the upper slope seaward of Laurentian Channel. (a) Huntec DTS boomer profile showing a mound of reflective incoherent sediment passing downslope into well-stratified sediment. (b) Airgun seismic reflection profile showing stratified sediments downslope from acoustically incoherent sediment cut by faults.

*Profils sismiques à travers le talus supérieur au large du chenal Laurentien. (a) Profil obtenu du boomeur Huntec montrant un monticule de sédiments meubles devenant en aval bien stratifiés. (b) Profil de sismique réflexion obtenu d'un fusil à air comprimé montrant des sédiments bien stratifiés en aval de sédiments meubles sectionnés par des failles.*

The stratified unit capped by the orange reflector has not been penetrated by cores, except for its extreme base in core 99036-01. This core, located within a slump scar, penetrates a thin sequence of the diamict unit near its downslope limit, together with the underlying stratified sediment (Fig. 7). The uppermost 30 cm consists bioturbated silty mud that rests apparently unconformably on stiff grey mud, 1.3 m thick, with sparse dropstones and alternating bioturbated and unbioturbated intervals. This is interpreted as the base of the stratified unit that is capped by the orange reflector. It overlies 55 cm of alternating laminae (1-3 cm) of brown and grey sandy gravelly mud, interpreted as a proximal ice-meltout facies. Stratification becomes thicker near the base of the unit, which passes into 35 cm of diamict with a wide range of clast sizes, including stones up to 6 cm in size. Maximum clast size is limited by the 10 cm diameter of the corer. The dominant rock type is reddish sandstone and siltstone, apparently derived from Upper Carboniferous-Permian strata of the Gulf of St. Lawrence (*cf.* Piper and Skene, 1998). The diamict and the overlying sandy gravelly mud are interpreted to correlate with the diamict acoustic unit. The diamict overlies > 1 m of bioturbated grey mud with sparse dropstones, which corresponds to the lower stratified acoustic unit (Fig. 4). Neither diamict nor underlying grey mud appears overconsolidated, suggesting that if the diamict is a till, then ice was essentially supported by its buoyancy. Three radiocarbon dates from this core show a progressive increase in age downcore. A date of 16.37 ka was obtained from a single valve of a bivalve mollusc at a depth of 1.15 m in the core, 45 cm above the top of the laminated sandy gravelly mud. Bivalve mollusc fragments in the diamict (presumably reworked from the underlying sediment) yielded an age of 16.53 ka and bivalve mollusc fragments (probably broken during core splitting) from the underlying grey mud dated at 16.55 ka (Table I). The consistency of these dates suggests that they reliably date the diamict and the underlying erosion surface as younger than 16.53 ± 0.15 ka but older than 16.37 ± 0.05 ka.

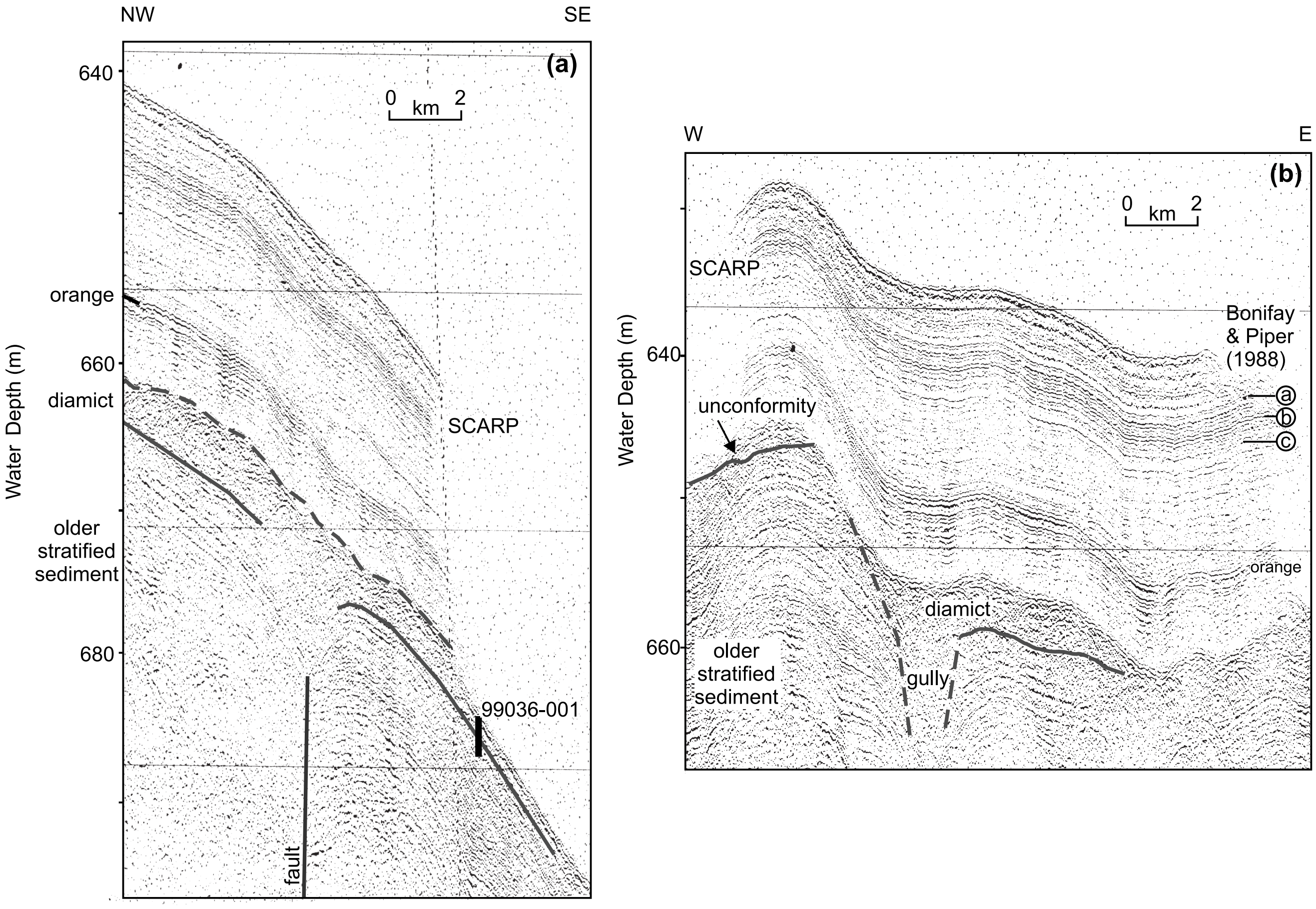


FIGURE 4. Huntec DTS boomer profiles near core 99036-1, showing acoustic stratigraphy. (a) Dip line showing position of core. (b) Strike line showing general acoustic character.

*Profils sismiques obtenus du boomeur Huntec près de la carotte 99036-1, montrant la stratigraphie acoustique. (a) Profil de pendage montrant l'emplacement de la carotte. (b) Isohypse montrant le caractère acoustique général.*

## DISCUSSION

### INTERPRETATION OF ACOUSTIC FACIES AND LITHOFACIES

The bioturbated grey muds of the lower stratified unit closely resemble glaciomarine muds described by Gipp (1994) as lithofacies 2 of the Emerald Silt Formation from Emerald Basin on the Scotian Shelf (Fig. 1). Off Laurentian Channel, these muds appear to pass upslope into a morainal ridge (Fig. 3a), similar to relationships seen elsewhere on the Scotian and Grand Banks margins (Bonifay and Piper, 1988; Mosher *et al.,* 1989; Piper, 2000). If sedimentation rates are similar to the 20 m/ka determined by Bonifay and Piper (1988) close to ice margins on St. Pierre Slope, then the 15 m of muds could represent as little as a thousand years of sedimentation, but on the steep continental slope, overall sedimentation rates were likely lower than in an enclosed basin.

The overlying diamict is interpreted as a till, on the basis of its acoustic character, downslope limit at about 700 mbsl, and lithology. The possibility that it is an aquatill rather than a lodgement till cannot be excluded. The downslope limit has been mapped at about the same water depth over a distance of 6 km, suggesting that it is not an ice-margin debris flow facies, which would show more irregular downslope extent. Likewise, if it were a proximal glaciomarine facies, its abrupt termination in acoustic records is difficult to account for. The alternating brown and grey sandy gravelly muds are similar to lithofacies 1 of Gipp (1994), interpreted as deposited proximal to melting and calving ice. They have a much higher proportion of coarse ice-rafted detritus than the muds underlying the diamict, which seismic reflection profiles show accumulated only 1.5 km from the ice margin marked by the morainal ridge. The overlying alternating bioturbated and unbioturbated muds with dropstones are similar to Gipp's lithofacies 2. He demonstrated that these accumulated within 10 km of a marine ice margin. Only the extreme base and top of this acoustically stratified section between the diamict and reflector c has been sampled (Figs. 4b and 5). It has a mean sediment accumulation rate of about 3 m/ka. Given the radiocarbon age of reflector c as 10.75 ka and the 16.37 ka date just above the diamict, the interpolated age of the orange reflector is about 14.1 ka (Fig. 3b). This prominent reflection thus has an age similar to the brick-red sandy-mud ice-rafted horizon "d" described by Piper and Skene (1998) on the Scotian margin, whch they interpeted as transported by ice-rafting during rapid calving

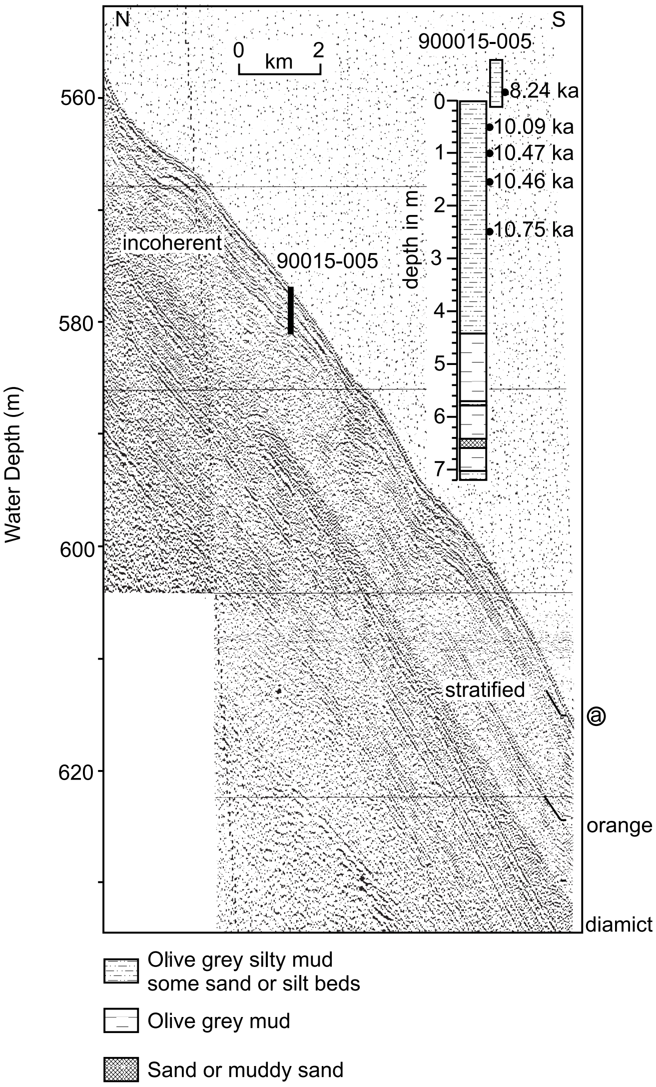


FIGURE 5. Downslope Huntec DTS boomer profile through core 90015-15, showing facies, chronology and seismic stratigraphy.

*Profil obtenu du boomeur Huntec à travers la carotte 90015-15 vers l'aval, montrant les faciès, la chronologie et la stratigraphie sismique.*

and retreat of an ice tongue in Laurentian Channel (Josenhans and Lehman, 1999). The concentration of coarse-grained sediment in this prominent ice-rafted horizon results in a strong reflector elsewhere (*e.g.*, Fig. 4 of Piper *et al.,* 1999) and it is suggested that this may be the origin of the orange reflector in the study area. The seismic profiles do not show the relationship of this unit below orange to tills on the upper slope.

The acoustically transparent unit that corresponds to slumps or debris flow deposits on the upper slope correlates along strike with the section identified by Bonifay and Piper (1988) as ice-margin diamict derived from southeastern Newfoundland, with an extrapolated age of 11.2-11.6 ka[3]. The ice appears to have crossed St. Pierre Bank and extended to a water depth of about 500 mbsl. Beyond the ice margin, glaciomarine muds accumulated. We suggest that loading by this ice on the upper slope probably triggered upper slope failure and development of slumps and debris flows (as proposed elsewhere on the Scotian Slope by Mulder and Moran, 1995).

## A GLACIOLOGICAL INTERPRETATION OF THE SEDIMENT SEQUENCE

The morainal ridge at 500 mbsl is interpreted as a stable ice margin position of perhaps 1 ka duration that is a little older than 16.4 ka (Fig. 8). We suggest that this is likely the *ca*. 18 ka Last Glacial Maximum position of ice in Laurentian Channel and that the ice margin was stable for at least a thousand years, based on the thickness of proglacial stratified sediment. Following this, there was an erosional event that cut deeply incised gullies in places and appears to have had little effect in other places. The erosional agent was presumably sediment-laden water: the gullies appear too narrow (Fig. 4b) for the erosion to have been by ice. The gully erosion also continues into deeper water, suggesting that it was not exclusively by subglacial meltwater. The position of the ice-margin at this time is unknown, but with the shelf break at 380 mbsl, this erosion cannot be related to a lowstand of sea level. Neither is upper slope sediment failure an adequate mechanism to explain such 10-20 m deep erosion. We suggest that the erosion resulted from an event that released erosive subglacial meltwater, which continued to flow down the steep slope as hyperpycnal flows. Overlying the erosion surface is a discontinuous stony diamict that extends to water depths of about 700 mbsl. Its age is less than 200 years younger than the erosional surface, suggesting that the two events may have been glaciologically related. They appears to represent a change in glacial conditions similar to that inferred for Heinrich events in Hudson Strait, *i.e.* either a change in basal temperature regime to warm-base conditions (MacAyeal, 1993) or release of dammed subglacial water (Johnson and Lauritzen, 1995). The age of this event corresponds to the Scotian Phase of Stea *et al.* (1998).

Following deposition of the diamict, the abundance of ice-rafted detritus suggests proximity to an ice margin that calved or melted much more vigorously than the LGM ice margin, perhaps because of changed thermal regime of the ice. The rapid upward decrease in abundance of ice-rafted detritus suggests that the ice margin retreated rapidly. It may have restabilised at the lip of Laurentian Channel, at about 380 mbsl, where there is a prominent morainal ridge in the Lower Till (Fig. 1). We suggest that this ice margin persisted until about 14.2 ka and supplied suspended sediment that accumulated as mud turbidites on Laurentian Fan. Deposition of these mud turbidites terminated abruptly and typically 0.5 m above the topmost turbidite is a distinctive bed of ice-rafted sandy-gravelly mud derived from the Gulf of St. Lawrence and dated at about 14.0 ka (Piper and Skene, 1998).

3. Reservoir corrected: note that radiocarbon dates as originally cited by Bonifay and Piper, 1998, lacked a reservoir correction.

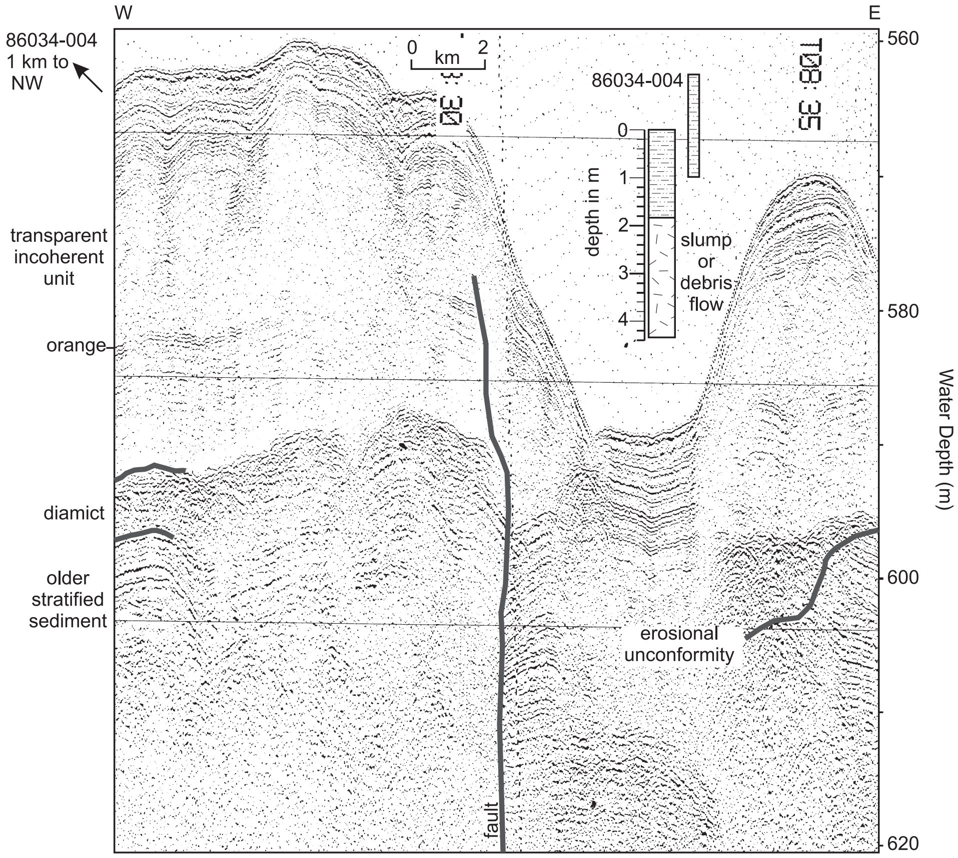


FIGURE 6. Huntec DTS boomer profile on upper slope showing seismostratigraphic markers, acoustic facies, relative position and lithofacies of core 86034-4, and shallow faulting.

*Profil obtenu du boomeur Huntec sur le talus supérieur montrant les marqueurs sismostratigraphiques, les faciès acoustiques, l'emplacement relatif de la carotte 86034-4 et son lithofaciès, ainsi que les failles peu profondes.*

Available radiocarbon dates suggest that the retreat of ice from the end of Laurentian Channel back into the Gulf of St. Lawrence took place at about 14 ka within a span equivalent to the error range of radiocarbon dating and uncertainties in reservoir corrections and bioturbational mixing. The youngest date in red mud turbidites on Laurentian Fan, 4 m below the ice-rafted ice-rafted sandy-gravelly mud bed, is 14.09 ± 0.09 ka (Piper *et al.*, 1999). Keigwin and Jones (1995) obtained an age of 14.00 ± 0.06 ka from 15 cm above the mud turbidites and Piper and Skene (1998) reported an age of 14.0 ± 0.2 ka at a similar stratigraphic level. About 100 km southwest of Cabot Strait, Josenhans and Lehman (1999) reported an age of 14.31 ± 0.15 at the base of glaciomarine sediment in core V17-179 and 80 km northeast of Cabot Strait, a date of 14.02 ± 0.17 ka at the base of the glaciomarine section in core HU90028-037. The rapid retreat of ice implied by the Josenhans and Lehman (1999) dates was probably responsible for the the release of voluminous ice-rafted detritus to give ice-rafted sandy-gravelly mud bed over much of the Scotian margin (Piper and Skene, 1998). This event initiated the rapid retreat of ice from Laurentian Channel, which Josenhans and Lehman (1999) documented as retreating to Anticosti Island (Fig. 1) by 13.7 ka. Shaw *et al.* (2000) reported open water along the southwest coast of Newfoundland starting about 14.2 ka. Following this retreat, ice occupied Halibut Channel (Moran and Fader, 1997) and crossed St. Pierre Bank (Bonifay and Piper, 1988) at about 12 ka. Whether this represented local ice developed on St. Pierre Bank or was derived from southeastern Newfoundland, probably the Avalon Peninsula, as suggested by detrital petrology, is not clear. We postulate that this ice advance caused the widespread slumping on the upper slope off the eastern Laurentian Channel.

## CONCLUSION

1. At the LGM, ice was grounded to 500 mbsl seaward of Laurentian Channel and built a morainal ridge.

2. A change in thermal regime or a subglacial meltwater outburst, between 16.54 ± 0.15 ka and 16.37 ± 0.05 ka, resulted in release of sediment-laden meltwater that caused local gully erosion on the continental slope. This erosion surface is overlain by a prominent stony diamict that extends to about 700 mbsl and may represent till deposition from a glacial surge.

3. The ice margin then appears to have retreated upslope, probably to the prominent moraine at 380 mbsl at the lip of the Laurentian Channel. Evidence from mud turbidites on Laurentian Fan suggests that this ice marginal position persisted until about 14.2 ka.

4. Ice retreated rapidly northwards up Laurentian Channel at about 14 ka. Younger proglacial sediment on the upper continental slope slumped at about 12 ka, probably as a result of loading by a late-ice advance across St. Pierre Bank.

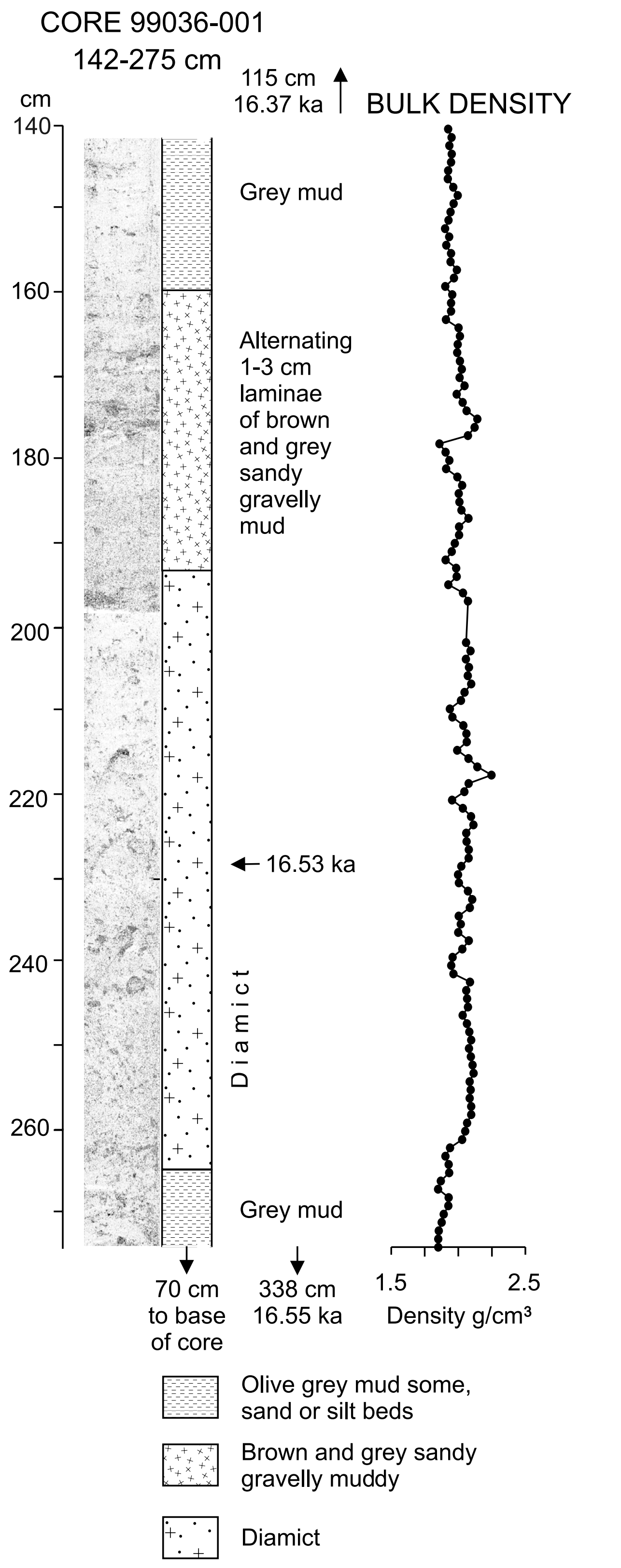


FIGURE 7. Photographs and lithostratigraphy of the middle part of core 99036-1.

*Photographies et lithostratigraphie de la partie centrale de la carotte 99036-1.*

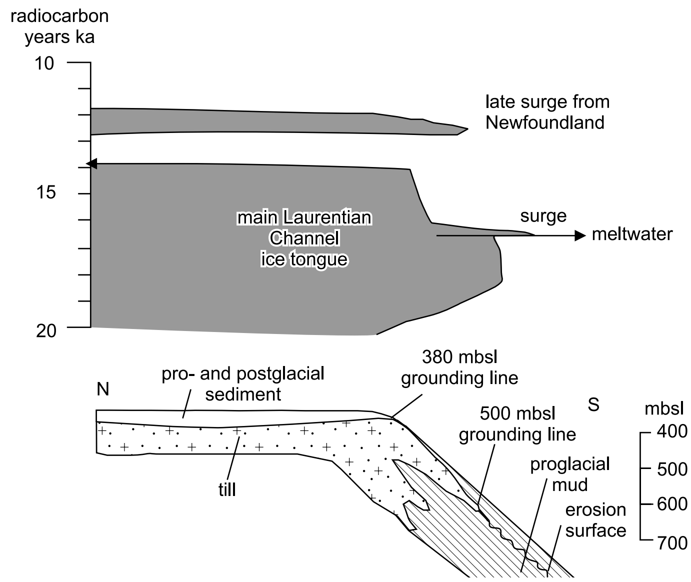


FIGURE 8. Cartoon showing generalised stratigraphy and inferred ice history at the seaward end of the Laurentian Channel in the Late Wisconsinan.

*Stratigraphie générale et évolution glaciaire du chenal Laurentien à sa limite vers le large pendant le Wisconsinien supérieur.*


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