Géographie physique et Quaternaire

Late Quaternary Paleoceanography and Sedimentary Environments in Hudson Strait
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Paläo-Ozeanographie im späten Quaternär und Sediment-Umwelt in der Hudson Meerenge

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Volume 43, numéro 2, 1989

URI : https://id.erudit.org/iderudit/032767ar
DOI : https://doi.org/10.7202/032767ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Citer cet article

Vilks, G., MacLean, B., Deonarine, B., Currie, C. G. & Moran, K. (1989). Late Quaternary Paleoceanography and Sedimentary Environments in Hudson Strait. *Géographie physique et Quaternaire*, *43*(2), 161–178. https://doi.org/10.7202/032767ar

Résumé de l'article

L'utilisation d'un fusil à air comprimé et d'un dispositif explosif Huntec en sismique réflexion a permis d'obtenir des profils à haute résolution révélant que des sédiments glaciaires, glaciomarins et postglaciaires d'une épaisseur de 130 m surmontent la roche en place. Un bassin, à l'entrée est du détroit d'Hudson, renferme des sédiments de surface qui, pour la plupart, se sont déposés au cours de la dernière glaciation. On a relevé cinq unités acoustiques dont au moins trois ont été explorées par carottage. Les foraminifères de la carotte extraite, dans le bassin est, à la plus grande profondeur révèlent qu'existaient un milieu glaciomarin proximal et, vraisemblablement, une plate-forme de glace flottante. La datation au 14C fait remonter à 8060 ± 70 BP (TO 750) les coquilles de mollusques et confère ainsi un âge minimal à la portion supérieure des sédiments glaciomarins distaux, laminés par acoustique. Les foraminifères du début de la période postglaciaire laissent croire que les eaux profondes du large ont pendant un certain temps exercé une influence accrue sur les fonds du bassin de l'est. Dans toutes les carottes, les sédiments de surface renferment des espèces indigènes au milieu aquatique actuel, plus froid et moins salé. Le taux 18OZ16O trouvé chez le foraminifère benthique Cibicides lobatulus se rapporte ici à la salinité des fonds aquatiques. Plus bas, dans les carottes, on a relevé sur C. lobatulus un taux de 818O qui révèle une paléosalinité plus faible d'environ 0,5%o, précédant tout juste l'horizon daté à 8000 BP. À cette époque, le détroit d'Hudson était suffisamment libre de glace pour que s'établissent les marées telles qu'on les connaît actuellement. Plus bas encore, la salinité révèle que les eaux de fusion glaciaire provenant de la baie d'Hudson se sont mêlées aux contre-courants venus du large.

Géographie physique et Quaternaire, 1989, vol. 43, n° 2, p. 161-178, 22 fig., 1 tabl.

LATE QUATERNARY PALEOCEANOGRAPHY AND SEDIMENTARY ENVIRONMENTS IN HUDSON STRAIT*

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ABSTRACT Airgun and high resolution Huntec seismic reflection profiles are interpreted to show up to 130 m of glacial, glaciomarine and postglacial sediments overlying bedrock. In a basin at the eastern entrance to Hudson Strait most of the surficial sediment was deposited during the last deglaciation, but in western Hudson Strait multiple till sequences from previous glaciations are recognized. Five acoustic units were identified, at least three of which were penetrated with piston cores. Foraminifera of the stratigraphically deepest core in the eastern basin indicate a proximal glaciomarine environment and a likely presence of an ice shelf. A ^{14}C date of 8060 ± 70 yBP (TO 750) on molluscan shells gives a minimum age for the top of the acoustically laminated distal glaciomarine sediments. The early postglacial foraminifera suggest a period of increased influence of offshore bottom waters restricted to the deep eastern basin. The surface sediments of all cores contain species indigenous of colder and fresher inshore waters of the present time. The ratio of $^{18}O/^{16}O$ in the benthic foraminifer *Cibicides lobatulus* is herein related to bottom salinity. Downcore measurements of $\delta^{18}O$ on *C. lobatulus* tests indicate bottom paleosalinities lower by about 0.5‰ shortly before the dated horizon of 8000 yBP. By this time Hudson Strait was sufficiently clear of glacial ice for establishment of the present tidal regime. The lower bottom salinities indicate that tidal mixing took place between glacial meltwater leaving Hudson Bay and the offshore counterflow. This process is thought to have reduced the sharpness of the salinity difference between the offshore water and the surface plume of Laurentide meltwater as it entered the ocean.

RÉSUMÉ *Paléo-océanographie du Quaternaire supérieur et milieux sédimentaires dans le détroit d'Hudson.* L'utilisation d'un fusil à air comprimé et d'un dispositif explosif Huntec en sismique réflexion a permis d'obtenir des profils à haute résolution révélant que des sédiments glaciaires, glaciomarins et postglaciaires d'une épaisseur de 130 m surmontent la roche en place. Un bassin, à l'entrée est du détroit d'Hudson, renferme des sédiments de surface qui, pour la plupart, se sont déposés au cours de la dernière glaciation. On a relevé cinq unités acoustiques dont au moins trois ont été explorées par carottage. Les foraminifères de la carotte extraite, dans le bassin est, à la plus grande profondeur révèlent qu'existaient un milieu glaciomarin proximal et, vraisemblablement, une plate-forme de glace flottante. La datation au ^{14}C fait remonter à 8060 ± 70 BP (TO 750) les coquilles de mollusques et confère ainsi un âge minimal à la portion supérieure des sédiments glaciomarins distaux, laminés par acoustique. Les foraminifères du début de la période postglaciaire laissent croire que les eaux profondes du large ont pendant un certain temps exercé une influence accrue sur les fonds du bassin de l'est. Dans toutes les carottes, les sédiments de surface renferment des espèces indigènes au milieu aquatique actuel, plus froid et moins salé. Le taux $^{18}O/^{16}O$ trouvé chez le foraminifère benthique *Cibicides lobatulus* se rapporte ici à la salinité des fonds aquatiques. Plus bas, dans les carottes, on a relevé sur *C. lobatulus* un taux de $\delta^{18}O$ qui révèle une paléosalinité plus faible d'environ 0,5‰, précédant tout juste l'horizon daté à 8000 BP. À cette époque, le détroit d'Hudson était suffisamment libre de glace pour que s'établissent les marées telles qu'on les connaît actuellement. Plus bas encore, la salinité révèle que les eaux de fusion glaciaire provenant de la baie d'Hudson se sont mêlées aux contre-courants venus du large.

ZUSAMMENFASSUNG *Paläo-Ozeanographie im späten Quaternär und Sediment-Umwelt in der Hudson Meerenge.* Mit Hilfe eines Luftgewehrs und einer Huntec Explosionsanlage mit seismischer Reflexion gewonnene Profile mit hoher Auflösung lassen bis zu 130 m glazialer, glaziomariner und postglazialer Sedimente erkennen, die den Fels überlagern. In einem Bassin am östlichen Eingang zur Hudson-Meerenge ist der grösste Teil der Oberflächensedimente während der letzten Vereisung abgelagert worden, aber in der westlichen Hudson-Meerenge lassen sich vielfache Grundmoränen-Sequenzen von früheren Vereisungen erkennen. Fünf akustische Einheiten wurden identifiziert, von denen mindestens drei durch Kernbohrung ergründet wurden. Die Foraminifera des stratigraphisch tiefsten Kerns im östlichen Bassin weisen auf eine proximale glaziomarine Umwelt und die mögliche Existenz einer Eisdecke. Eine ^{14}C Datierung von 8060 ± 70 Jahren v.u.Z. (bis 750) für Molluskenschalen ergibt ein Minimalalter für den oberen Teil der distalen glaziomarinen Sedimente, die durch Akustik eine blättrige Struktur bekommen haben. Die frühen postglazialen Foraminifera lassen auf eine Periode wachsenden Einflusses des küstenfernen Tiefwassers auf das tiefe östliche Bassin schliessen. Die Oberflächensedimente aller Bohrkerne enthalten Gattungen, die spezifisch für die kälteren und frischeren Küstengewässer der gegenwärtigen Zeit sind. Der Anteil an $^{18}O/^{16}O$ in dem benthischen Foraminifer *Cibicides lobatulus* ist hierin mit dem Salzgehalt auf dem Grund verbunden. Tiefer im Bohrkern hat man auf *C. lobatulus* Werte von $\delta^{18}O$ gefunden, was einen um etwa 0.5% geringeren Grund-Paläosalzgehalt ergibt, kurz vor dem auf 8000 Jahre v.u.Z. datierten Horizont. Zu diesem Zeitpunkt war die Hudson-Meerenge von glazialem Eis ausreichend befreit, so dass sich der gegenwärtige Gezeiten-Wechsel etablieren konnte.

* Geological Survey of Canada Contribution No. 37488

Manuscrit reçu le 16 novembre 1988; manuscrit révisé accepté le 30 mars 1989

INTRODUCTION

The Late Quaternary marine environment in Hudson Strait was mainly governed by glacially related sedimentary and oceanographic processes. Hudson Strait was a key area along the marine margin of the Laurentide Ice Sheet, serving as a major outlet of glacial ice and influencing ice sheet stability and geometry throughout the Quaternary. During the Wisconsinan, Hudson Strait is thought to have been an active conduit of ice for the multiple glaciations in the Hudson Bay area (Andrews *et al.*, 1983). Models of the Laurentide Ice Sheet based on glacial theories and field evidence show a major convergence of the ice flow towards Hudson Strait (Dyke and Prest, 1987; Laymon, 1988) and an ice stream in Hudson Strait, with a calving front at the marine margin (Mayewski *et al.*, 1981).

Hudson Strait is sufficiently wide and deep to have been a major area of ice drawdown. Deep sea sediment and foraminiferal data in the North Atlantic suggest that between 16,000 and 13,000 yBP marine drawdown rather than melting was important for the reduction of the Laurentide Ice Sheet (Ruddiman and McIntyre, 1981). The drawdown due to increased calving rates in Hudson Strait was postulated to be one of the mechanisms responsible for the rapid ablation of the central dome in the Hudson Bay region (Andrews and Peltier, 1976). Thus, during the period of ablation, large volumes of Laurentide ice must have moved through Hudson Strait.

Late Labrador/Ungava ice has been postulated to have crossed Hudson Strait and impinged on Meta Incognita Peninsula (Mercer, 1956) and Resolution Island (Andrews *et al.*, 1985; Stravers, 1986). Thus, eastern Hudson Strait may occasionally have been blocked by converging glacial ice. Because of the obstructed connection to the open sea, there may have been periods of time when Hudson Strait contained fresh or only partially saline water. Evidence for reduced salinities during deglaciation at the entrance to Hudson Strait was presented by Andrews *et al.* (1987).

This paper discusses paleoceanographic and sedimentary environments in Hudson Strait interpreted from foraminiferal and seismic evidence. The latter is based on Huntec Deep Tow high resolution and single channel reflection data. Foraminifera were extracted from piston cores collected from basins in eastern and western Hudson Strait. The changing environments and their chronology provide further evidence on dynamics of the Late Wisconsinan deglaciation in Hudson Strait.

PREVIOUS WORK IN MARINE SEDIMENTS

The paleosedimentary history of the surficial sediments in Hudson Strait has been investigated by high resolution seismic profiling and sediment sampling (*e.g.* Grant and Manchester, 1970; Fillon and Harmes, 1982; MacLean *et al.*, 1986). On the basis of seismic data, Josenhans *et al.* (1986) recognized a till unit overlying glacial marine sediments on the shelf at the eastern entrance to Hudson Strait. They interpreted this upper till as having been deposited by a late glacial ice surge. A reconnaissance survey of the strait by MacLean *et al.* (1986) indicated the widespread presence of glacial deposits, including multiple sequences of morainal deposits, and thick acoustically stratified sediments in the eastern and western parts of Hudson Strait. Five distinct *till* sequences are present on the shelf in the lee of a sill at the entrance to Hudson Strait (Josenhans *et al.*, 1986) and four tills occur northeast of Resolution Island (MacLean, 1985; Praeg *et al.*, 1986). These provide evidence that Hudson Strait was a major ice dispersal route.

METHODS

Sediment samples and oceanographic measurements were obtained during Cruise 82027 (Jones and Drinkwater, 1982) and seismic reflection profiles, piston cores and grab samples during Cruise 85027 (MacLean *et al.*, 1986) (Fig. 1). The coring was carried out in conjunction with high resolution seismic surveys using 655 cu cm airgun and Huntec Deep Tow boomer systems. Piston core stations were positioned to sample specific acoustic units identified from the Huntec profiles. The location of these profiles is shown in Figure 1.

Split cores were x-rayed with a videoscanner x-radiograph system developed at the Bedford Institute of Oceanography and images were stored on videotape. Sediment color, texture and major depositional features were documented by visual inspection of the freshly split cores and interpretation of x-radiographs.

Foraminifera were collected from sediment subsample grain size fractions greater than 63 microns. Stable isotopes of oxygen and carbon of *Cibicides lobatulus* were analysed under contract by the Stable Isotope Laboratory, Centre of Marine Geology, Dalhousie University, Halifax, N.S. Radiocarbon dates on molluscan shells were obtained from ISOTRACE laboratory at the University of Toronto using the Accelerator Mass Spectrometry (AMS) method (Table I). Detailed data on foraminiferal distribution is reported in Vilks *et al.* (1989).

TABLE I

Radiocarbon dates

Sample	Material	Weight (gm)	Lab. No.	Age*
Core 85027-57				
782-788 cm	*Portlandia arctica* Single valve	0.051	TO 748	7880 ± 70
814-822 cm	*Portlandia arctica* Paired shell	0.260	TO 749	7730 ± 70
862-870 cm	*Portlandia arctica* Single valve	0.041	TO 750	8060 ± 70
Core 85027-68				
989-996 cm	*Portlandia arctica* Fresh fragments	0.064	TO 751	7903 ± 70
Core 85027-65				
294-299 cm	*Clinocardium ciliatum* Single valve	0.610	TO 293	6280 ± 50

* *By Accelerator Mass Spectrometry*

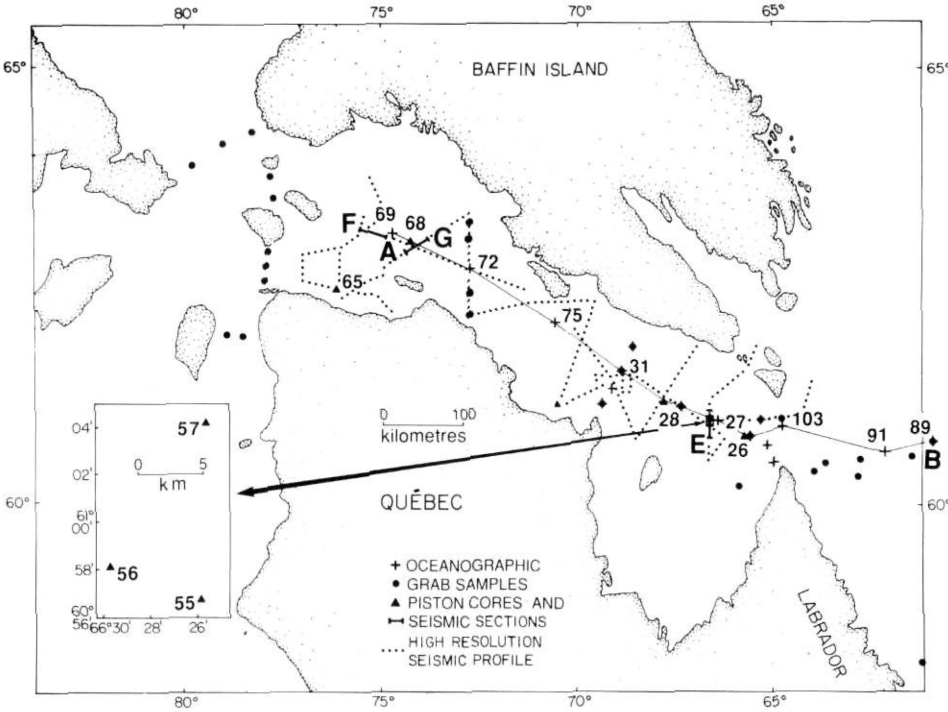


FIGURE 1. Station locations, salinity *vs* depth profile along line A-B and airgun seismic reflection section E, F, and G discussed in text. Seismic lines that assisted interpretation of the sections are also shown.

Localisation des stations; salinité et profil des profondeurs suivant une ligne AB; sismique réflexion par fusil à air comprimé dans les sections E, F et G. Sont également illustrées les lignes sismiques qui ont servi à l'interprétation des sections.

Physical properties, including shear strength, water content, and density of the core samples were measured at the Atlantic Geoscience Centre geomechanics laboratory. Shear strength was measured using a modified Wykham Farrance vane shear device at a strain rate of 50 degrees per minute. The density was measured by subsampling the cores with a constant volume sampling device (piston operated) and measuring the mass of the subsample. Water content was determined following the methods of Noorany (1984).

PHYSICAL ENVIRONMENT

BEDROCK, BATHYMETRY AND SEDIMENTS

Seismic reflection profiles and samples from Hudson Strait document the presence of Paleozoic and Precambrian bedrock overlain by unconsolidated sediment of various thicknesses (Grant and Manchester, 1970; MacLean *et al.*, 1986; Miller and Williams, 1987). Paleozoic rocks are present on Akapatok Island and extend northward beneath Hudson Strait and contact Precambrian rocks offshore of Meta Incognita Peninsula. The submarine section locally may also contain post-Paleozoic rocks. In Ungava Bay, south-southeast of Akpatok Island, the Paleozoic bedrock terminates in a series of cuestas.

The bedrock geology largely determines the basic features of the sea floor morphology. Eastern and western parts of the Strait are half-grabens, but the central region is mostly synclinal in structure. The bottom is relatively smooth in the central part of Hudson Strait and Ungava Bay where the unconsolidated sediments are underlain by Paleozoic rocks (MacLean *et al.*, 1986). The sea floor between the shoreline and the margins of the Paleozoic deposits is underlain by Precambrian rocks and is more irregular. Ungava Trough, which borders the southeastern margin of the Paleozoic sediments, is connected to the deep trough in Gray Strait to the northeast (Fig. 2).

In the central part of Hudson Strait water depths range between 300 and 400 metres (Fig. 2). At the western end of the Strait there are elongated depressions in which depths exceed 400 metres. At the eastern end, a basin exceeding 900 metres occurs behind a sill shallower than 400 metres, which separates Hudson Strait from the adjacent continental shelf and Labrador Sea.

Unconsolidated sediments are up to 130 m thick in the depressions at the eastern and western ends of Hudson Strait (MacLean *et al.*, 1986; Grant and Manchester, 1970). The most widespread sediments are acoustically unstratified basal deposits interpreted to be glacial drift. Acoustically stratified glaciomarine and postglacial sediments occur mainly in the eastern and western basins, where they make up a significant portion of the sedimentary section. Sediments in the eastern basin also include some debris flows, and the data suggest that such sediments are also present in the western basin sections.

PHYSICAL OCEANOGRAPHY

Major features of watermass characteristics in Hudson Strait have been summarized by Drinkwater (1986). The water in Hudson Strait is influenced by runoff entering Ungava Bay, Foxe Basin and Hudson Bay and by the offshore bottom water counterflow from the Labrador Sea. The mixing of these offshore and nearshore waters is enhanced by strong tidal currents.

The basic circulation pattern of the water reflects its source. The Baffin Land Current enters Hudson Strait from the north around Resolution Island and becomes the northwesterly drift along the Baffin Island side of the strait (Fig. 3). Cross channel

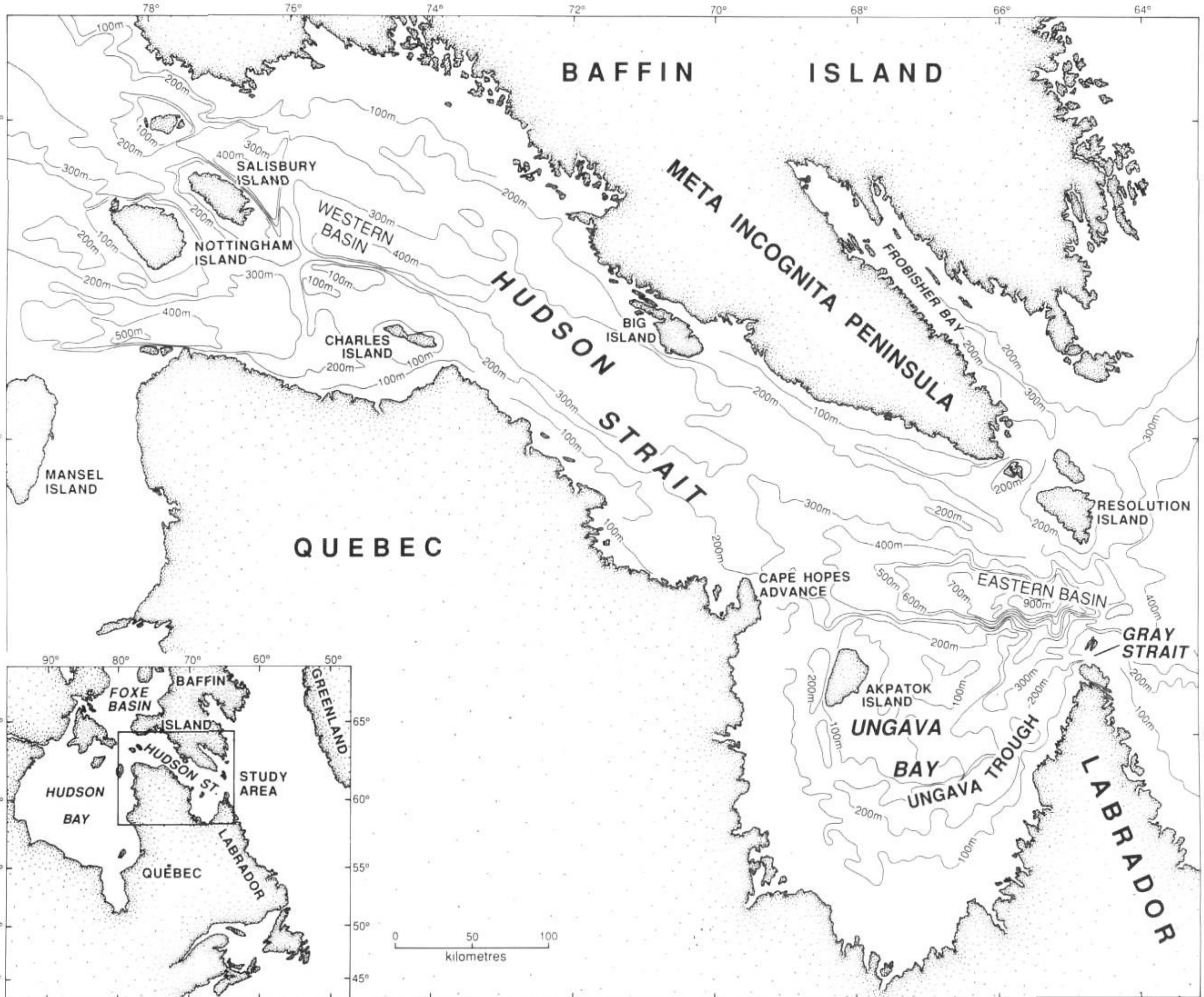


FIGURE 2. Index map and bathymetry. *Carte index et bathymétrique.*

flow is common between the eastern entrance and Big Island, at which point most of the northwestward drift has crossed the Strait to join the southeasterly flow along the coast of Québec. Waters originating in Hudson Bay and Foxe Basin are the major contributors to the southeasterly flow. The Foxe Basin water may contain additions from the Arctic channels through Fury and Hecla Strait at the northern entrance to the Foxe Basin.

For about eight months of the year Hudson Strait is covered with sea ice, but usually is ice free between the first week of August and second week of November (Drinkwater, 1986). In summer, most of the heat from solar insolation is lost in melting ice. The water is therefore generally cold; between −1.5 and +2.0°C. Occasionally a warm surface layer of river runoff may reach 5°C. Because the low-salinity runoff and meltwater are major contributors to the Hudson Strait water, the stratification basically results from variations in salinity rather than temperature.

Salinity profiles based on the data collected during Cruise 82027 (Unpublished data, P. Jones and K. Drinkwater, Bedford Institute of Oceanography) document the basic characteristics of the water in Hudson Strait (Fig. 4). A wedge of deep water from the Labrador Sea is recognized by the 34 parts per thousand isohaline reaching the bottom at station 28.

RESULTS

SEISMOSTRATIGRAPHY

Five units are recognized on the basis of their acoustic character and relationships. These are related to core lithologies and foraminiferal zones in Figure 5. Unit 1 represents acoustically unstratified sediments on top of the bedrock and is interpreted to be glacial drift (Figs. 6, 7). Its acoustic character, stratigraphic position, and morphology, are similar to glacial drift identified in other offshore areas (*e.g.* Josenhans *et al.*, 1986, King and Fader, 1986, King *et al.*, 1987, Praeg *et al.*, 1986, MacLean *et al.*, in press). The overlying Unit 2, is more acoustically transparent and generally thicker. The unstratified character, stratigraphic position, and lateral extent of this unit suggest that it too may be glacial drift. Unit 3 is a distinctive sequence of laterally consistent acoustically stratified sediments

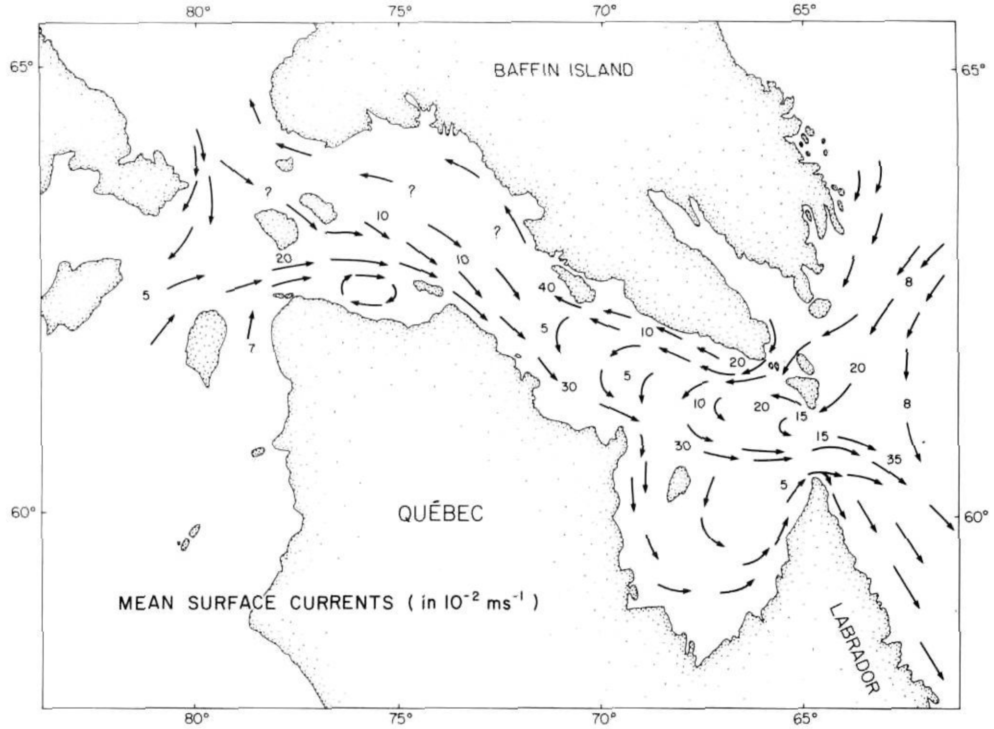


FIGURE 3. Surface currents in Hudson Strait (after Drinkwater, 1986)

Courants de surface, dans le détroit d'Hudson (d'après Drinkwater, 1986).

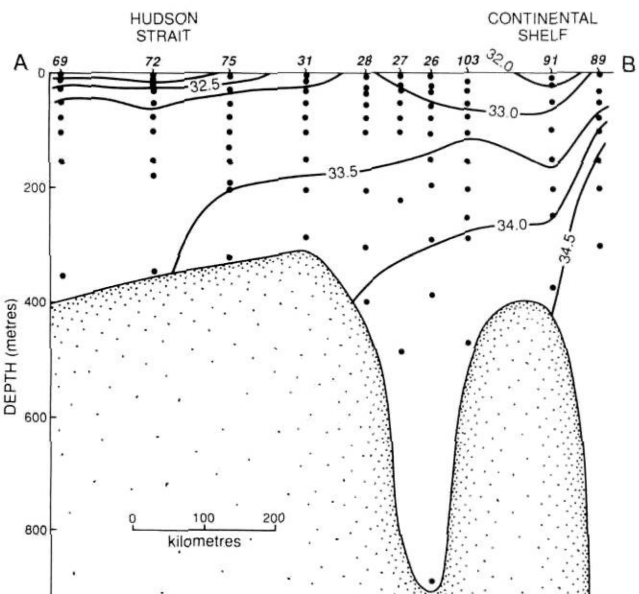


FIGURE 4. Salinity related to water depth along profile A-B (see Fig. 1 for location)

Profil AB illustrant la salinité et la profondeur (voir fig. 1 pour localisation).

overlying Unit 2. Sediments of Unit 4 are also acoustically stratified, they overlie conformably those of Unit 3, but are more variable in thickness (Figs. 6, 7). Acoustically stratified sediments of Unit 5 are the most recent. They unconformably overlie Unit 4, and locally may be too thin to be recognized on the acoustic records.

Eastern Hudson Strait

A maximum of 90 metres of unconsolidated sediment is present at the sites of Cores 55, 56 and 57 (Figs. 1, 6, 7). The sequence includes the two basal units 1 and 2, reaching maximum thicknesses of 26 and 13 m, respectively. Unit 2 locally contains two sequences, one superimposed on the other with a thin interval of stratified sediments in between (See 3-4 km along the section in Fig. 6). These resemble "till tongues" defined by King and Fader (1986) on the Scotian Shelf and recognized by Josenhans *et al.* (1986) on the Labrador Shelf and Praeg *et al.* (1986) on the Baffin Shelf. Although we favor that interpretation, the degree of acoustical transparency also resembles apparent debris flow sediments that occur near the northern flank of this basin (Fig. 7, 8-10 km along section). Thus the possibility exists that Unit 2 may represent marine sediments remolded by debris flow activity, or perhaps by light ice loading. Debris flow sediments illustrated in Figure 7 appear to have originated upslope 4-5 km northward along the section.

Unit 1, and possibly Unit 2 are interpreted to represent the last sediments deposited directly from grounded glacial ice in this part of the eastern basin. The overlying sequences consist entirely of acoustically stratified sediments. The stratigraphic relationships of these units are indicated in Figure 6.

Western Hudson Strait

In western Hudson Strait a maximum of 130 metres of sediment overlie the bedrock in the basin north and northwest of Charles Island (Figs. 1, 2, 8, 9). The lowermost Unit 1 is up to 90 m thick, and is characterised by a massive acoustic signature (Fig. 9). It includes two and in places three members.

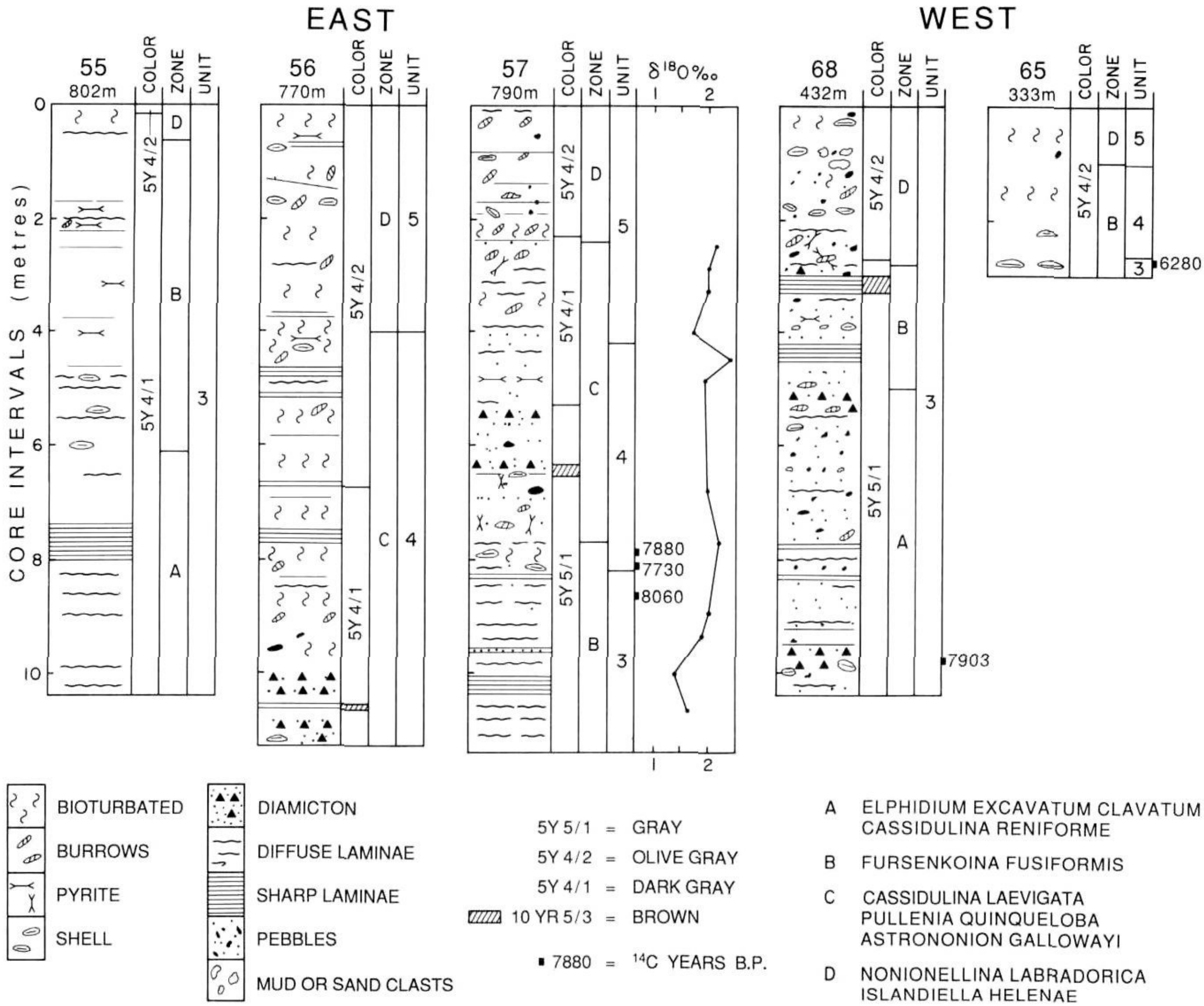


FIGURE 5. Core lithologies based on the interpretation of x-radiographs related to sediment color, faunal zones, seismic units and oxygen isotopes of *Cibicides lobalatus* downcore. Core locations: core 55, 60°56,7'N-66°25,8'W; core 56, 60°58,1'N-66°29,7'W; core 57, 61"04,3'N-66°25,6'W; core 65, 62°21,6'N-76°04,2'W; core 68, 63°04,5'N-74°18,6'W.

Contenu des carottes après interprétation radiographique, en tenant compte de la couleur des sédiments, des zones fauniques, des unités sismiques et des isotopes d'oxygène de Cibicides lobatulus. *Les échantillons ont été prélevés aux endroits suivants: carotte 55, 60°56,7'N-66°25,8'W; carotte 56, 60°58,1'N-66°29,7'W; carotte 57, 61°04,3'N-66°25,6'W; carotte 65, 62°21,6'N-76°04,2'W; carotte 68, 63°04,5'N-74°18,6'W.*

The upper member has an irregular surface and locally forms mounds up to 35 m thick which are interpreted as moraines. It lies for the most part on a smooth, relatively flat surface that marks the top of the underlying member (Fig. 9). The unstratified, acoustically massive character of the sediments, the presence of multiple sequences, and the morphology of the unit suggest that it is composed of glacial drift. However, at an oblique crossover 2.5 km east of Station 68 (Fig. 10; Section G, Fig. 1), this unit occupies only part of the floor and southern flank of the basin and resembles an erosional remnant. These sediments are tentatively interpreted to be pre-Late Wisconsinan glacial drift, but may include older material.

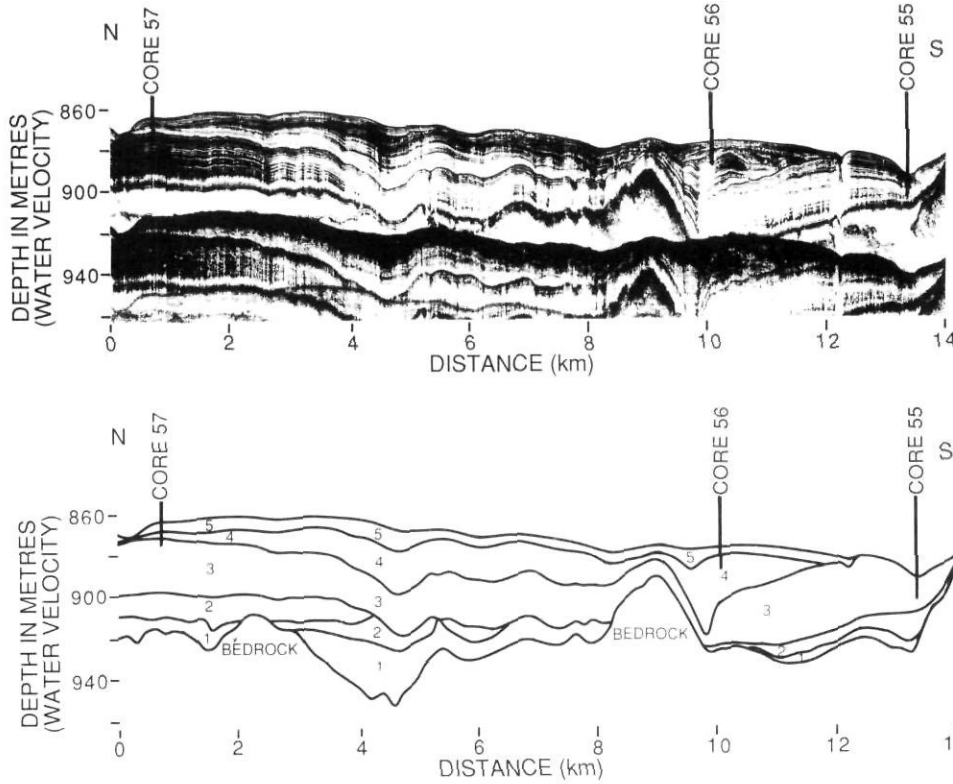
A short section shown in Figure 11 illustrates the seismostratigraphic setting at the site of Core 65 in southwestern Hudson Strait (See Fig. 1). It is 24 km north of the coast and 100 km north of the *circa* 10,000 yBP moraine system in the Baie de Déception region of northern Québec described by Gray and Lauriol (1985). Units 2, 3, 4 and 5 are represented at the core site and Unit 1 is missing at this locality. The glaciomarine sediments of Unit 3 may include equivalents of sediments dated onshore by Gray and Lauriol (1985).

OXYGEN ISOTOPES AND SALINITY

The correlation between $\delta^{18}O$ values in the tests of *C. lobatulus* and salinity is less significant in the Hudson Strait sediments than on the Labrador Shelf as reported by Vilks and Deonarine (1988). The Hudson Strait regression line has a steeper slope (Fig. 12) due to the low $\delta^{18}O$ values from inner Hudson Strait stations. The $\delta^{18}O$ values from grab sample stations across the approach to Foxe Basin (Fig. 1) are below

FIGURE 6. Huntec seismic reflection profile across core locations 55, 56 and 57. The lower part of the interpreted section is supplemented with information from the airgun profile. See location indicated on Figure 7. Numbers identify the acoustic stratigraphic units.

Profil obtenu par sismique réflexion, après utilisation d'un dispositif Huntec, entre les points 55, 56 et 57. En bas, on a complété le profil grâce aux données obtenues par fusil à air comprimé. Voir localisation à la figure 7. Les chiffres marquent les unités stratigraphiques acoustiques.



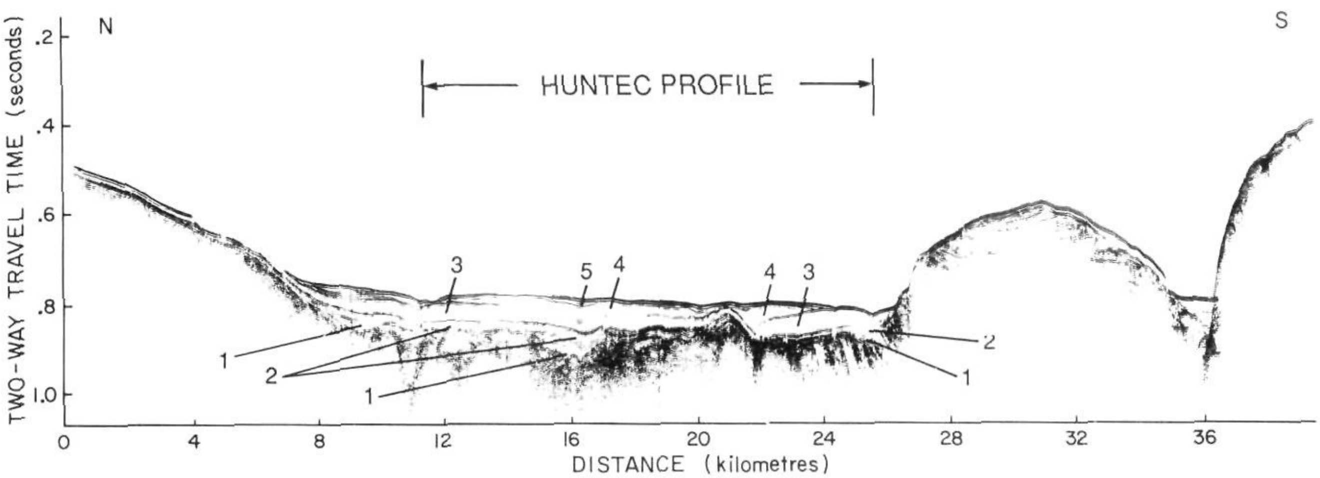


FIGURE 7. Airgun seismic profile across core locations 55, 56 and 57 (Section E in Fig. 1) illustrating Quaternary sediments and underlying bedrock in the western part of the eastern Hudson Strait Basin.

Profil obtenu par fusil à air comprimé entre les points 55, 56 et 57 (section E, à la fig. 1), illustrant les sédiments quaternaires et la roche en place sous-jacente, dans le secteur ouest du bassin est du détroit d'Hudson.

the regression line by about 0.5 parts per mill and stations crossing the approaches to Hudson Bay by about 0.5 to 0.25 parts per mill. The lower $\delta^{18}O$ values between the salinities of 33.0 and 33.8 in comparison to the Labrador Shelf are likely due to the large runoff component and extensive local formation of sea ice.

Foxe Basin contains mostly water from the Arctic Ocean which has been modified by the runoff of large Siberian rivers and by the formation of sea ice. Patches of open water persist in Foxe Basin during winter (Dunbar, 1954), thus constant sea ice formation also takes place in Foxe Basin, increasing the salinities for corresponding $\delta^{18}O$ values. Campbell (1964) reported the presence of cold and saline (−1.90 C, 34.00‰.) water in Foxe Basin and explained its origin due to freezing processes of sea water.

Of the two factors responsible for the lower $\delta^{18}O$ content, the formation of sea ice may be more important in the bottom waters than the reduction due to the addition of river runoff. The latter may never reach the bottom of the deeper basins before reaching the ocean. As sea ice freezes, the liberated brine sinks to the bottom increasing the salinity without changing the stable isotope content. The freezing of 2 m of ice would increase the salinity by 0.6 parts per thousand (Redfield and Friedman, 1969). It is interesting to note that *C. lobatulus* tests record the low $\delta^{18}O$ values, which is a characteristic of winter conditions. This implies that the growth of the test is not limited to summer conditions.

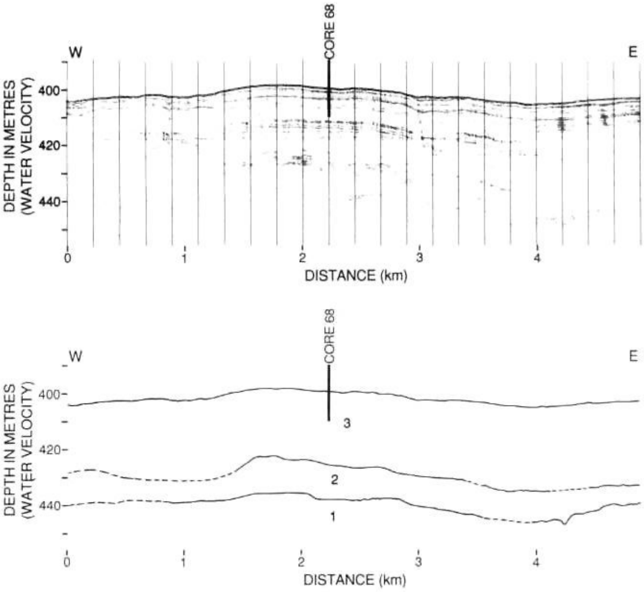


FIGURE 8. Huntec seismic profile northwest to southeast across core location 68 in the western Hudson Strait Basin. Numbers identify acoustic stratigraphic units.

Profil obtenu par dispositif Huntec et traversant du nord-ouest au sud-est le point 68, dans le bassin ouest du détroit d'Hudson. Les chiffres marquent les unités stratigraphiques acoustiques.

FAUNAL ZONES DOWNCORE

The ^{14}C dates (discussed below) textural, micropaleontological and high resolution seismic reflection data indicate that some of the piston cores reached the late glacial sediments. Major species of the faunal zones allow us to speculate on possible changes in the environment as the glacial influence diminished. Of the many readjustments that have taken place, foraminiferal populations best reflect the variations in bottom paleosalinities. The distribution of foraminiferal species is also commonly related to water temperature, but in the cold Arctic and subarctic inner shelf environments, postglacial readjustment in water temperature has been relatively small. For this study, only paleosalinities are used to describe postglacial changes.

For the purpose of late Quaternary biostratigraphy, *Elphidium excavatum clavatum* and *Cassidulina reniforme* are the two most important foraminiferal species in North America and Europe (Vilks, 1981), and are the most common indicators of late glacial sediments on both sides of the North Atlantic. In the North Sea, the two species dominate the Weichselian sediments, representing the glacial shallow water Arctic facies (Knudsen, 1986).

Foraminiferal Zone A found at the bottom of cores 55 and 68 (Figs. 13, 16) is characterized by *E. excavatum clavatum* and *C. reniforme*, low diversity of fauna and frequent barren intervals. Similar characteristics in sediment cores have been interpreted to represent proximal glacial marine environments in the nearshore waters of eastern Canada (Osterman and Andrews, 1983; Vilks *et al.*, 1987) and in the southeastern channels of the Canadian Arctic Archipelago (MacLean *et*

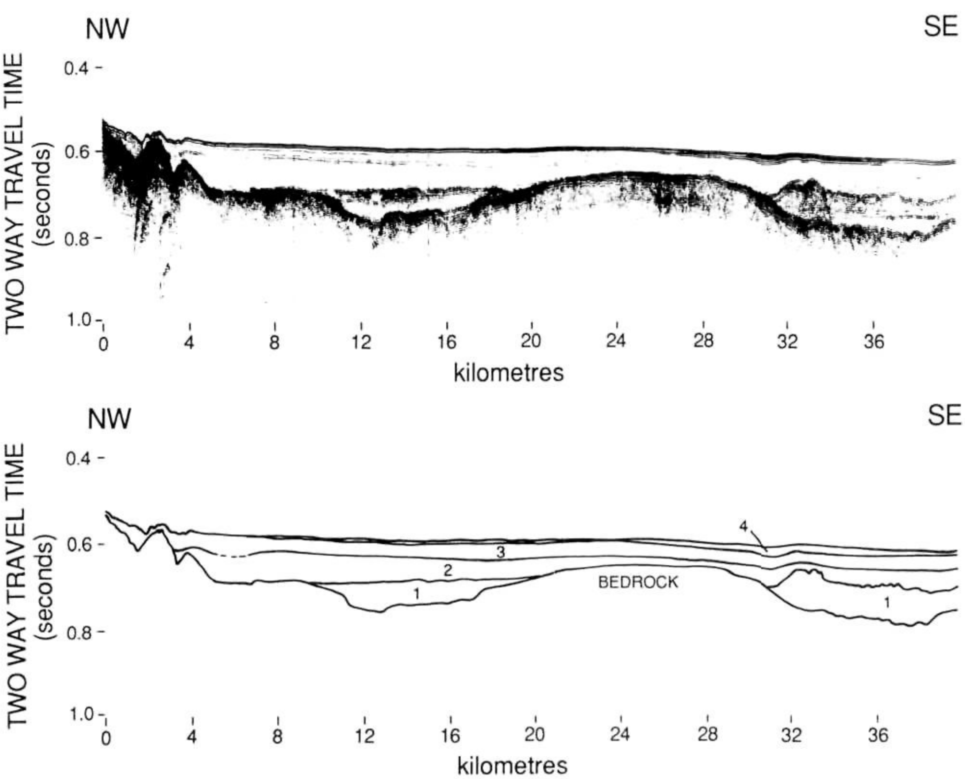


FIGURE 9. Airgun seismic profile along the western basin to the west of Core 68 (Section F) illustrating sediments interpreted to be multiple drift sequences (from 12-18 km and from 32 km to the southeastern end of the section). These are overlain by glaciomarine sediments.

Profil obtenu par fusil à air comprimé le long du bassin ouest et jusqu'à l'ouest du point 68 (section F), illustrant des sédiments interprétés comme étant des séquences de matériel détritique (de 12 à 18 km et de 32 km jusqu'à l'extrémité sud-est de la section). Ils sont recouverts de sédiments glaciomarins.

al., in press). In the modern environment, *C. reniforme* and *E. excavatum clavatum* are the two dominant species in front of a tidewater glacier in Spitsbergen (Elverhoi *et al.*, 1980).

Zone B is identified by the addition of *Fursenkoina fusiformis* to the Zone A faunas (Figs. 13, 16). Similar faunal sequences have been observed on the Labrador Shelf (Vilks *et al.*, 1984) and in eastern Barrow Strait, Canadian Arctic Archipelago (MacLean *et al.*, in press) where *F. fusiformis* is found in abundance on top of sediments rich in *E. excavatum clavatum* and *C. reniforme*. In surface sediments of Hudson Strait *F. fusiformis* ranks low and is more abundant in the inner Strait sediments. Regionally *F. fusiformis* has been recorded in continental shelf sediments as far south as Cape Hatteras (Culver and Buzas, 1980). The species is very abundant in Gullmar Fjord, Sweden, in sediments deeper than 20 m of water depth, and in the Skagerrak in about 200 m of water ("*Bulimina*" *fusiformis* in Hoglund, 1947). At these depths the

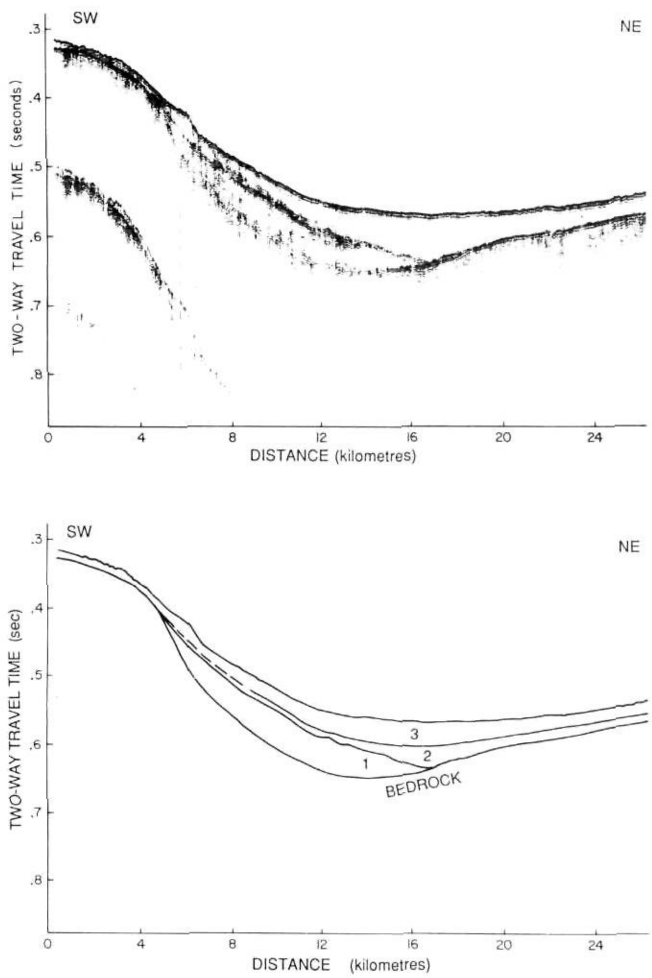


FIGURE 10. Section G — airgun seismic profile illustrating sediment relationships where the western basin was diagonally intersected east of the Core 68 locality. Unit I is confined to the area on and adjacent to the southern flank of the basin (see Fig. 1 for location).

Profil obtenu par fusil à air comprimé dans la section G et illustrant les rapports entre les sédiments, à l'est du point 68, là où le bassin ouest a été coupé en diagonale. L'unité 1 est limitée à la zone adjacente au versant sud du bassin (voir fig. 1 pour localisation).

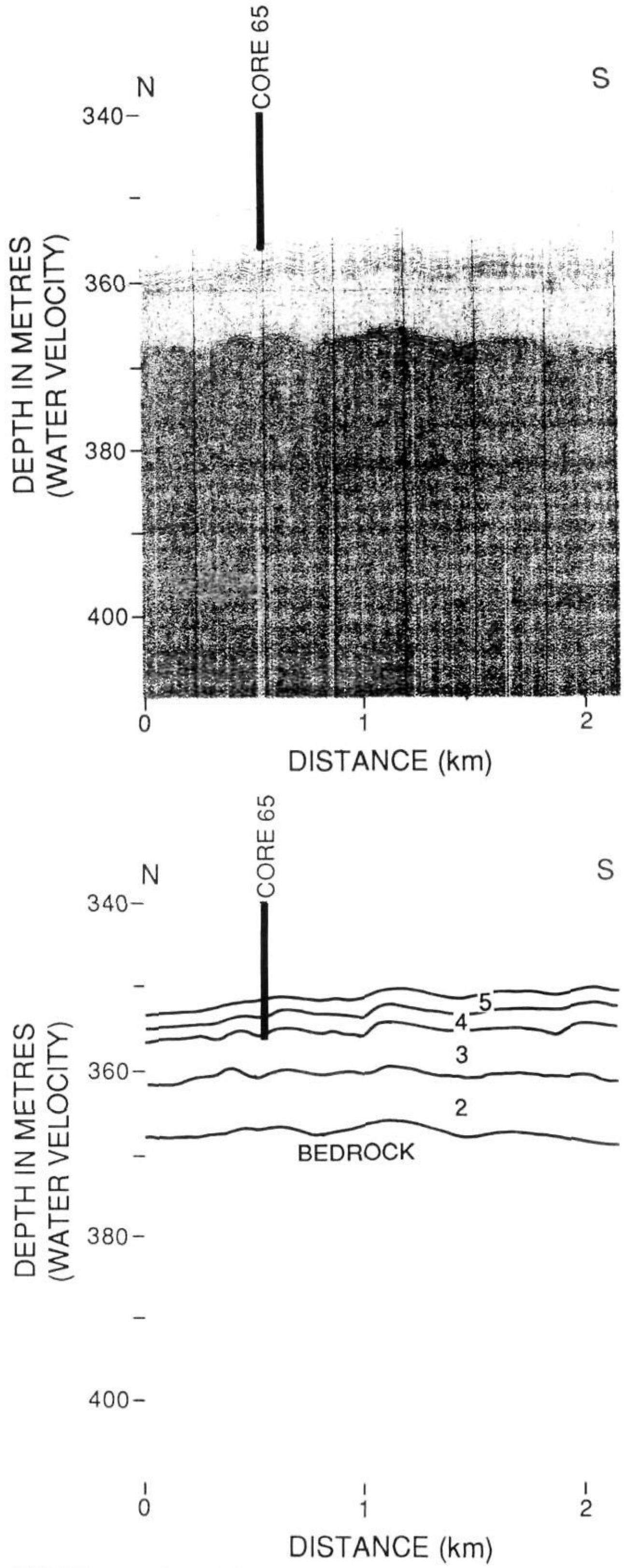


FIGURE 11. Huntec high resolution profile showing the Quaternary sediment units at core locations 65 southwest of Charles Island.

Profil à haute résolution obtenu par dispositif Huntec, illustrant les unités sédimentaires du Quaternaire au point 65, au sud-ouest de l'île Charles.

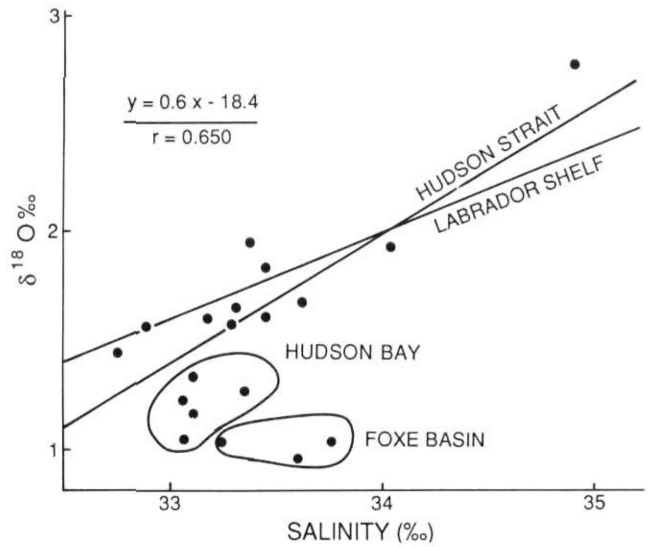


FIGURE 12. Salinity related to $\delta^{18}O$ content in *Cibicides lobalatus* tests.

Teneur en $\delta^{18}O$ *et salinité de* Cibicides lobatulus.

salinities range slightly over 35‰ in the Skagerrak (Larson and Rodhe, 1979) and between 33.0 and 34.6‰ in Gulmar Fjord (Rydberg, 1975). Botton oxygens in Gulmar Fjord vary seasonally between 7 ml/l and 2 ml/l and April temperature between 6 and 7° C. In Baffin Island fiords *F. fusiformis* is important in the distal deep basin settings and it dominates glacier front sediments in Jones Sound, Canadian Arctic Archipelago (C. T. Schafer and T. Cole, personal comm. 1989). In the Bay of Fundy, off Nova Scotia, *F. fusiformis* is common to dominant in muddy sediments where the bottom salinities range between 32 and 33‰ (unpublished data). Evidently, the species can tolerate a large salinity range and low oxygen levels and could be associated with an ice distal glaciomarine environment when found in sediment cores.

Zone C is characterized by the addition of *Cassidulina laevigata, Pullenia quingueloba* and *Astrononion gallowayi*. It is present only in cores 55, 56 and 57 (Figs. 13, 14, and 15) in water depths close to 800 m. In the surface sediments of Hudson Strait *C. laevigata* ranks low in the outer Strait and is not present in the inner Strait. In the Canadian Arctic Archipelago *C. laevigata* is the dominant species in surface sediments at depths within the relatively warm and saline water of Atlantic origin (MacLean *et al.*, in press). Across the Atlantic, in the Skagerrak, *C. laevigata* is associated with waters of Atlantic origin with salinities of 35.00‰ and greater (Van Weering and Qvale, 1983). On the Norwegian Shelf *C. laevigata* is considered to be a cosmopolitan species associated with both the Arctic and Boreal taxa (Vorren *et al.*, 1983). In the North Sea, it was one of the major species during the Eemian in deep water environments and below the shallow-water Weichselian sediments dominated by *E. excavatum clavatum* and *C. reniforme* (Knudsen, 1986). The increased presence of *C. laevigata* in eastern Hudson Strait sediments suggests an increased influence of the more saline and warmer Labrador Sea waters. We conclude an early postglacial setting is indicated by Zone C.

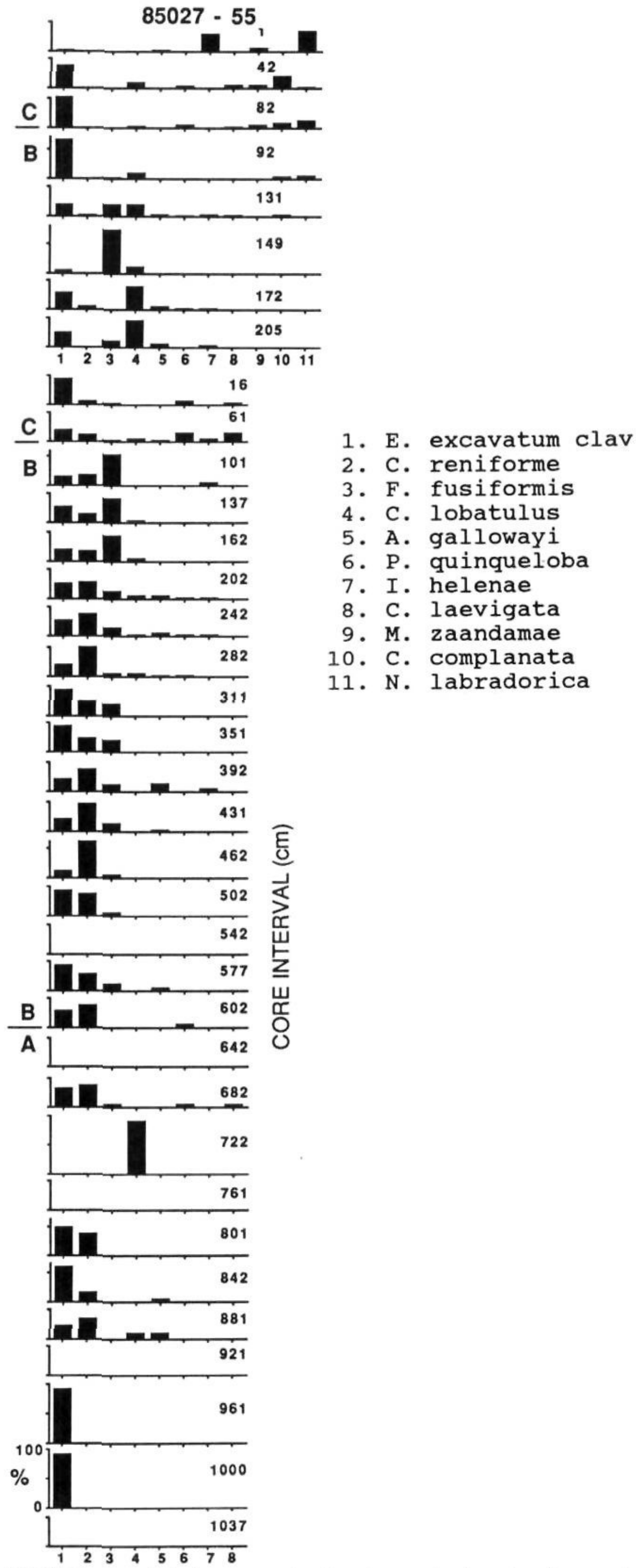


FIGURE 13. Relative percents of major species in subsurface sediments in trigger weight (top) and piston Core 55. Capital letters indicate faunal zones discussed in text.

Valeurs relatives, exprimées en pour cent, des principales espèces contenues dans les sédiments de subsurface prélevés dans la carotte 55. Les lettres marquent les zones fauniques (voir texte).

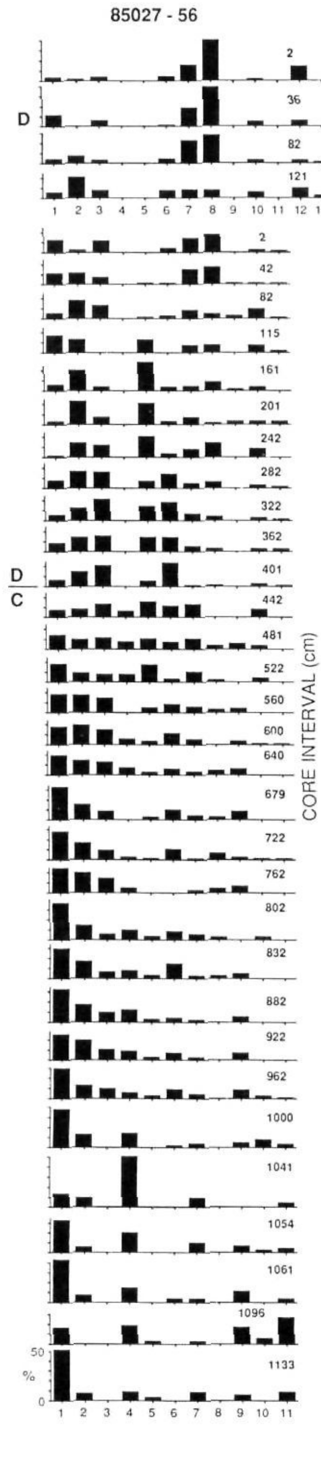


FIGURE 14. Relative percents of major species in subsurface sediments in trigger weight (top) and piston Core 56. Capital letters indicate faunal zones discussed in text.

Valeurs relatives, exprimées en pour cent, des principales espèces contenues dans les sédiments de subsurface prélevés dans la carotte 56. Les lettres marquent les zones fauniques (voir texte).

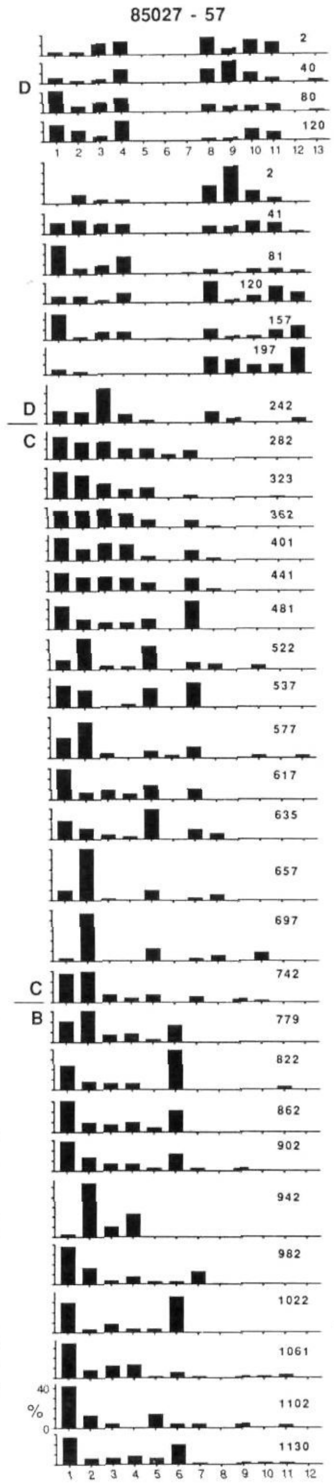


FIGURE 15. Relative percents of major species in subsurface sediments in trigger weight (top) and piston Core 57. Capital letters indicate faunal zones discussed in text.

Valeurs relatives, exprimées en pour cent, des principales espèces contenues dans les sédiments de subsurface prélevés dans la carotte 57. Les lettres marquent les zones fauniques (voir texte).

The restriction of Zone C to the deep eastern basin suggests that the mixing of the runoff from Hudson Bay has always been sufficiently deep to prevent the migration of the offshore bottom water to the west beyond the deep basin. The surface water dilution has not been shallower than about 300 m (present water depth).

Zone D is present in all cores as a surface layer, including Core 65 (Fig. 17). It is characterized by the addition of *Nonionellina labradorica, Islandiella helenae* and *Astrononion gallowayi*. These species rank high in the surface sediments in both inner and outer Hudson Strait. *N. labradorica* and *A. gallowayi* are common in Labrador Shelf sediments in water depths that correspond to wide salinity ranges (Vilks and Deonarine, 1988). *I. helenae* prefers the cold waters of the Labrador Shelf within salinity ranges between 32.5‰ and 33.5‰. It is very common in the Beaufort Shelf sediments

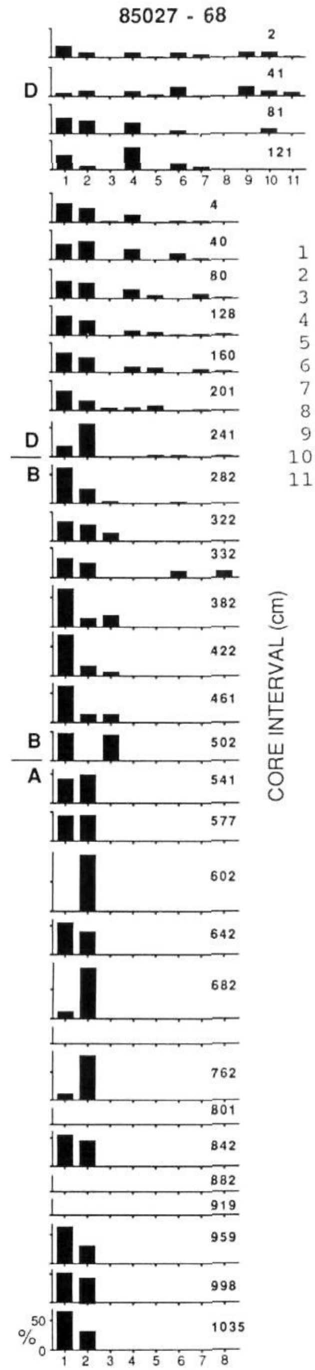


FIGURE 16. Relative percents of major species in subsurface sediments in trigger weight (top) and piston Core 68. Capital letters indicate faunal zones discussed in text.

Valeurs relatives, exprimées en pour cent, des principales espèces contenues dans les sédiments de subsurface prélevés dans la carotte 68. Les lettres marquent les zones fauniques (voir texte).

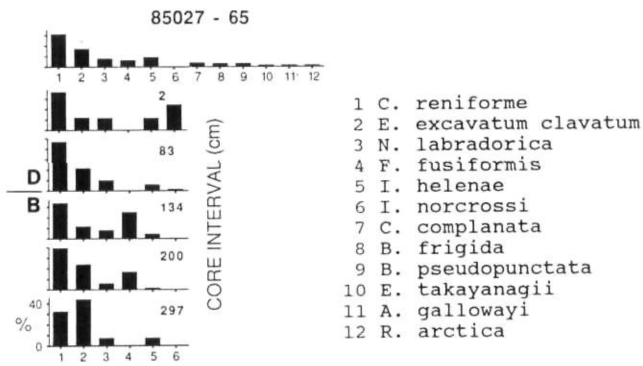


FIGURE 17. Relative percents of major species in subsurface sediments in trigger weight (top) and piston Core 65. Capital letters indicate faunal zones discussed in text.

Valeurs relatives, exprimées en pour cent, des principales espèces contenues dans les sédiments de subsurface prélevés dans la carotte 65. Les lettres marquent les zones fauniques (voir texte).

(Vilks *et al.*, 1979), and is present on the Scotian Shelf (Williamson *et al.*, 1984), which may be the limit of its southern range. The dominant Zone D species suggest an increasing effect of the Arctic-Subarctic inner shelf waters in a late postglacial setting

FAUNAL ZONES RELATED TO PHYSICAL PROPERTIES

Although physical properties do not have a direct influence on foraminiferal assemblages, they are compared with faunal zones because both are affected by similar changes in depositional environment. The physical properties of zones C and D clearly show distinct differences (Figs. 18, 19 and 20) indicating either a change in sediment source or depositional environment. Although the C/D faunal boundary between the two zones coincides with a change in physical properties, visual description of the core lithologies and color did not show any sharp changes. In general, Zone D has the lowest strength and density and the highest water content, which is expected for the youngest sediment. In contrast, Zone C has the highest shear strength, which suggests slight overconsolidation. In zones A and B, the shear strength seems to have been affected by bioturbation, pyritization and structure. For example, the shear strength shows no change in the upper Zone B of Core 55 (Fig. 21) suggesting influence of bioturbation. Pyrite is seen below this depth with a concurrent sharp increase in strength, indicative of more brittle (early diagenetic?) behaviour. Consequently, the shear strength profiles do not compare well with the faunal zones due to the more dominant influence of other processes. The density and water content, however, distinctly define differences between zones D and C and show that the properties of these zones are different from zones A and B. The similarity in properties of zones A and B (Fig. 21) suggests only a very subtle change in the depositional environment between the two zones with respect to physical properties.

FAUNAL ZONES RELATED TO ^{14}C DATES

The ^{14}C dates are considered to be reliable because they were determined from well preserved *in situ* molluscan shells. The dates suggest that the faunal zones are time transgressive from east to west. The top of Zone B in Core 57 (Fig. 5) from the eastern basin is 7730 ± 50 yBP (TO 749) (according to the most reliable date on a paired shell), whereas a 7903 ± 70 yBP (TO 751) date was recorded in the middle of Zone A in Core 68, 500 km to the west of core site 57. Still farther to the west, but closer to the south shore of the strait, Core 65 yielded a date of 6280 ± 50 yBP (TO 293) one metre below the top of Zone B. These dates indicate that at about 8000 yBP a proximal glacial marine environment prevailed in inner Hudson Strait, while in outer Hudson Strait the envi-

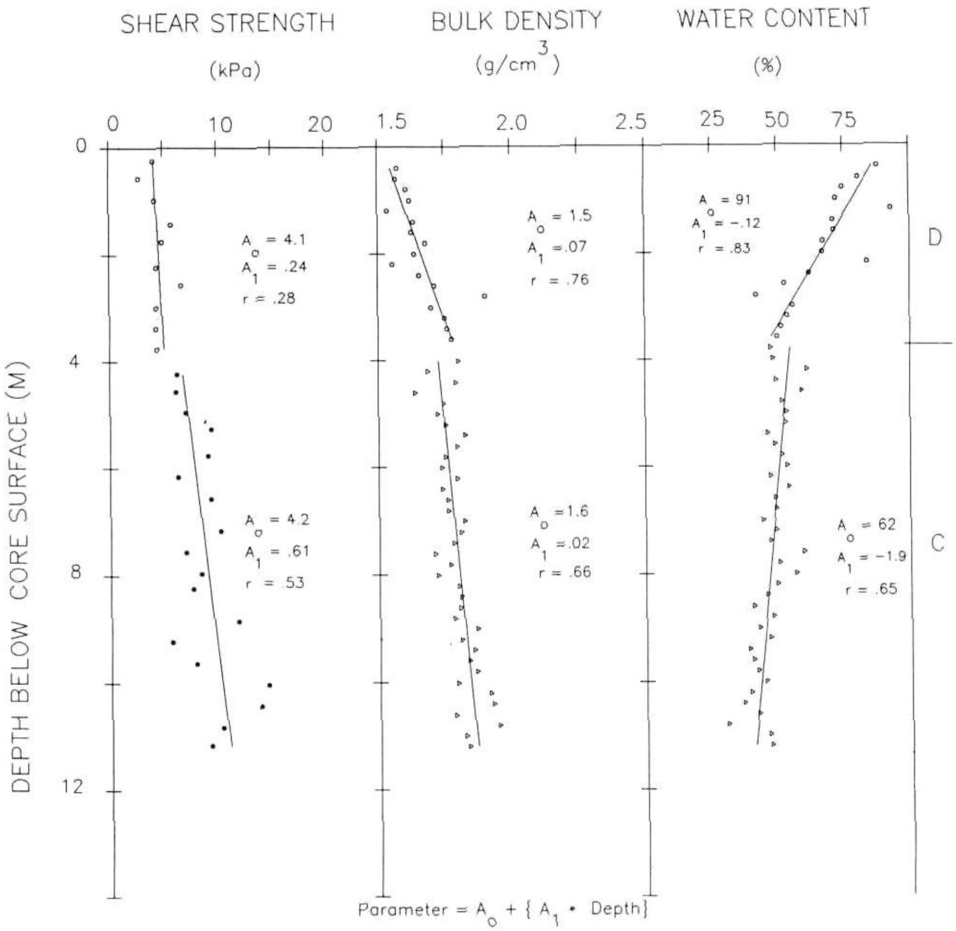


FIGURE 18. Shear strength, bulk density and water content in Core 56.

Résistance au cisaillement, densité apparente et teneur en eau de la carotte 56.

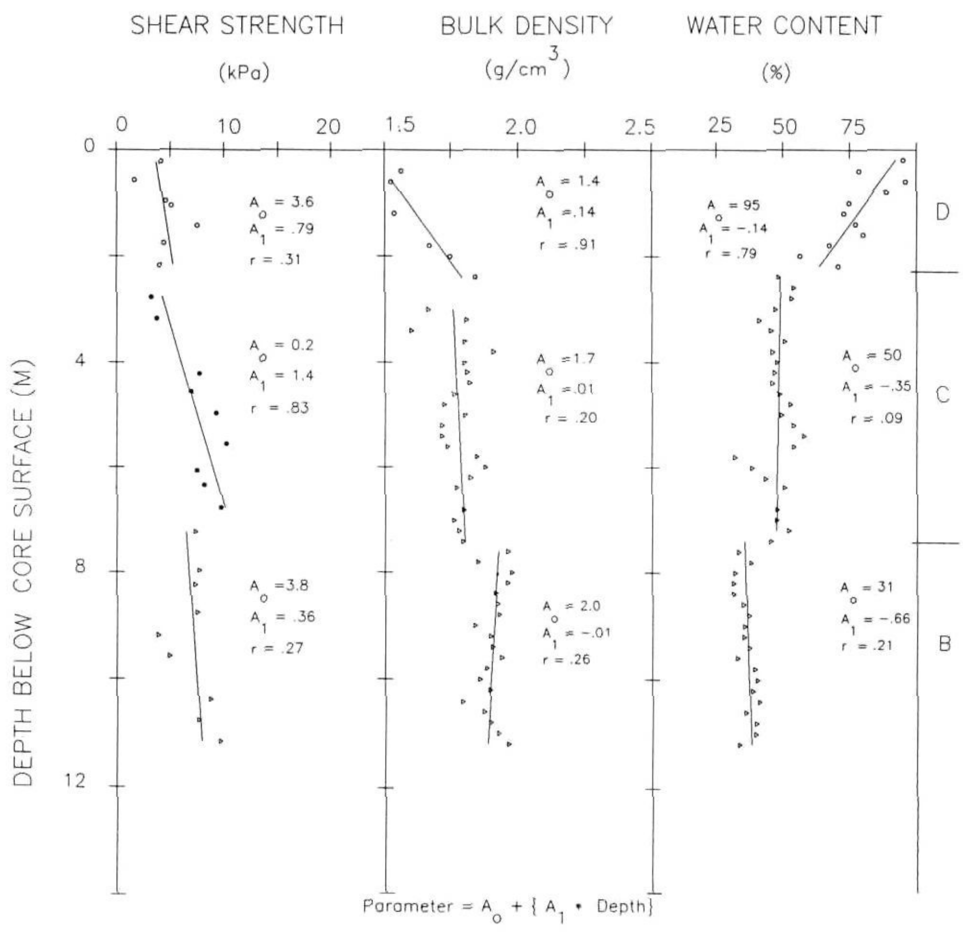


FIGURE 19. Shear strength, bulk density and water content in Core 57.

Résistance au cisaillement, densité apparente et teneur en eau de la carotte 57.

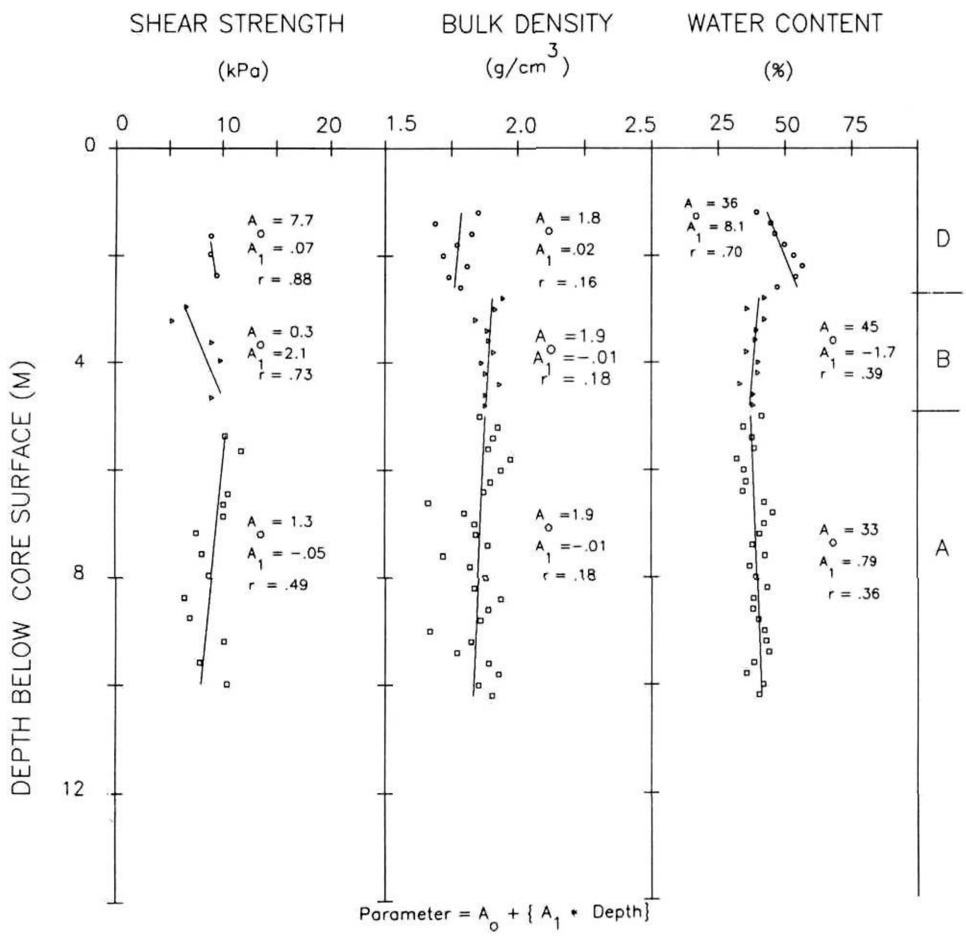


FIGURE 20. Shear strength, bulk density and water content in Core 68.

Résistance au cisaillement, densité apparente et teneur en eau de la carotte 68.

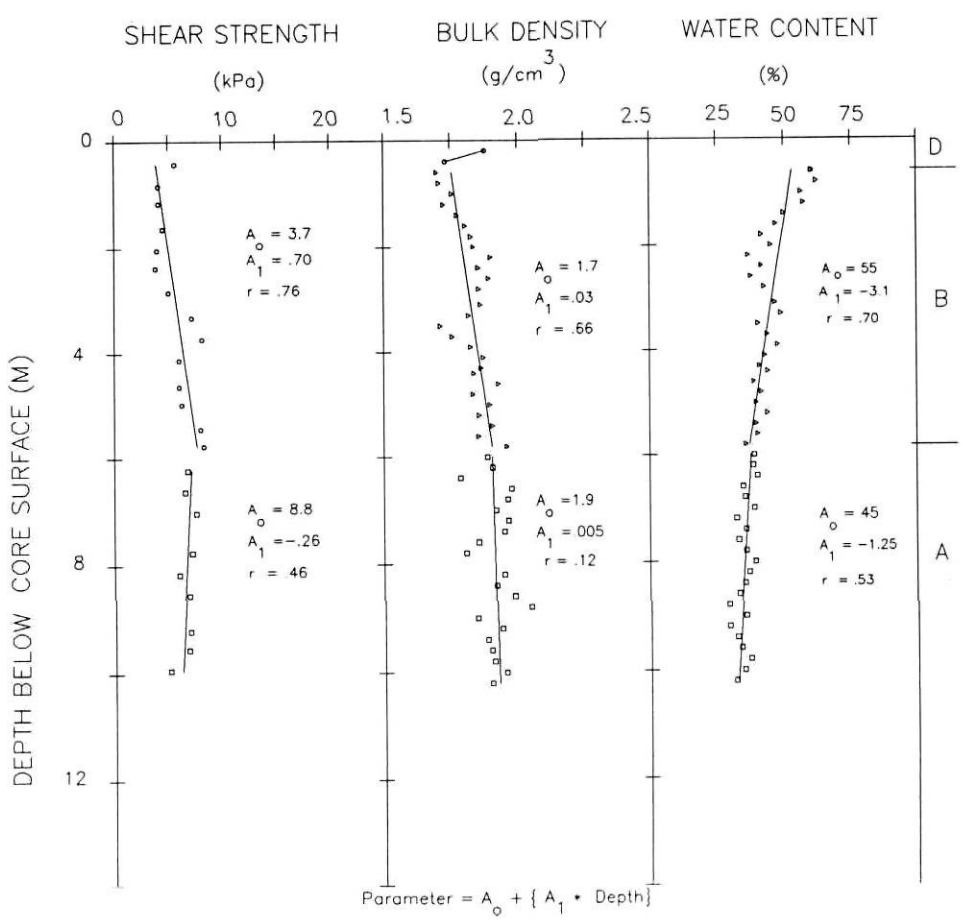


FIGURE 21. Shear strength, bulk density and water content in Core 55.

Résistance au cisaillement, densité apparente et teneur en eau de la carotte 55.

ronment was more distal. However, in an environment of fast sedimentation rates, the apparent east-west migration may not be significant with respect to time.

Fillon and Harmes (1982) reported an 8730 ± 250 yBP (GSC-2698) date from molluscan shells in Core HU77-154, 60 km to the east of Core 57. The inspection of foraminifera in the vicinity of the sample horizon suggests that the shells were taken close to the top of the foraminiferal Zone B of this report. The 1000 years older date substantiates the westward migration of Zone B and the ablating glacial front in Hudson Strait. On the basis of these and other dates and seismic evidence Fillon and Harmes (1982) suggested that deglaciation in Hudson Strait was "well underway by 10450 BP". We have no reason to dispute this interpretation.

DEPOSITIONAL ENVIRONMENTS

Paleoenvironments in Hudson Strait are described by combining foraminiferal evidence with acoustic stratigraphic data from Huntec and airgun seismic reflection profiles (Fig. 22). Unit 1 sediments are in contact with bedrock and are interpreted as glacial drift deposited by grounded ice. In eastern Hudson Strait the drift could have been deposited during the last glacial maximum but parts of Unit 1 could be older. Ice must have been sufficiently thick to reach the bottom of the 900 m basin. In the western part of the Strait, seismic sections suggest several superimposed glacial drift sequences, some of which presumably could be of earlier Quaternary age.

Unit 2 has a massive seismic character, but less dense than Unit 1, suggesting possibly higher water content in the sediments. These deposits could have originated as waterlain till in a subglacial basin (Vorren *et al.*, 1983) from a thinner and partly buoyant ice sheet as deglaciation progressed. Alternately, the sediments of Unit 2 originally may have been laminated glaciomarine outwash deposits which were subsequently remolded by gravity flows. Seismic profiles show evidence for sediment mass movement close to topographic highs along both the southern and western margins of the basin. The basal units 1 and 2 have not been sampled with our piston cores (Fig. 22).

The glaciomarine Unit 3 was recognized on all the profiles in both the eastern and western basins. It was sampled by cores 55, 68 and partly by cores 57 and 65 (Figs. 7 and 22). X-radiographs of these cores show massive to laminated sediments with commonly occurring dropstones in Core 68, but less common in 55 and 57 (Fig. 5). There is little evidence for bioturbation. The low diversity faunas of the proglacial zones A and B in Unit 3 are dominated by *E. excavatum clavatum* and *C. reniforme*.

Core 55 penetrated deepest in the stratigraphic section with the bottom metre dominated entirely by *E. excavatum clavatum* in addition to low numbers and small planktonic percentages. In contrast to the other cores, the sediments at the bottom of Core 55 also lack evidence for high organic productivity, such as, preserved diatom frustrules or pyritized organic debris. Using Osterman's (1982) definition of under ice shelf faunas in the region (exclusive dominance of *E. excavatum clavatum*), the bottom metre of the sediments in Core 55 may have been deposited under ice proximal conditions, either near a glacial ice front or beneath an ice shelf.

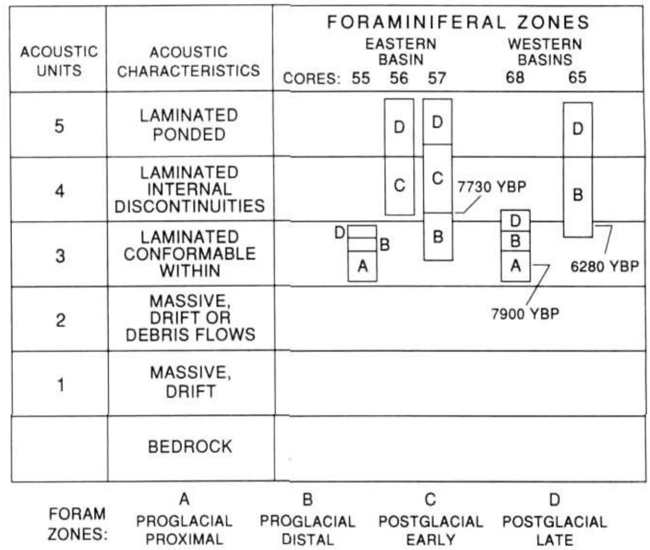


FIGURE 22. Core faunal zones related to seismostratigraphy. The definition of foram zones and the laboratory numers with accuracies for the ^{14}C dates are discussed in text.

Zones fauniques après séismostratigraphie. (Voir texte pour les détails relatifs aux zones de foraminifères et aux datations au ^{14}C.)

The glaciomarine sediments of Unit 3 are time transgressive from east to west. In the eastern basin, the top of Unit 3 coincides with the top of foraminiferal zone B, a horizon rich in molluscan shells. The ^{14}C age range of the sampled shells is from 7880 ± 70 (TO 748) to 8060 ± 70 yBP (TO 750). A ^{14}C date from a shell at the bottom of Core 68 in the western basin yielded a 7903 ± 70 (TO 751) yBP age well within Zone A. Thus, an ice distal glaciomarine environment prevailed in the eastern basin at about 8000 yBP, while at the same time an ice proximal environment was present at the western basin. Farther to the southwest and closer to the shores of Québec, a specimen of *Clinocardium ciliatum* in Core 65 yielded a ^{14}C age of 6280 ± 50 yBP (TO 293). The shell was collected in the upper part of Unit 3 and foraminiferal Zone B. Here the younger age of the glaciomarine sediments apparently signifies the effects of the last remnants of the Laurentide Ice Sheet on the Northwestern Ungava Peninsula shortly before this date (Dyke and Prest, 1987; Laymon, 1988).

Evidence for meltwater is documented in Core 57 close to the top of Unit 3. The $\delta^{18}O$ values in *C. lobatulus* tests are lower by about 0.5 parts per thousand in comparison to units 4 and 5 (Fig. 5). On the basis of the present day $\delta^{18}O$ and salinity relationships, the bottom water in the deep basin at the eastern entrance to Hudson Strait was less saline by about the same amount. However the presence of planktonic foraminifera in percentages close to and larger than the present, indicate that there was not a surface plume of low salinity water emanating from Hudson Strait at this time. This would suggest that extensive tidal mixing was already taking place in Hudson Strait.

The acoustically laminated sediments of Unit 4 are locally discontinuous and were penetrated only by the eastern basin cores 56, 57 and by core 65 in the southwestern Hudson Strait basin. X-radiographs show zones of bioturbated sediments containing distinct biogenic burrows and pyritized organic remains. Dropstones occur in concentrated horizons that possibly could be correlated, *e.g.,* bottom of Core 56 with the 550-650 cm level in core 57 (see Fig. 5).

The depositional and oceanographic environment of Unit 4 was characterized by higher bottom currents and salinities relative to Unit 3. The discontinuous character of the seismic reflectors, lense shaped accumulations, and local thickening and thinning, suggest increased bottom currents (see Fig. 6). By this time, the present tidal regime must have been in place, implying that the geometry of Hudson Strait was more or less similar to the present and that the Strait was clear of massive glacial ice.

Seismostratigraphic Unit 4 sediments coincide with foraminiferal zone C, in the eastern basin, representing the early postglacial environment at the entrance to Hudson Strait. It is dominated by species of deeper offshore waters. Thus, there was a period during early postglacial time when the more saline and warmer offshore Labrador Sea water occupied the eastern basin in greater proportions than at present. The larger offshore component could reflect smaller amounts of Arctic water in the flow entering Hudson Strait from the north.

In the southwestern basin of core site 65, Unit 4 sediments appear to coincide with foraminiferal Zone B. The relatively young 6280 ± 50 yBP (TO 293) ^{14}C date at the bottom of the core in comparison to the eastern basin, signifies the effects of the glacial retreat towards the northwest Ungava Peninsula.

The variable thickness of Unit 5 reflects the relatively strong bottom currents of the present time. Acoustic Unit 5 coincides with the foraminiferal Zone D (Fig. 22). The foraminifera in Zone D indicates a relatively cold environment versus Zone C, suggesting more pronounced Arctic influence concurrent with stronger bottom currents.

SUMMARY AND CONCLUSION

Seismic, lithologic and foraminiferal data show at least one glacial/deglacial phase in Hudson Strait. Basal ice contact tills (Unit 1) lie on bedrock. On top of these is relatively transparent, unstructured acoustic unit, interpreted to contain waterlain tills or remolded glacial marine sediments (Unit 2). The glacially derived acoustically massive sediments are overlain by thick sequences of acoustically laminated glacial marine sediments (Unit 3). Foraminiferal Zones A and B and core lithologies of the glacial marine sequences of Unit 3 suggest sedimentation in a marine environment respectively proximal and distal to a glacial ice sheet. The sediments are not extensively bioturbated and in the eastern basin contain very few coarse ice rafted clasts. This reflects the relatively fast sedimentation rates of approximately one metre per 1000 years. In the western basin coarse clasts are present throughout core 68, signifying the closer proximity of the source for ice rafted debris.

Unit 4, which locally contains discontinuous and disturbed acoustic laminae, corresponds with Zone C containing faunas characteristic of higher bottom salinities in the deep eastern basin, but not in the shallower western basin. The overlying Unit 5 contains present day faunas that are associated with slightly lower bottom salinities and colder Arctic waters. Thus, in the outer Hudson Strait during the early postglacial setting of Unit 4 and Zone C, the offshore influence of saltier and warmer deep waters was more extensive than at the present.

Faunal zones relate only approximately with physical properties of the sediment, which are reflected by the acoustic units (Fig. 22). The glacially related zones A and B are prominent in Unit 3. The postglacial zones C and D are related to Units 4 and 5. Zone D is present at the top of Cores 55 and 68 which may indicate the presence of an acoustically unresolved interval of Unit 5 overlying Unit 3. Zone C is restricted to the deep eastern basin with corresponding watermass properties, which are different from the shallower environment of the Core 65 site. This explains the presence of Zone B rather than C in Core 65.

The chronology of deglaciation is established on three dated horizons (Fig. 5). In the eastern basin, sediments close to the bottom of the early post glacial Zone C are dated at 7730 ± 50 yBP (TO 749) on the basis of a ^{14}C date from a paired *Portlandia arctica* shell. In the western basin the late glacial Zone A environment still prevailed at 7903 ± 70 yBP (TO 751), according to a ^{14}C date on fresh fragments of *P. arctica* shells in Core 68. Farther southwest and closer to the shore, the top of Unit 3 and the distal proglacial Zone B was dated at 6280 ± 50 yBP (TO 293) in Core 65. This implies that the glacially derived sedimentation was still taking place at this locality this late.

We do not have direct evidence for the proposed glacial readvance across eastern Hudson Strait between 8500-8600 yBP as postulated by Stravers (1986). Closely spaced samples of Core 57 below the dated horizon of *circa* 8000 yBP contained Zone B faunas characteristic of a distal proglacial environment and high percentages of the planktonic foraminifer *N. pachyderma*. On the basis of the dated horizon, glaciomarine conditions have not prevailed at the Core 57 locality in the eastern basin since at least 8000 yBP. However, before 8000 yBP a period of slightly lower paleosalinities is suggested by an oxygen isotope profile on the benthic foraminifer *C. lobatulus*. The peak of lower oxygen isotopes could be considered as evidence for glacial ice readvance across the shallower sill at the entrance to the Strait, where grounded ice would prevent the counterflow of the more saline Labrador Sea bottom waters. The event could have been sufficiently short lived that it did not leave more distinct evidence of its presence in the marine record.

ACKNOWLEDGEMENTS

We have benefitted from the critical review of the manuscript by H. Josenhans, G. Fader and D. Buckley, Atlantic Geoscience Centre, Dartmouth, N.S. We are grateful to Captain F. W. Mauger, officers and crew, C. S. S. Hudson for their assistance and cooperation during Cruise 85027, and to Peter Jones and Ken Drinkwater, Bedford Institute of Oceanography, Darmouth, N.S., who collected oceanographic data and sediment samples.

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