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G. Vilks
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# LATE QUATERNARY MARINE GEOLOGY OF LAKE MELVILLE, LABRADOR


## *Abstract*

*On the basis of high resolution Huntec Deep Tow seismic profiles, and Foraminifera and lithology in piston cores, the Late Wisconsinan to Holocene sedimentary environment is described against the background of contemporary sedimentary and oceanographic processes in Lake Melville. At present, Lake Melville is an estuary in the physiographic setting of a fiord. The bottom water is brackish as a result of a relatively shallow sill that prevents the counterflow of saline bottom waters from Labrador Sea.*

*The evidence for the presence of glacial ice and subsequent retreat of the ice margin is deduced from the seismic profiles. Thin and discontinuous till-like deposits are overlain by intermittently stratified deposits interpreted as undermelt diamicton or sediment slumps and massive turbidites associated with processes along an active glacial margin. These deposits grade to closely stratified sequences, which are conformable on the ridges, but may be ponded in the basins. The stratified deposits have been sampled with piston cores and are interpreted as proglacial or early postglacial on the basis of foraminifera. The acoustically transparent surface sediments represent the postglacial pelagic sedimentation. Along steep basin margins these fine sediments have undergone considerable post-depositional reworking due to slope failures that led to sediment slumping.*

*Fourteen organic carbon and shell dates from piston cores give a minimum age of 8000 BP for the beginning of the proglacial environment in central Lake Melville. With a 1m/1000 years sedimentation rate, the extrapolated age is approximately 10 000 BP, which is older than the proposed deglaciation isochrons on the basis of terrestrial evidence in southeastern Labrador.*



## *Résumé*

*La présente étude décrit le milieu sédimentaire qui a existé au cours du Wisconsinien supérieur et de l'Holocène par rapport aux processus sédimentaires et océanographiques qui ont lieu actuellement dans le lac Melville, et ceci en se fondant sur des profils sismiques à haute résolution obtenus à l'aide du système Huntec à remorquage en profondeur, ainsi que sur l'étude des foraminifères et de la lithologie d'échantillons prélevés au moyen d'une carotteuse à piston. Aujourd'hui, le lac Melville forme un estuaire dans un fjord. Les eaux de fond y sont saumâtres car un filon-couche relativement peu profond empêche le retour des courants d'eau salée de la mer du Labrador.*

*Les profils sismiques permettent de déduire la présence de glace glaciaire et le recul ultérieur de la marge glaciaire. Des dépôts minces et discontinus rappelant des tills reposent sous d'autres dépôts parfois stratifiés qui pourraient représenter un diamicton sous-glaciaire ou des sédiments effondrés et des turbidites massives associées à des processus se produisant le long d'une marge glaciaire active. Ces dépôts se transforment progressivement en séquences étroitement stratifiées, qui reposent en concordance sur les crêtes mais qui peuvent parfois être endiguées dans les bassins. Les dépôts stratifiés ont été échantillonnés à l'aide d'une carotteuse à piston et d'après les foraminifères qu'ils contiennent, ils auraient une origine proglaciaire ou postglaciaire ancienne. Les sédiments superficiels acoustiquement transparents sont le produit d'une sédimentation pélagique postglaciaire. Ces sédiments fins ont par la suite été considérablement remaniés le long des marges raides des bassins, ce remaniement étant attribué à des ruptures de pente qui ont entraîné l'effondrement des sédiments.*

*La datation du carbone organique et des coquillages provenant d'échantillons prélevés à l'aide d'une carotteuse à piston a donné quatorze dates; les conditions de milieu proglaciaire dans la partie centrale du lac Melville auraient débuté il y a au moins 8 000 BP. La vitesse de sédimentation étant de 1 m par 1 000 ans, l'âge extrapolé indiquerait qu'elles auraient commencé il y a environ 10 000 BP, soit une date plus ancienne que les isochrones proposées pour la déglaciation et fondées sur des indices terrestres trouvés dans le sud-est du Labrador.*

## INTRODUCTION

### *Background information and objectives*

Sediments in the coastal inlets of Labrador have not been studied extensively despite the abundance and variety in size and shapes of inlets along the Labrador Coast (Fig. 1). Piper and Iuliucci (1978) and Barrie and Piper (1982) studied Makkovik Bay to compare sedimentary processes along an emerging coastline in Labrador with those of a submerging coastline in Nova Scotia. Their seismic profiles and analysis of sediment structures and textures suggest that glacial erosion took place during one of the mid-Quaternary glaciations and that during the last maximum the inlet contained grounded glacial ice. The erosional effect of the last glaciation was minimal and the retreat rapid, leaving thin deposits of till. Subsequent deglaciation left deltaic ice-proximal glaciomarine deposits that grade to distal deposits of conformable grey clay towards the offshore. The postglacial processes are dominated by the erosion of the glaciomarine deposits and redeposition of fine muds in the depressions, leaving a coarser lag in the open areas. This part of the Labrador Shelf is typically sediment-starved, and thin and intermittent nearshore sands alternate with exposed bedrock highs and muds in isolated basins.

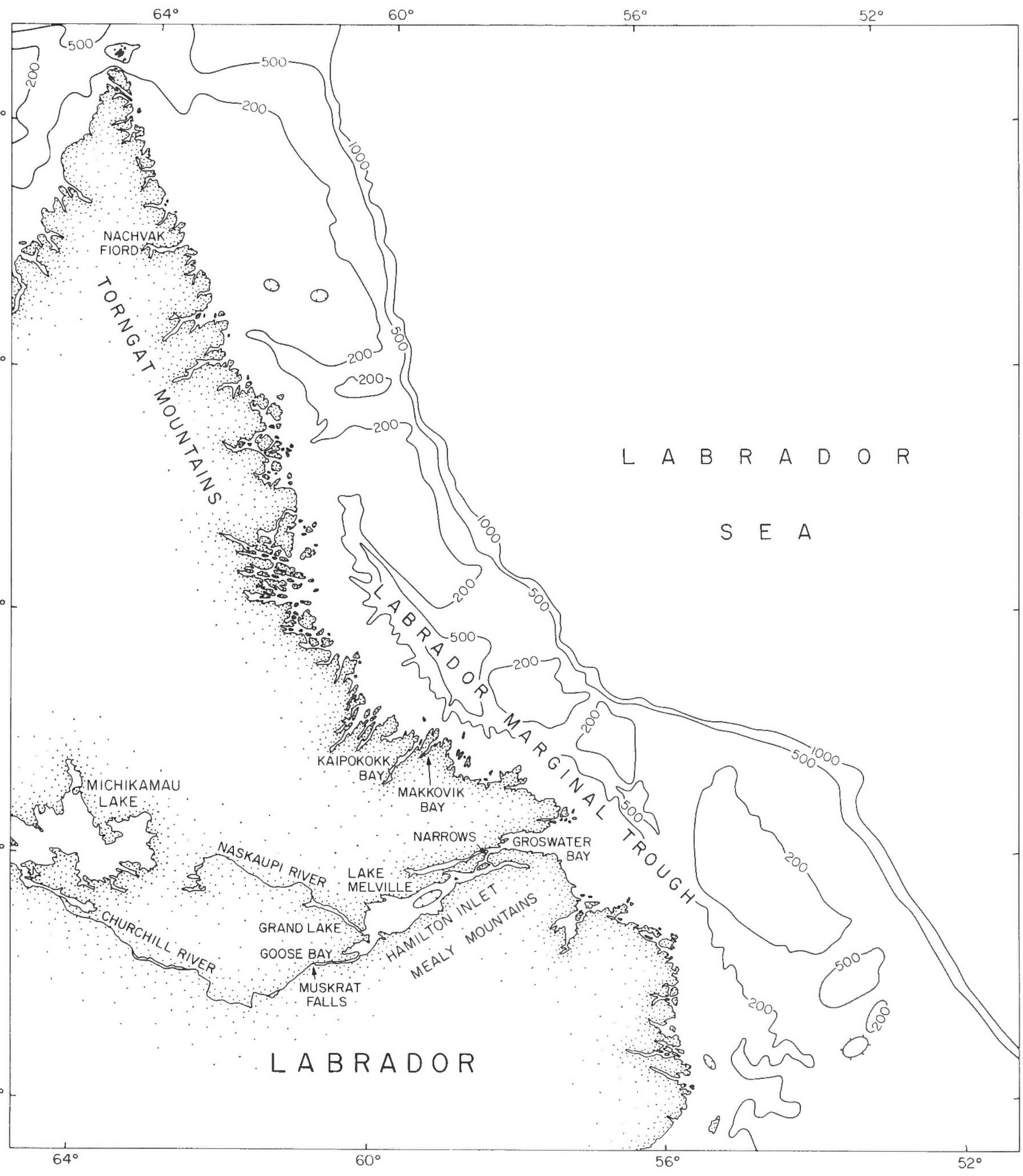


**Figure 1.** Index map showing Labrador coastline and the major rivers to the Lake Melville Basin.

Initial interpretation of Huntec DTS profiles and piston core samples in Kaipokok Bay (Kontopoulos and Piper, 1982) indicate isolated deposits of till up to 50 m thick, overlain by stratified sediments, possibly deposited by subglacial streams in an ice-proximal setting beneath floating ice in a marine environment. Here too the postglacial sedimentary environment is characterized by redeposition of glaciomarine sediments as the energy level of the depositional environment increased.

In an attempt to correlate glacial events documented in the Torngat Mountains and offshore Labrador, Robertson et al. (1986) described the sedimentology and a possible deglacial history of Nachvak Fiord. They discuss evidence for step-wise deglacial sequences consisting of two till deposits in the shape of moraines which could have been deposited during stillstands in glacial recession.

In the inlets of Labrador Shelf the acoustic surveys and sediment cores show evidence for the former presence of glacial ice. Sedimentary features of a retreating ice margin are preserved in the sheltered inlets, but postglacial processes obliterated the more salient glacial deposits on the exposed inner shelf. Regional correlation of the retreating Laurentide Ice margin through the various inlets is not yet well established because of the discontinuous acoustic information and the large variety of localized sedimentary environments along a complex nearshore. For regional synthesis of the nearshore ice margin isochrones, a systematic study of both processes and historical evidence in a series of representative inlets is required, such as the Baffin Island fiord study (Syvitski and Schafer, 1985).

The Hamilton Inlet system — Groswater Bay, the Narrows, Lake Melville and Goose Bay — is the largest of the Labrador coastal inlets and extends 250 km inland from the coastline. The area of Lake Melville is about 2100 $km^2$, and it receives approximately 100 $km^3$ of water annually from the surrounding drainage basin. The maximum water depth is slightly over 200 m behind a 36 m sill. Because of the isostatic readjustment of the Labrador-Ungava peninsula since deglaciation, the Lake Melville basin has become progressively more isolated from marine influence of the Labrador Sea. The physiographic setting of Hamilton Inlet is favorable for the preservation of undisturbed sediments and thus provides a unique opportunity to study the glacial, deglacial and postglacial history of southwest Labrador. The change in depositional environment from glacial to interglacial and a subsequent change in sea level within a relatively short period of time are recorded by lithologic and faunal boundaries in the sediments of Lake Melville.

This paper describes the lithology and foraminifera from a series of piston cores, acoustic characteristics of unconsolidated sediments, and major watermass characteristics of Lake Melville and approaches. By combining this information with the concepts of the regional Quaternary geology in published studies, a deglaciation scenario is proposed for the Lake Melville basin.

### *Previous work*

Marine geological investigations in Hamilton Inlet began with Grant (1975) who carried out airgun surveys in Lake Melville. These established that deeper parts of the basin contained nearly 400m of unconsolidated sediment deposited on top of Cambrian-Precambrian basement, and that the basin has been overdeepened by glacial erosion to close to 600m below the present datum.

Vilks et al. (1982) compared surface benthic foraminifera from piston core tops and box core samples collected in Lake Melville and the inner Labrador shelf. The fauna in Lake Melville surface sediments were dominated by arenaceous species both in piston core tops and box cores. On the inner Labrador Shelf the arenaceous species were present only in a few centimetres near the surface and were missed by the piston cores. However, the Lake Melville arenaceous assemblage was different from that on the Labrador Shelf, reflecting the different salinity ranges.

Vilks and Mudie (1983) reported on postglacial paleoceanographic and paleoclimatic changes in Lake Melville area based on a study of a 13 metre piston core (Core 111 of this report). Changes in foraminiferal assemblages downcore were related to higher paleosalinities, which were explained by greater paleosill depths at the entrance of Lake Melville. Concurrently with the changes in marine conditions, pollen profiles showed a gradual change in flora from tundra to spruce forest in the interval 6000-4000 BP and finally to the present boreal forest.

### *Acknowledgments*

We are indebted to David Piper, James Syvitski and Brian MacLean of the Atlantic Geoscience Centre for critically reviewing the draft manuscript. Their contributions to the improved final report is gratefully acknowledged. John Lazier and Pat Keenan of the Department of Fisheries and Oceans, Bedford Institute of Oceanography, gave invaluable assistance in collecting the oceanographic data. Eric Levy of DFO collected the CTD data and SPM during Cruise 83030. Iris Hardy of AGC conducted the replicate subsampling of cores 1 and 2 to test the extent of dissolution of foraminifera while in storage.

## REGIONAL SETTING

### *Bedrock geology*

The Labrador-Ungava Peninsula is part of the Canadian Shield and Hamilton Inlet lies entirely within the Proterozoic Grenville Province. The main rock types that surround the Hamilton Inlet are intrusive and high grade metamorphic rocks (Greene, 1974)(Fig. 2). Arkosic sedimentary rocks of the Double Mer Formation outcrop in a small area along the north shore of Lake Melville and Double Mer. The age of these rocks is not well established but they are believed to be Cambrian.

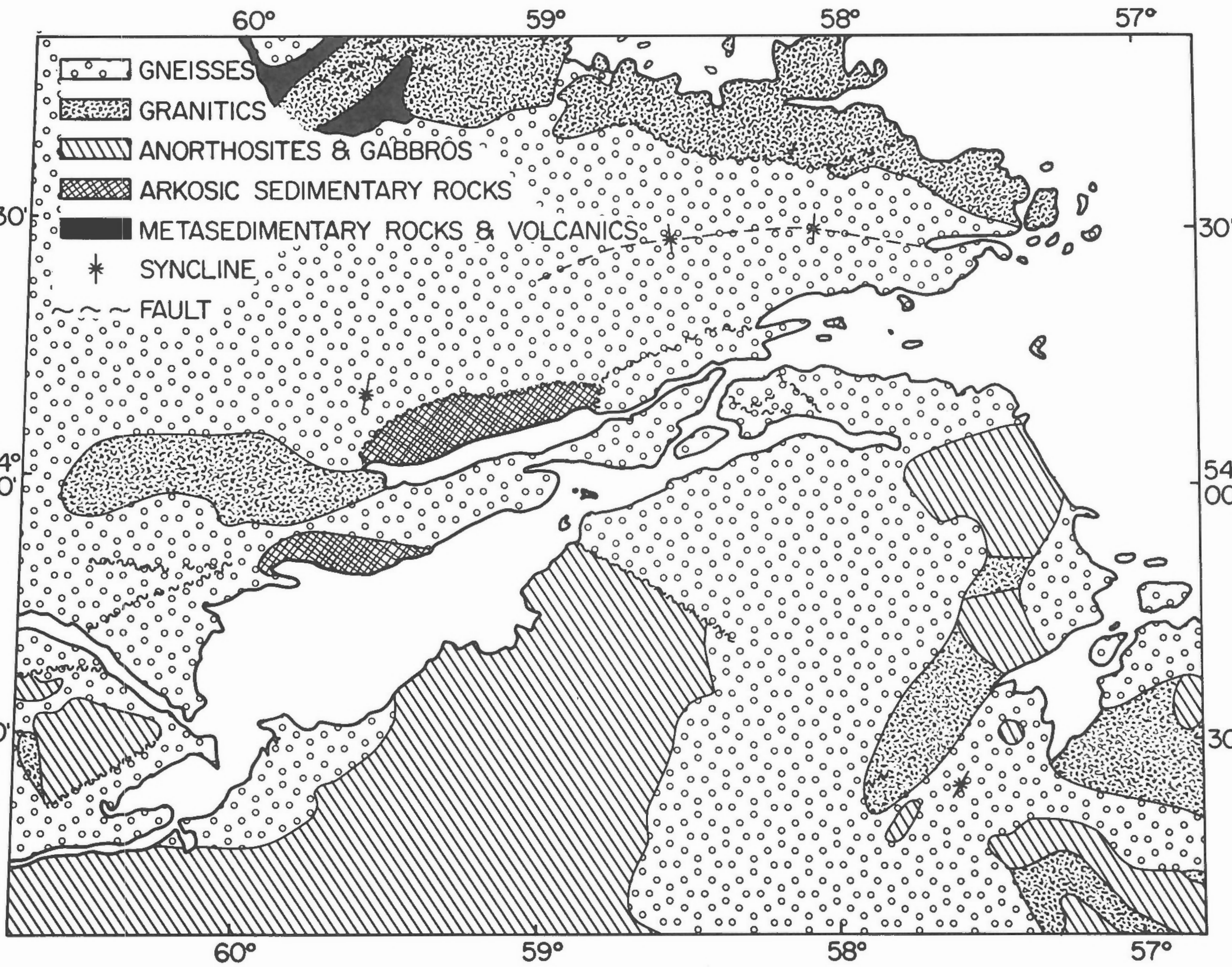


**Figure 2.** Generalized bedrock geology (After Reinson et al., 1979).

## *Physiography*

The Lake Melville area has been divided into four physiographic subdivisions (Greene, 1974): (1) Bedrock-controlled plateaus, (2) drift-controlled plateaus, (3) the Lake Melville Lowland, and (4) the Mealy Mountains (Fig. 3). The peneplaned topography is characteristically flat, and the plateaus only occasionally reach the elevation of 1100m in the Mealy Mountains. The lowland elevations along the northwestern shore of Lake Melville are less than a few hundred metres.

Glacial features are common. The drift-controlled plateaus are covered by a profusion of eskers and drumlins (Greene, 1974) with proglacial outwash deposits in many of the valleys. Extensive sandurs associated with moraines and kettle holes are common in the Porcupine Strand region (Rogerson, 1977) (Fig. 4). Early postglacial marine deposits are present in the Lake Melville Lowlands, the Porcupine Strand area, around the Narrows and the lower valleys of Naskaupi and Churchill rivers.

## *The Laurentide Ice Sheet*

Glacial landforms on the southeastern Labrador Peninsula are dominated by recessional features with limited evidence for periods prior to the ice decay. As a result, the geometry of the Laurentide Ice Sheet during the Wisconsinan is widely different in many of the proposed models. The discrepancies are most pronounced in descriptions of the ice sheet growth and inferred ice limits over the continental shelves. For example, the single spreading dome model (Mayewski et al., 1981) proposes that ice extended over the continental shelf and that the floating ice shelves were anchored by offshore banks. The multidome concept (Occhietti, 1983) maintains that since the Sangomanian the Laurentide ice sheets were formed by several different coalescing ice masses and the margins were diachronic both in space and time. Such a multidome ice sheet is smaller than the ice sheet of a single spreading dome and the margins are inferred to coincide approximately with the coastline (Occhietti, op. cit.). Boulton et al. (1985) reconstructs the Laurentide

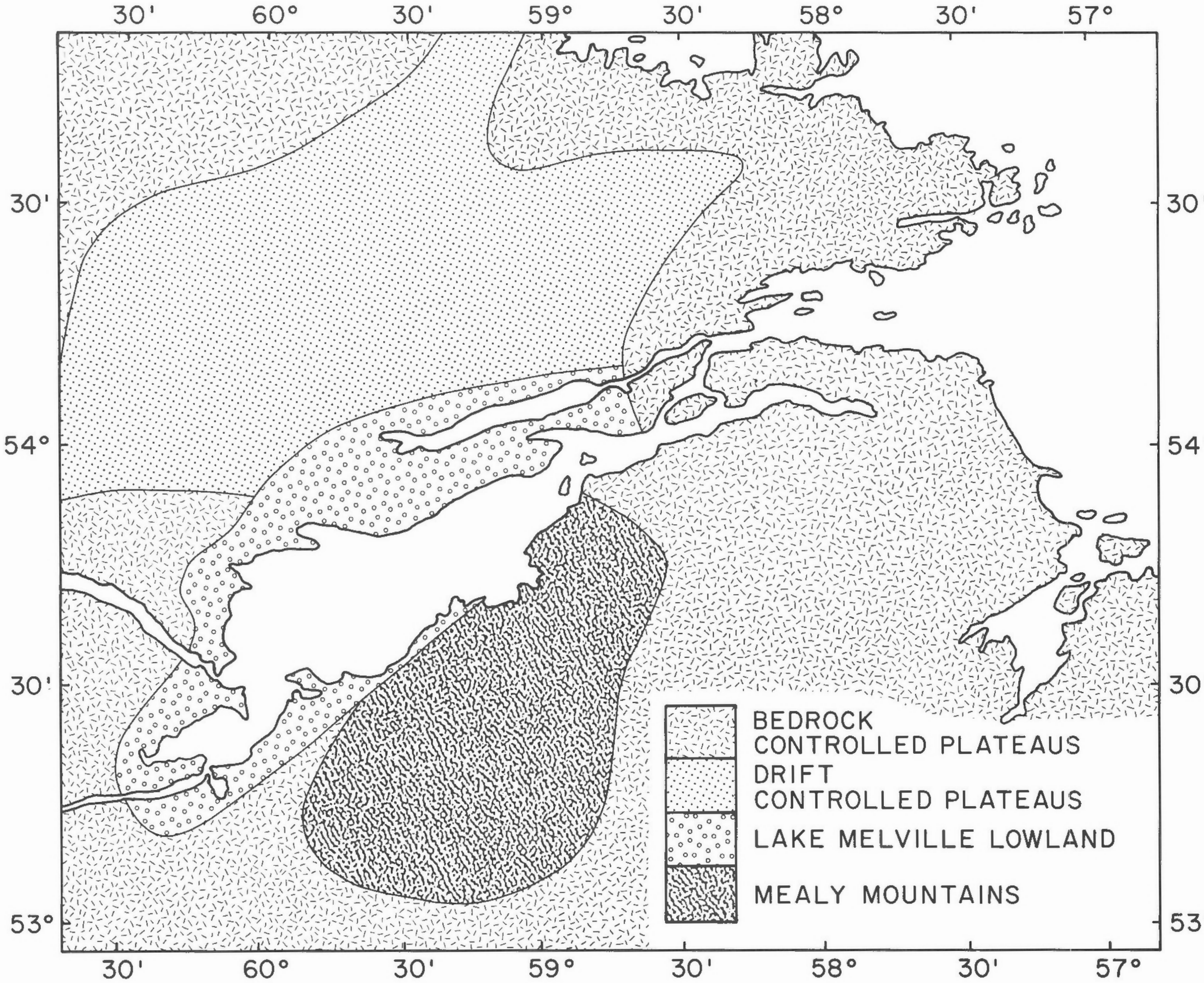


**Figure 3.** Generalized physiography (Adapted from Greene, 1974).

Ice Sheet based on more complex basal conditions of water-soaked sediments. This model compares reasonably well with the multidome model of Dyke et al. (1982), which is based on field evidence, such as the dispersal trains of erratics.

Field evidence also shows that Wisconsinan ice spread towards the Labrador coast from a horseshoe-shaped divide that occupied the central part of the Labrador Peninsula (Dyke et al., 1982). In the Lake Melville area the ice deviated from the regional easterly flow in response to the topography. The Mealy Mountains either deflected the flow or acted as a spreading centre for an ice cap (Fulton and Hodgson, 1979) (Fig. 4). The ice flow to the south of Lake Melville was affected by the drawdown into the Lake Melville depression, which also acted as an iceberg calving bay.

Ice mass-balance models give only approximate offshore boundaries where the changing depths of water add another complexity. Evidence for the offshore limits of the Laurentide Ice Sheet is provided by high resolution seismic surveys (Josenhans et al., 1986), which show acoustical units interpreted as till extending as far as the upper continental slope. The maximum limits of the last major glaciation on the shelf are defined by the limit of the stratigraphically highest till units, which occupy the inner shelf and reach the shelf edge only through saddles. The till is most likely diachronous, and $^{14}C$ dates indicate it is older than 20 000 BP. The acoustic information suggests that the Laurentide Ice maximum could be pre-Late Wisconsinan.

Ice marginal features on land indicate that certain areas in the coastal zone may have been ice free during the last glacial readvance. Unglaciated areas in the coastal regions of the Labrador Peninsula have been identified as coastal or highland nunataks (Ives, 1978). In southeastern Labrador a late Wisconsinan ice front

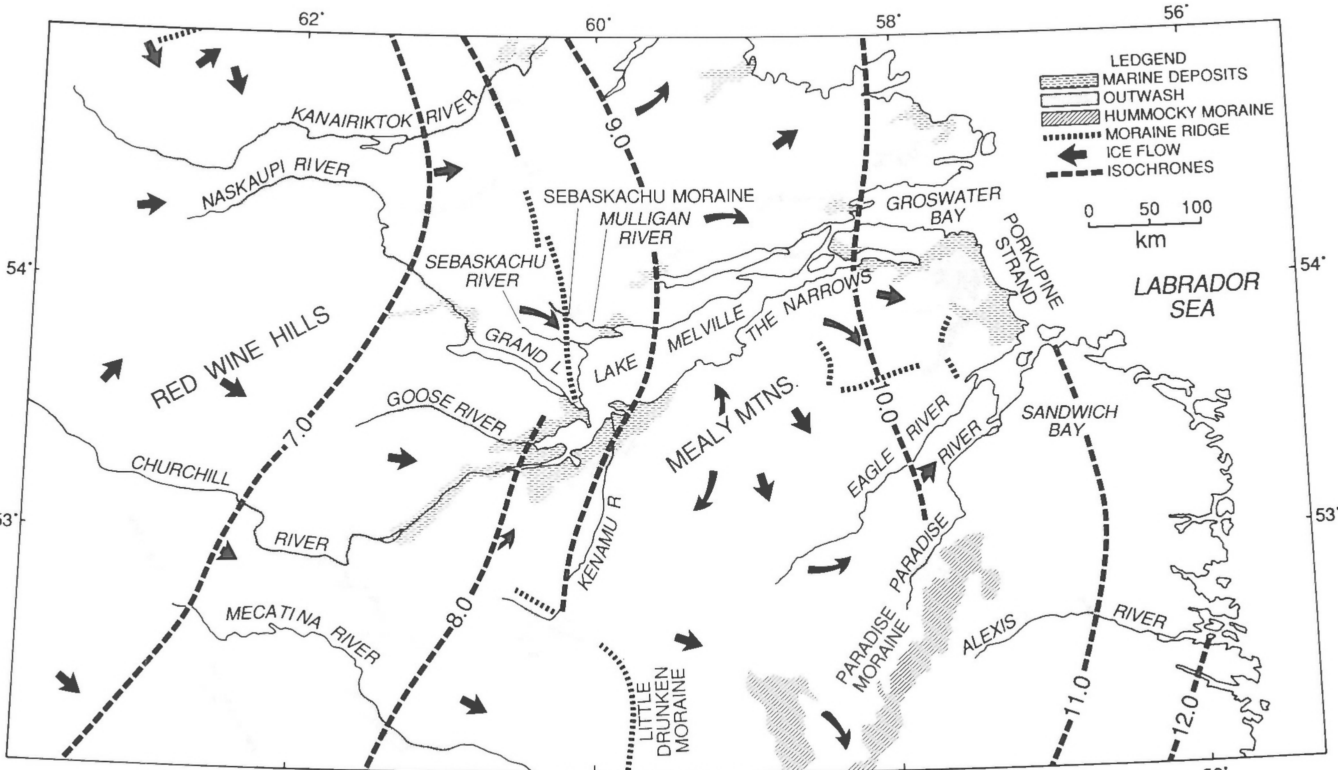


**Figure 4.** Ice margin isochrones in Lake Melville area during deglaciation (After King, 1985).

may have existed along the Paradise Moraine, extending to the eastern side of Sandwich Bay (Fulton and Hodgson, 1979). The large outwash areas south of Groswater Bay can also be considered as a glacial-margin feature.

It is possible that the highest peaks of the Mealy Mountains were also unglaciated during the last Wisconsinan maximum. Altitudinal limits of erratics and glacial striae suggest that at one time during the Wisconsinan the Mealy Mountains may have been overriden by continental glacial ice. However, the earlier glaciation was followed by a later event that bypassed the higher peaks of the mountains (Gray, 1969).

Oxygen isotope ratios of benthic foraminifera from the deep ocean show that the global ice volume maximum was around 18 000 BP (Peng et al., 1977). First evidence for ice retreat in offshore southeastern Labrador is recognized at about 13 000 BP (King, 1985). Thus, the global oxygen isotope record suggests that the Laurentide Ice Sheet had been considerably reduced in size before the marginal retreat phase recognized in Labrador. The mechanism for this initial ablation was marine drawdown and iceberg calving (Mayewski et al., 1981; Ruddiman and McIntyre, 1981). Low numbers of planktonic foraminifera in sediment cores under the North Atlantic subpolar gyre between 16 000-13 000 BP reflect the presence of icebergs and excessive volumes of meltwater in the euphotic zone (Ruddiman and McIntyre, 1981). The reduced surface salinities favoured the presence of sea ice in the North Atlantic, which minimized the winter moisture flux to the ice sheet, and enhanced the rate of deglaciation. The early period of rapid deglaciation was followed by a period of slower rates of ice ablation after 13 000 BP. A cooling interval of subpolar North Atlantic water between 11 000-10 000 BP was identified by Ruddiman and McIntyre (1981) and by Berger et al. (1985) for about the same period in the tropical Atlantic Ocean.

The chronology of deglaciation in the Hamilton Inlet area is poorly understood, due to the difficulty of correlating $^{14}C$ dates with ice margin features. Shell $^{14}C$ dates from raised marine deposits and organic matter from bogs range between 8640 and 5330 BP (Fulton and Hodgson, 1979). In the Porcupine Strand region the deglaciation sequence is based on a series of moraines and sandurs, and $^{14}C$ dates on materials collected from these features range between 8000 and 7000 BP (Rogerson, 1977). The discrepancy in time between these dates and the time when the ice margins locally were present remains unresolved.

King (1985) evaluated the radiocarbon dates in southern Labrador and estimated deglaciation isochrones, some of which are reproduced in Figure 4. The Paradise Moraine is dated at 10 000 BP and King (1985) suggests that this readvance or stillstand could coincide with the cooling period in the North Atlantic between 10 000 and 11 000 BP shown by the $^{18}O$ record in foraminifera (Ruddiman and McIntyre, 1981). The Little Drunken Moraine is dated at 9000 BP and predates the Sebaskachu Moraine. The Little Drunken moraine is due to the drawdown towards the Lake Melville Basin (Fulton and Hodgson, 1979) and thus may not have a climatic connotation.

## METHODS

Data were collected from *CSS Hudson* during various cruises between 1979 and 1984. High resolution Huntec Deep Tow Seismic (DTS) profiling was carried out during Cruise 79018 in Lake Melville and a short profile was obtained in Goose Bay during Cruise 83030 (Fig. 5). The Huntec DTS profiles were used to establish coring stations.

Bottom sediments were collected with a Benthos piston corer during cruises 79018, 83030 and 84038 (Table 1). Suspended sediments were collected with GO-FLO bottles mounted on General Dynamics CTD Rosette assembly during the 79018 cruise and with 5-L Niskin bottles during cruise 83030.

Suspended Particulate Matter (SPM) was estimated in situ by measuring the attenuance coefficients at a wavelength of 680 nm with a Larsen Multispectral Beam Attenuance meter and a Sea Tech Transmissometer. The data were reduced using the method of Winters and Buckley (1980). The coefficients were corrected for the attenuance by water. The resulting corrected attenuance coefficients were correlated with gravimetric analysis for suspended particulate matter (one litre of water was filtered through a 0.4 nm Nucleopore microfilter). All filters were examined under a microscope to determine the nature of the suspensate. Gravimetric weights for only those samples which contained negligible amounts of plankton were correlated with the corrected attenuance coefficients. Only variations in clay and fine silt concentration caused significant changes in the corrected attenuance coefficient. Our calibration factor is $SPM_{ppm} = 0.5*C^{680}$ (m/L), where C is the attenuance coefficient corrected for the attenuance in pure water at the wave length of 680 nm.

Vertical profiles of temperature and salinity were obtained along a transect from Groswater Bay, through the Narrows and in Lake Melville during August 1979 and mid-October 1983 (Fig. 5) on cruises 79018 and 83030. Temperature and current velocity were measured at the entrance of Lake Melville with an Anderraa current meter 4 m from bottom (Fig. 5) between October 19, 1983 and September 28, 1984.

Sediment-size analysis was performed by the AGC Soft Sediment Laboratory, using standard techniques of settling tube (sand) and Sedigraph (mud). Foraminifera were picked from sediment coarser 0.063 mm.

**Table 1.** Core locations, water depths and core lengths.

| Core | Latitude (N) | Longitude (W) | Water Depth (m) | Core Length (m) |
|---|---|---|---|---|
| 109 | 53°48.8′ | 59°11.6′ | 203 | 9.5 |
| 111 | 53°49.2′ | 59°11.7′ | 203 | 9.5 |
| 128 | 53°42.5′ | 59°35.1′ | 110 | 12.5 |
| 2 | 53°42.6′ | 59°34.6′ | 120 | 11.7 |
| 130 | 53°33.9′ | 59°54.5′ | 130 | 7.3 |
| 131 | 53°33.6′ | 59°46.4′ | 154 | 4.8 |
| 132 | 53°38.4′ | 59°43.2′ | 60 | 9.1 |
| 1 | 53°38.4′ | 59°43.2′ | 60 | 11.6 |
| 133 | 53°35.9′ | 59°31.9′ | 82 | 9.9 |
| 134 | 53°46.1′ | 59°17.7′ | 70 | 8.6 |
| 77 | 53°22.1′ | 60°06.9′ | 38 | 5.3 |

## OCEANOGRAPHY

### *Salinity and temperature*

#### Winter

Under the sea ice the water temperature is less than 0°C, increases to 1°C by 10 m and eventually decreases towards the bottom to a minimum of -1°C (Fig. 6A). A halocline exists close to the surface with salinities from 15% to 25%. The bottom salinity is over 28% throughout the Lake Melville basin at depths slightly over 100 m (Fig. 6B).

#### Summer

During early August of 1979 a surface thermocline between 15°C and 5°C was present in Lake Melville within the upper 20 m (Fig. 6A). In Groswater Bay the thermocline between approximately 5°C and -1°C was within 50 m of the surface. A cell of cold -1.5°C Arctic water was present at about 100 m. The bottom water in the Marginal Channel of the Labrador Shelf is slightly warmer than 2°C. A smaller temperature inversion was present in Lake Melville, where the bottom water was only slightly colder than -0.5°C.

The summer halocline in Lake Melville corresponds with the surface thermocline and ranges between 5‰ and 20‰. The mixing in the Narrows at the sill disrupts the effects of the runoff plume and as a result, the surface salinity increases laterally towards the east (Fig. 6B). The salinity of the bottom water in the Narrows is similar to that in Groswater Bay at 32‰. The bottom salinity in Lake Melville does not reach 28‰, but is over 34‰ in Groswater Bay.

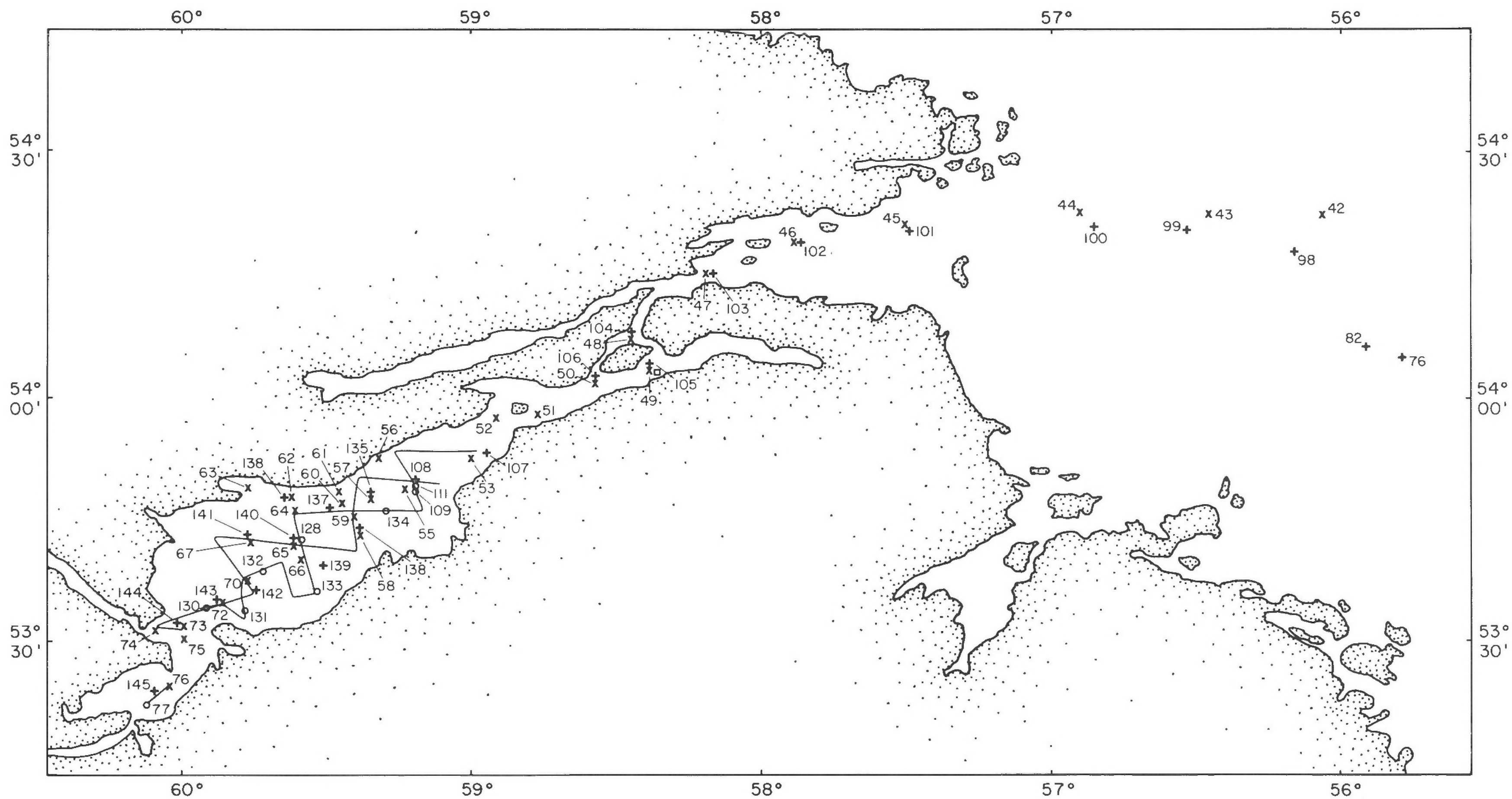


**Figure 5.** Location of sample stations and the Huntec DTS high resolution seismic lines. O — piston core stations, + — Cruise 79018 CTD stations, x — Cruise 83030 CTD stations, open square — bottom mooring monitoring current and temperature between October 19, 1983, and September 28, 1984.

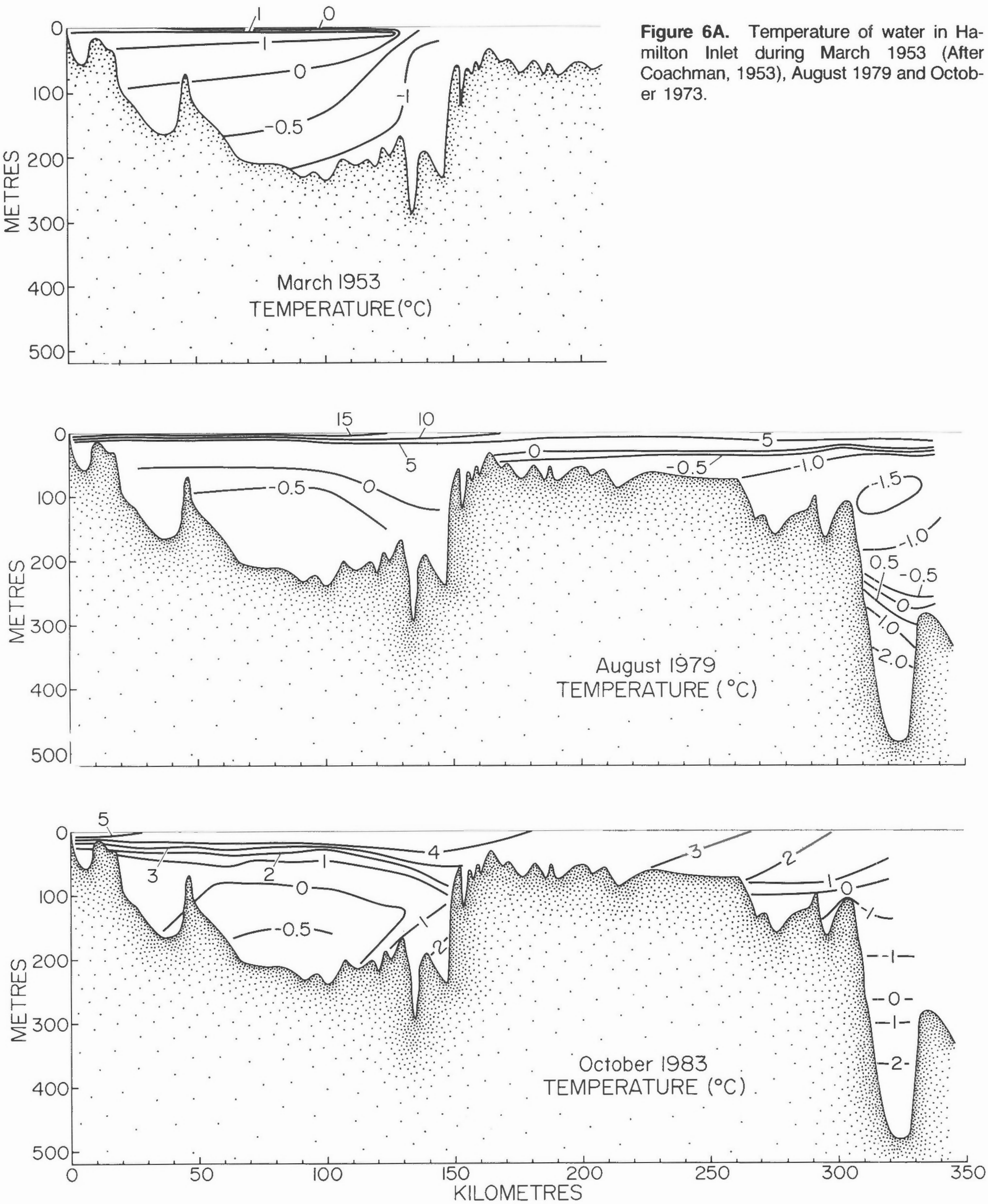


**Figure 6A.** Temperature of water in Hamilton Inlet during March 1953 (After Coachman, 1953), August 1979 and October 1973.

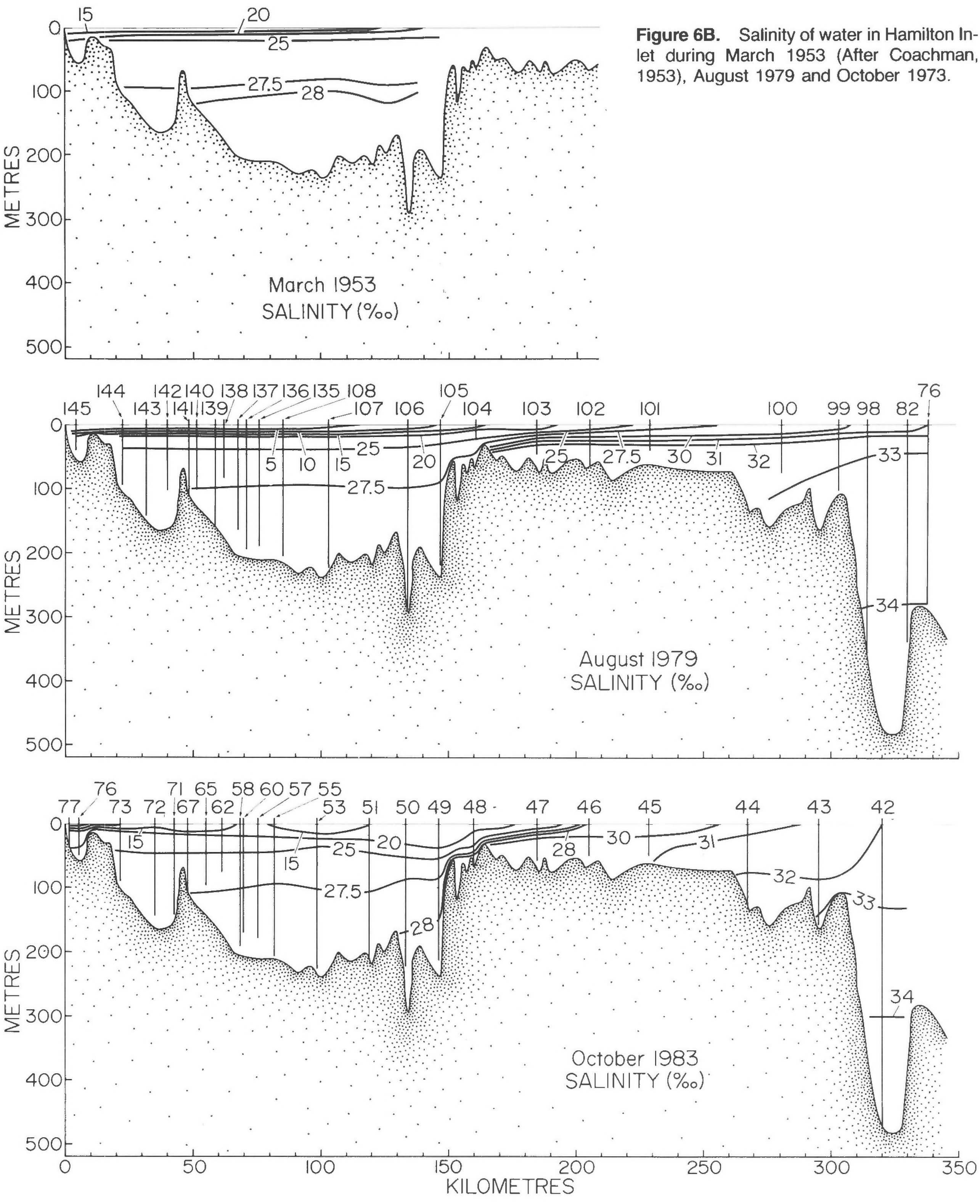


**Figure 6B.** Salinity of water in Hamilton Inlet during March 1953 (After Coachman, 1953), August 1979 and October 1973.

## Fall

In October, the waters of Lake Melville are poorly stratified and well mixed in the Narrows (Fig. 6A). The warmest surface temperatures are in Goose Bay at 5°C; the source of cold water is Groswater Bay, where surface water is colder than 2°C. Because of the mixing at the sill, relatively warm water spills over the sill and contains sufficient amounts of salt to sink to the bottom, under the colder water present in the Lake Melville Basin.

A surface halocline is present only in Goose Bay at depths of 6-8 m with a salinity gradient from 2‰ to about 10‰. The bottom salinity in Goose Bay is about 20‰. The surface runoff plume is dispersed in Lake Melville, where stratification is weak and surface salinities range between 10 and 20‰. In Groswater Bay and the Narrows the water is almost completely mixed with respect to the salinity, except at the sill, where the salt wedge is overridden by the surface ebb waters of Lake Melville.

## *Dynamics*

In October, water more saline than 28‰ spilled over the sill replacing the bottom water in Lake Melville. The temperature of the saline water was at least 2°C (Fig. 6A) but towards the end of October progressively colder water spilled over the sill, cooling the bottom water to -1°C by December (Fig. 7). These winter conditions lasted till June, when warmer water began to reenter the deep basin of Lake Melville.

The water that spills over the sill into Lake Melville is diluted by runoff water through mixing processes in the Narrows and at the sill. This mixing is mainly due to tidal currents. The Narrows restrict the tidal flow, which is reflected in the reduction of tidal amplitudes from a mean of 1.3 m in Groswater Bay to 0.4 m in Lake Melville. The maximum amplitude of 2.0 m in Groswater Bay is reduced to 0.6 m in Lake Melville (Anonymous, 1984).

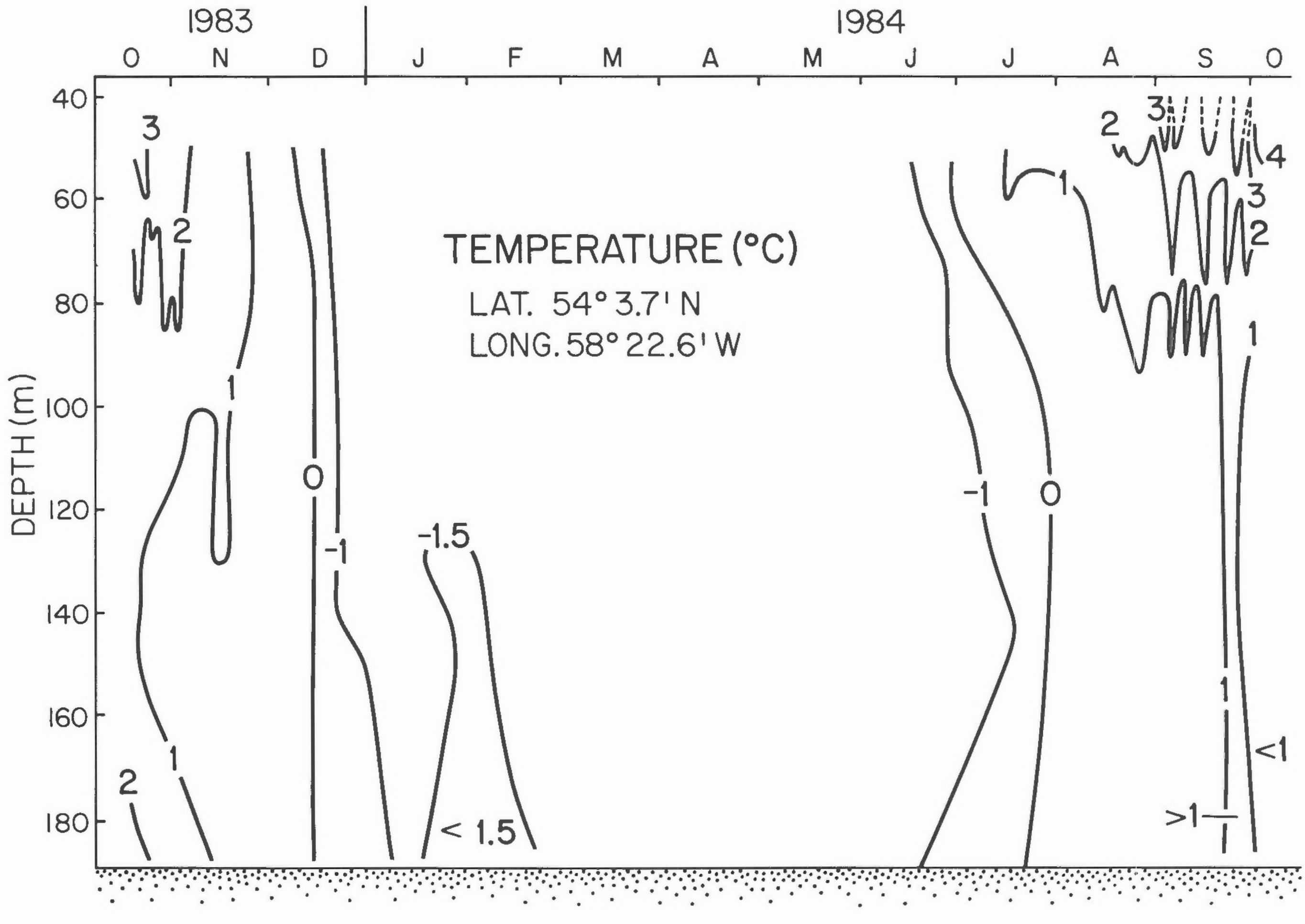


**Figure 7.** Temperature between bottom and 30 metres of the water column monitored between October 1983 and October 1984. The location is inside the sill at station 49 (See Figure 5).

A one-year record of bottom currents at the depth of 188m at station 49 showed residual tidal currents ranging from less than 5 cm $s^{-1}$ to 100 cm $s^{-1}$, with the higher velocities (40-100 cm $s^{-1}$) during neap tides and in an inward direction. Possibly this is due to the two-layer circulation during neap tides with the inward flow of colder water along the bottom.

Our continuous one-year record for temperature begins during the time of neap tidal cycles in the middle of October 1983 (Fig. 7). During this time the 2°C isotherm was at maximum depth, but during the following cycle of spring tides, the 2°C isotherm was at minimum depth. This pattern was repeated during the following cycles of neap and spring tides, implying an influx of the colder and denser water during the spring tide cycles. This series of data indicates that tidal pulses are important in replacing the bottom water in Lake Melville.

### *Suspended particulate matter (SPM)*

The concentrations of SPM derived from light attenuance measurements were slightly higher in summer, 1979 than in fall, 1983 (Fig. 8). The SPM was concentrated in surface waters within the pycnocline and was dispersed throughout the water column in the Narrows and Groswater Bay during the fall of 1983, when the pycnocline was breaking down.

The SPM collected during the fall of 1983 was identified under microscope as predominantly clay with traces of fine silt-size material and organic detritus in some of the samples. The surface SPM in Goose Bay and Lake Melville appeared on filters as a dense mass of brown (organic stained?) clay-size material where individual flocs could not be distinguished. The clay-size material of SPM collected close to the bottom, where estimated concentrations are less than 0.2 mg $L^{-1}$, appears

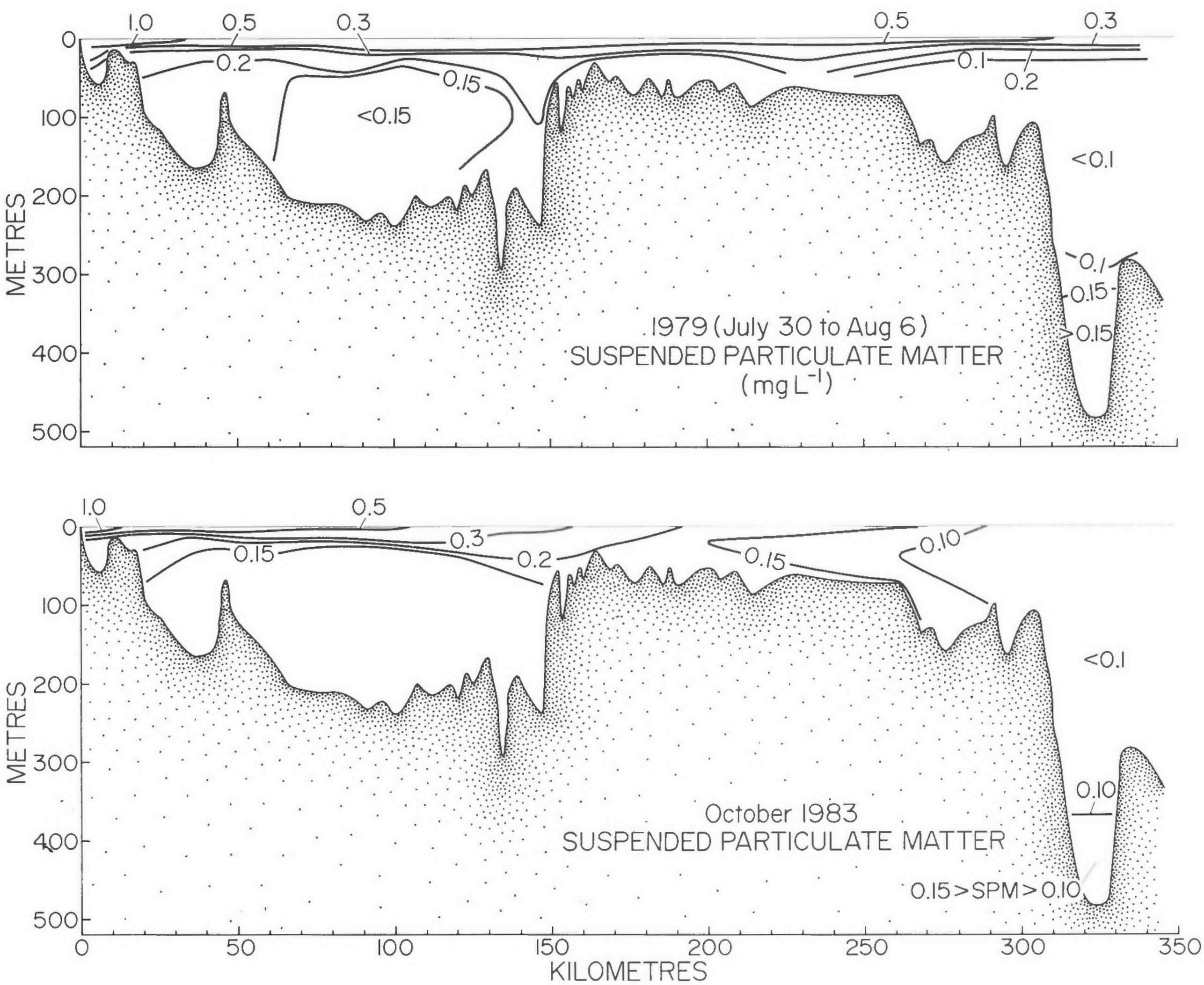


**Figure 8.** Suspended particulate matter in Hamilton Inlet during summer of 1979 and fall of 1983.

on the filter predominantly in flocs, about 1.5 mm in diameter. These sediments were less stained in comparison to the surface SPM.

In the Narrows the SPM consisted of clay and fine silt and small flocs. In Groswater Bay flocs were no longer present, instead organic detritus was found with the clay and silt.

During August, 1979, SPM was collected only in Groswater Bay, the Narrows and the east end of Lake Melville. The filtrate from surface waters is similar to the SPM collected during 1983 and consists mostly of clay, fine silt and brown (organic?) stain on the filter. In Lake Melville the intermediate water contained diatoms, fecal pellets and organic detritus, in addition to the clay and silt. The SPM in the near-bottom water was dominated by clay flocs, but trace amounts of silt, a few diatoms and organic detritus were also present. In Groswater Bay the SPM in surface water consisted predominantly of clay flocs with silt, organic detritus and diatoms. The deeper water contained a higher proportion of diatoms, organic detritus and fecal pellets.

Ratios of Particulate Organic Carbon (POC) (Tan and Vilks, in press) to the SPM values obtained from light attenuance measurements are plotted against distance from the Churchill River estuary (Fig. 9). In Goose Bay and Lake Melville the POC/SPM ratio is 0.2 in surface SPM, but less than 0.1 along the bottom due to the relatively high organic content in the surface SPM. The surface and bottom ratios are similar in the Narrows and at the sill due to the mixing of the water column. On the Labrador Shelf the near bottom and surface SPM ratios again separate, and are close to the values of Lake Melville, demonstrating the proportionally higher POC content in the surface waters in comparison to the near bottom.

## SEISMOSTRATIGRAPHY

### *Acoustic profiles*

High resolution seismic reflection signals of the Huntec DTS penetrated up to 160 ms into the sediment sequence, equivalent to 120 m, assuming 1.5 km/s sound velocity. Many of the reflection characteristics in Lake Melville as they appear on the DTS profiles are comparable to those in Scotian Shelf profiles and illustrated by King and Fader (1986). We use similar terminology to describe our four stratigraphic units: unit H, units M and M-1 and till.

The acoustic basement is defined as a continuous zone of strong reflectors below which the return of acous-

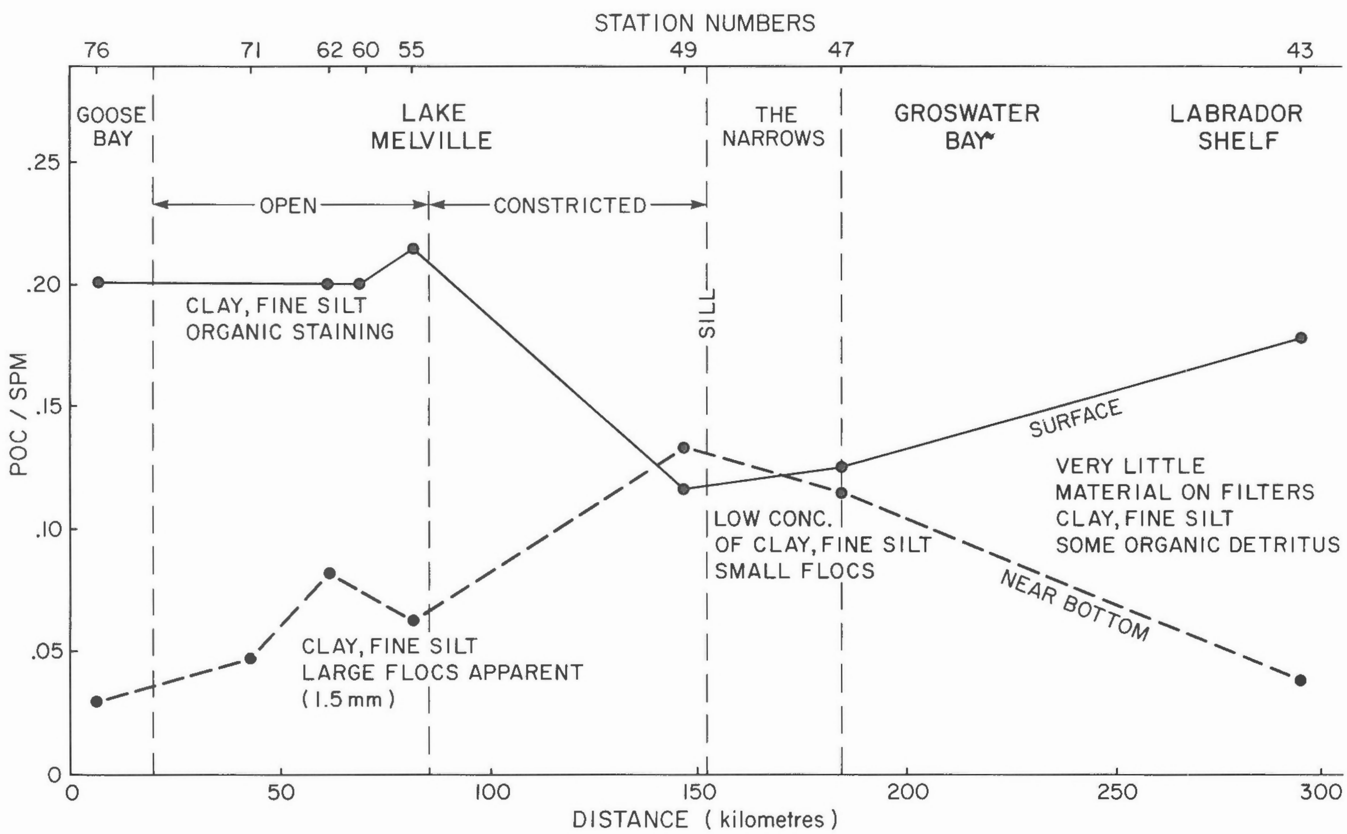


**Figure 9.** Ratios of Particulate Organic Carbon (POC) over Suspended Particulate Matter (SPM) in Hamilton Inlet during fall of 1983.

tic signals is negligible. Till is a lithologic equivalent to a correlatable acoustic unit with an acoustic signature characterized by incoherent reflectors, sometimes with scattered point source reflectors. Unit M is characterized by high amplitude continuous coherent reflectors and Unit M-1 by discontinuous coherent reflectors and acoustically nearly transparent zones that change laterally to moderate strength incoherent reflectors. Unit H consists of acoustically transparent sediments containing faint internal reflectors. These units are recognized in a series of type profiles described below.

**Profile A-B** (Figs. 10, 11)

The transect is transverse to the basin margin and floor. The acoustic basement is interpreted as Precambrian bedrock, seen as a smooth, solitary reflector on the upper slope but as a hummocky surface formed by tightly overlapping hyperbolae along the lower slope. Unit M-1 follows the bedrock surface towards the bottom of the basin, but laps on the basin margin towards the top. Unit M shows bands of strong continuous reflectors that conform to the bedrock on the slope, but change to horizontal and ponded beds in the basin. Unit M-1 is interbedded with Unit M as an acoustically unstratified sequence ranging in thickness from a few metres to over 20 metres.

The surface Unit H follows the slope containing undisturbed internal reflectors along grades up to 4°. However, at the bottom of the slope the hummocky appearance of seabed surface and the disturbed reflectors suggest sediment slumping downslope.

**Profile C-D** (Fig. 12)

The acoustic basement is bedrock on top of which is a thin veneer of till filling the depressions as a structureless deposit with a uniform dense grey acoustic pattern of incoherent reflections. The till is conformably covered with Unit M and M-1. Throughout the thick Unit M, bands of

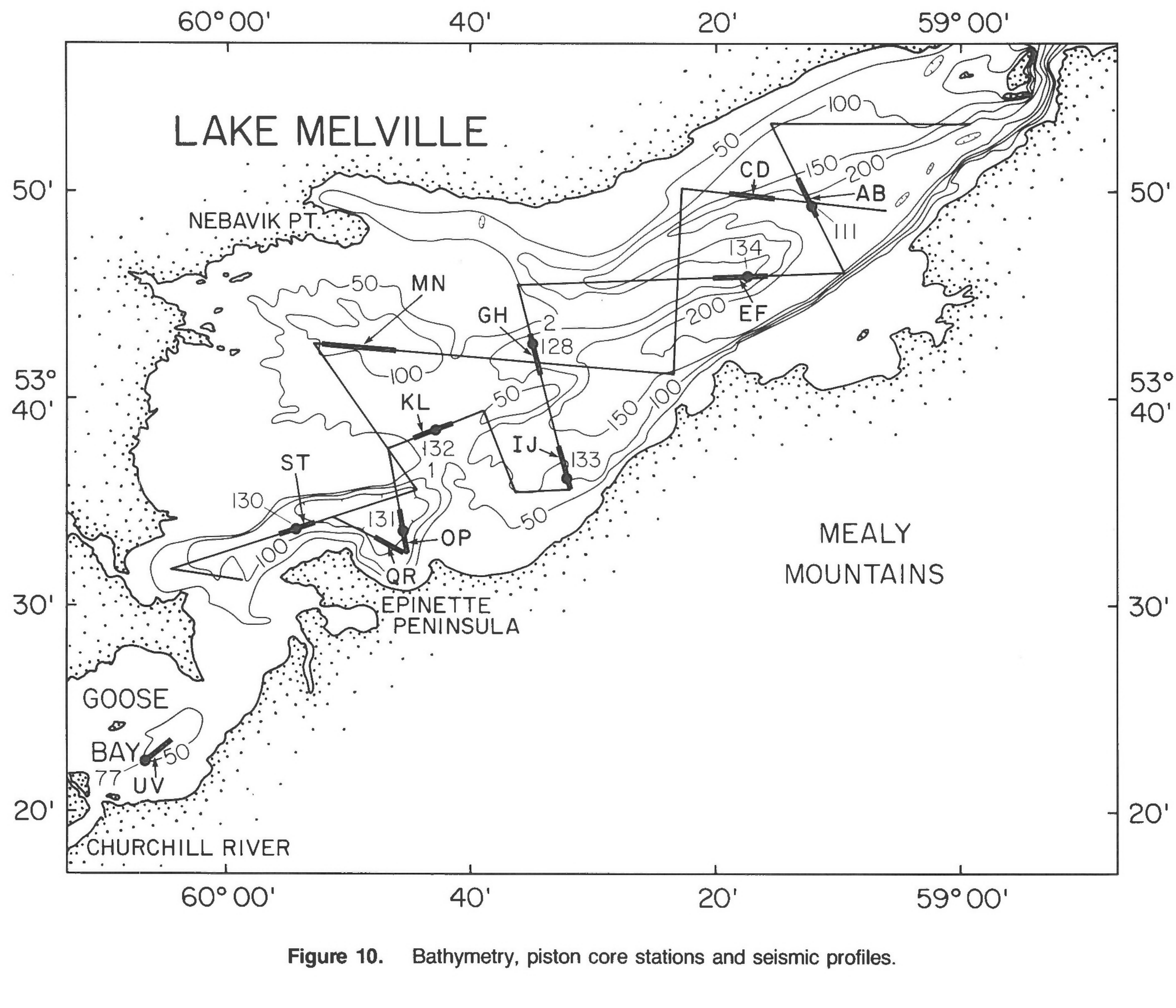


Figure 10. Bathymetry, piston core stations and seismic profiles.

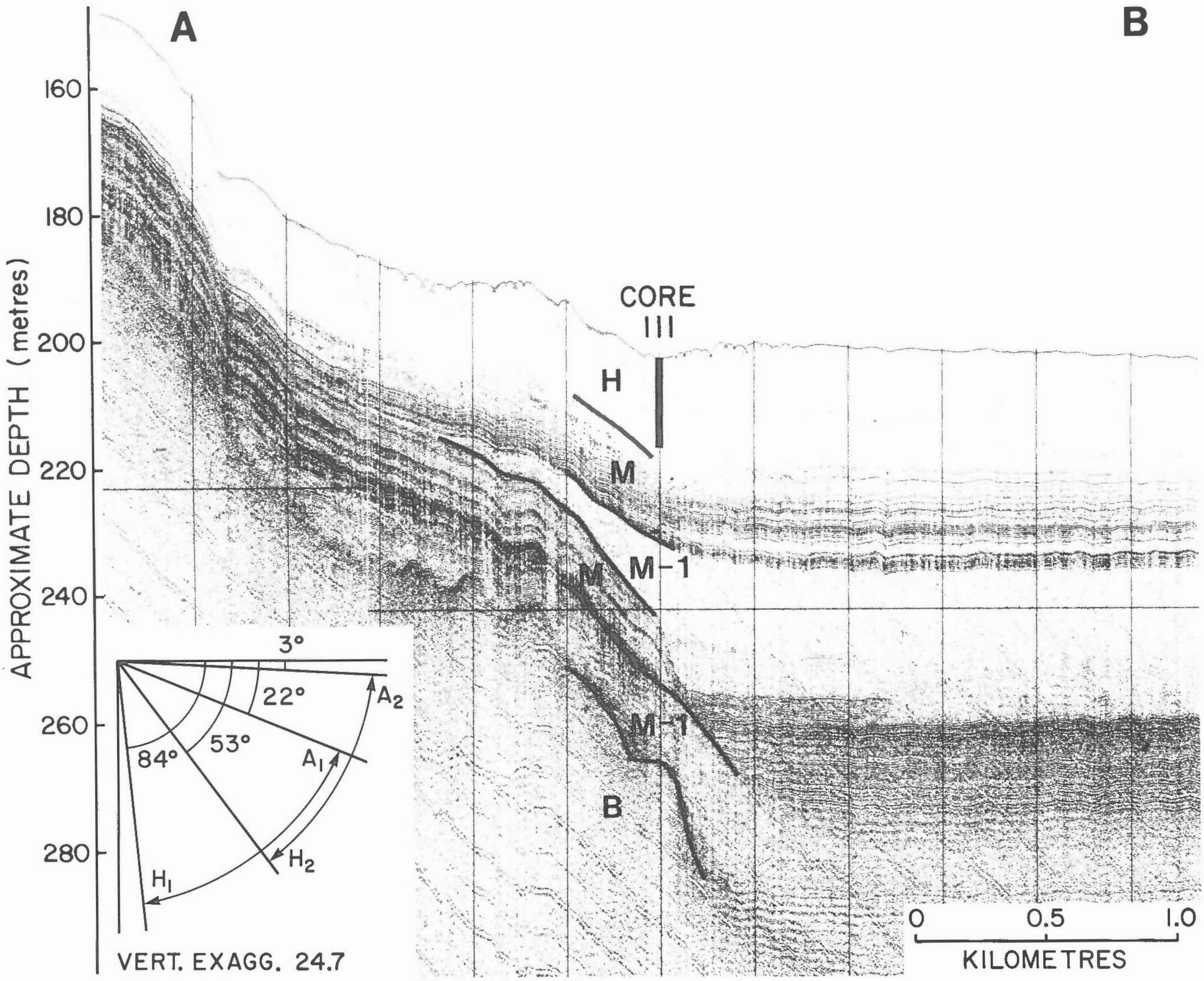


**Figure 11.** Seismic profile A-B. H — Huntec DTS slope, A — actual slope.

densely spaced parallel reflectors alternate with unstratified intervals of discontinuous coherent reflectors and single high amplitude reflectors that can be traced along the length of the profile. The contact between Unit M and the overlying acoustically transparent facies of Unit H is sharp and is defined by a single high amplitude reflector. Most of the faint internal reflectors of Unit H are disoriented, except for a single conformable continuous reflector close to the surface of the seabed.

**Profile E-F** (Fig. 13)

The profile crosses a ridge and approaches a slope break towards a basin margin. The acoustic basement is marked by a zone of closely spaced, strong, incoherent reflectors with a diffuse upper boundary. The acoustic character of the boundary suggests the presence of a thin layer of till over the bedrock. Unit M-1 is represented by an acoustically nearly transparent zone, containing blocks of moderate strength, incoherent reflectors. It fills minor depressions on the ridge and forms hummocky deposits on the slope. Truncated horizons and small depressions at the upper surface of Unit M-1 suggest an erosional boundary. The strong continuous reflectors of Unit M partly fill the depressions and partly conform with the uneven topography. Throughout Unit M bands of strong reflectors alternate with unstratified zones. Unit H conformably covers the uneven surface of Unit M below. The weak but coherent internal reflectors remain intact even at grades of up to three degrees.

**Profile G-H** (Fig. 14)

The profile crosses a basin and shows bedrock basement along both sides. Distinctive till beds could not be recognized, but a thin layer of Unit M-1 seems to cover the

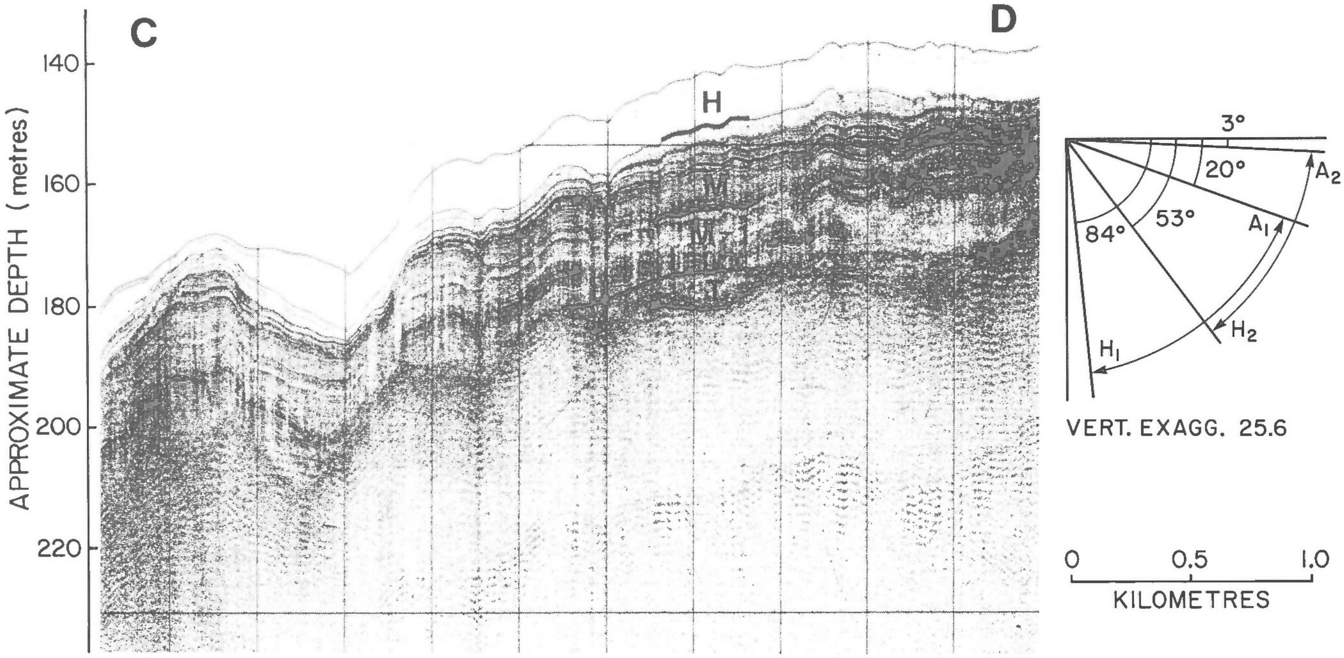


**Figure 12.** Seismic profile C-D.

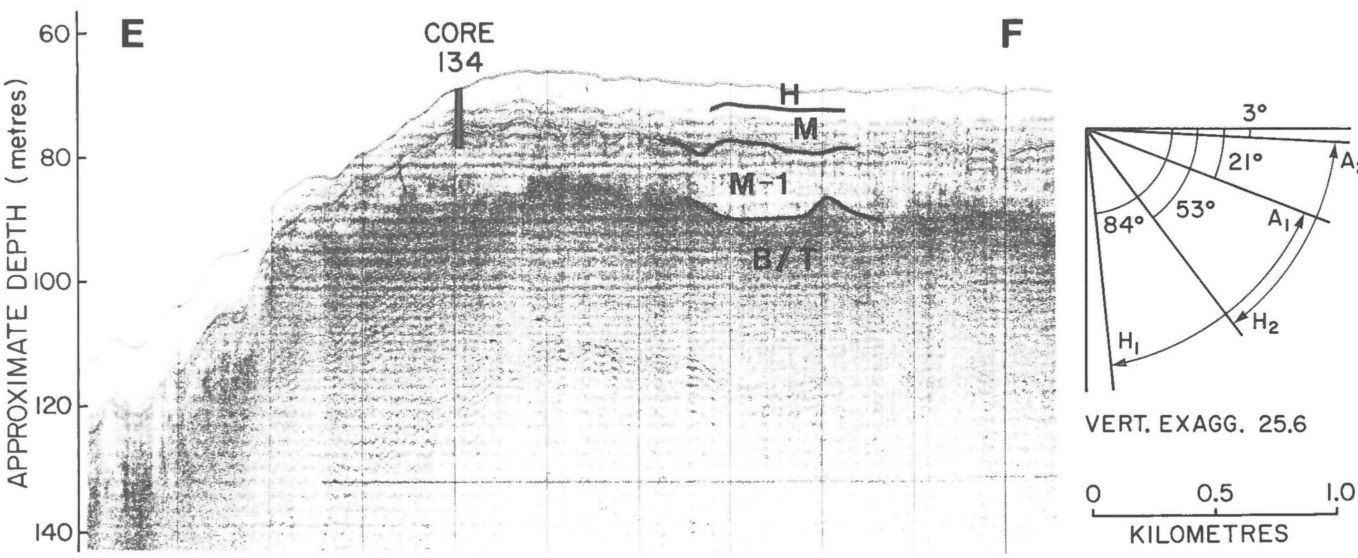


**Figure 13.** Seismic profile E-F.

bedrock on the sides of the basin and to fill the bottom of the basin. The sequences of continuous coherent reflectors of Unit M are frequently separated by wedges of discontinuous reflectors originating from the flanks of the basin and could be interpreted as sidewall debris flow. Unit H is about 10 m thick and shows several continuous internal reflectors. Closer to the basin margin the reflectors are less prominent or are entirely absent. This is interpreted as evidence for sediment slumping.

**Profile I-J** (Fig. 15)

The transect crosses a basin margin towards the south shore of Lake Melville. The bedrock surface is easily recognized along the steep slope of the basin, but on the uneven surface of the shelf the sediment-bedrock interface is diffuse. An airgun profile (Grant, 1975) indicates that the unconsolidated sediment on the shelf at this locality is around 50 m thick. Unit M-1 follows the uneven sur-

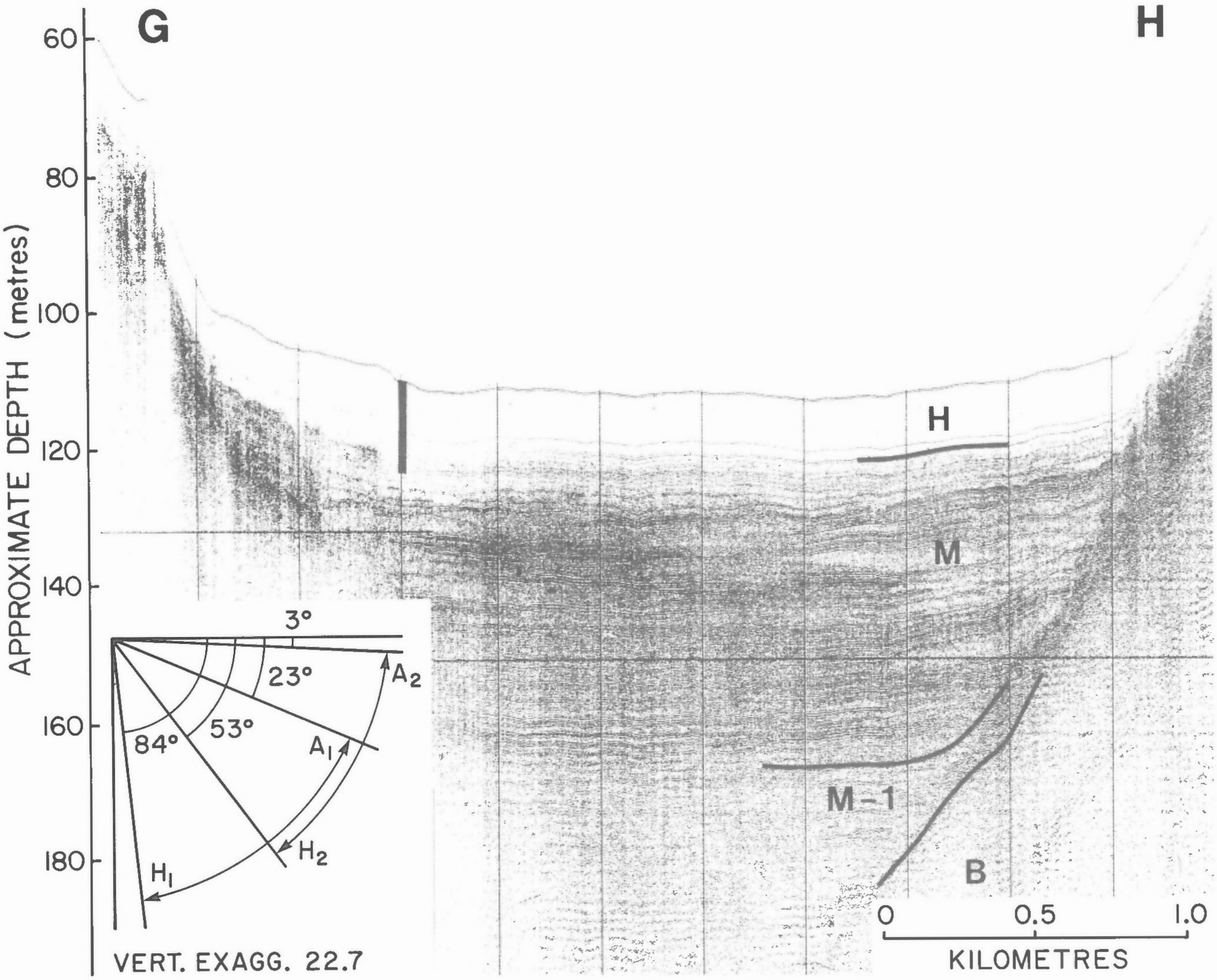


**Figure 14.** Seismic profile G-H.

face of the bedrock and is only slightly thicker in the depressions. The continuous coherent reflectors are intact on gradients of less than 2.5°, but are disturbed on steeper slopes. The acoustic reflectivity of the laminae decreases towards the upper surface of Unit M. Unit H also rests conformably on the uneven surface of the lower acoustic unit in the deeper water, but it pinches out at the shelf edge in 65 m of water.

**Profile K-L** (Fig. 16)

The transect crosses the top of a ridge in the central part of Lake Melville in around 60 m of water. Till is intermittently present between the bedrock and Unit M-1, as verified by Core 132 (see below). Unit M-1 conforms to the surface of the exposed till or bedrock. It contains lenses of acoustically incoherent sediment and a relatively continuous layer of acoustically massive but relatively transparent sediment in the upper part of the unit.

The acoustic reflectors of Unit M are continuous throughout the transect, and maintain a constant thickness of five metres. The acoustically transparent surface layer (Unit H) is discontinuous and varies in thickness. The unconsolidated sediment in this area is usually less than 20 m.

**Profile M-N** (Fig. 17)

The transect follows the basin floor in western Lake Melville. Although the water depths in the basin are over 150 m, sediment thickness barely exceeds 20 m. The acoustic basement is bedrock with changing reflector characteristics and surface expression from west to east (M to N). Along the western half of the profile, the bedrock is seen as a series of regularly spaced promontories with a thin acoustic boundary in the form of an almost solitary reflector. To the east, the basement surface is hummocky to irregular and the acoustic boundary consists of a zone

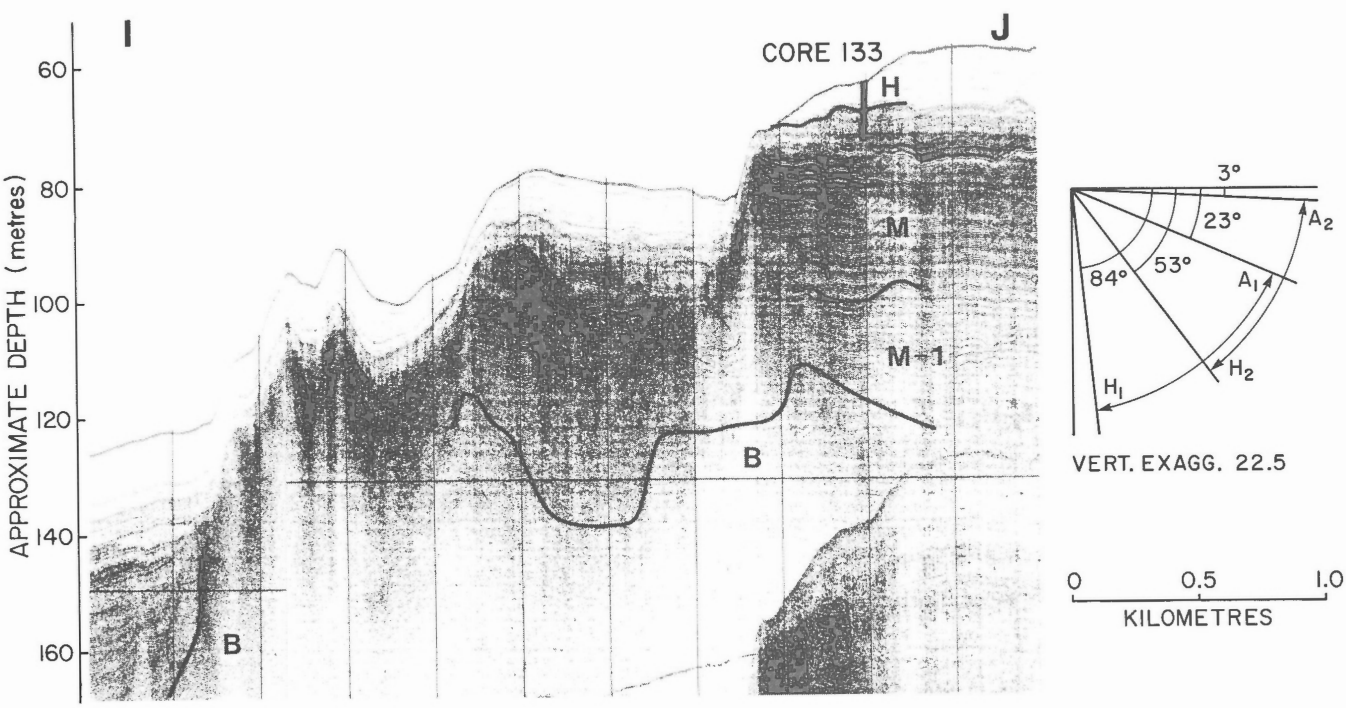


**Figure 15.** Seismic profile I-J.

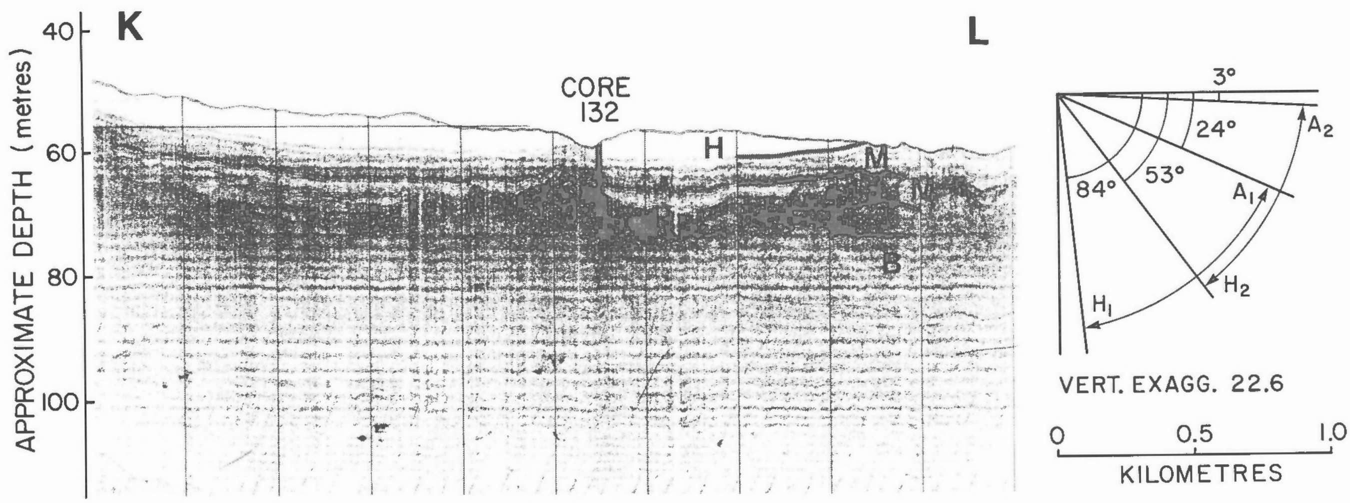


**Figure 16.** Seismic profile K-L.

of dense, overlapping semiparallel reflectors. Here, Grant (1975) inferred a geological boundary, between the Precambrian igneous rocks to the west and the Double Mer sandstone to the east. The contact between the two different styles of bedrock surface may represent this boundary.

Most of Unit M-1 is unstratified and is ponded in bedrock depressions. One of these appears to contain gas. Unit M conformably overlies the uneven surfaces with the laminated beds remaining intact on slopes up to 3°. The thick deposits of Unit H, also finely laminated, are conformable and undisturbed on the 4° slopes over the bedrock peaks. Small point-source reflectors are dispersed in these acoustically transparent sediments and may indicate the presence of boulders.

**Profile O-P** (Fig. 18)

Profile O-P transects a basin and shows a thick section of relatively confused reflectors. The acoustic basement is not detected. The chaotic layering of the reflectors strongly suggests postdepositional movement of sediments towards the centre of the basin. The facies change

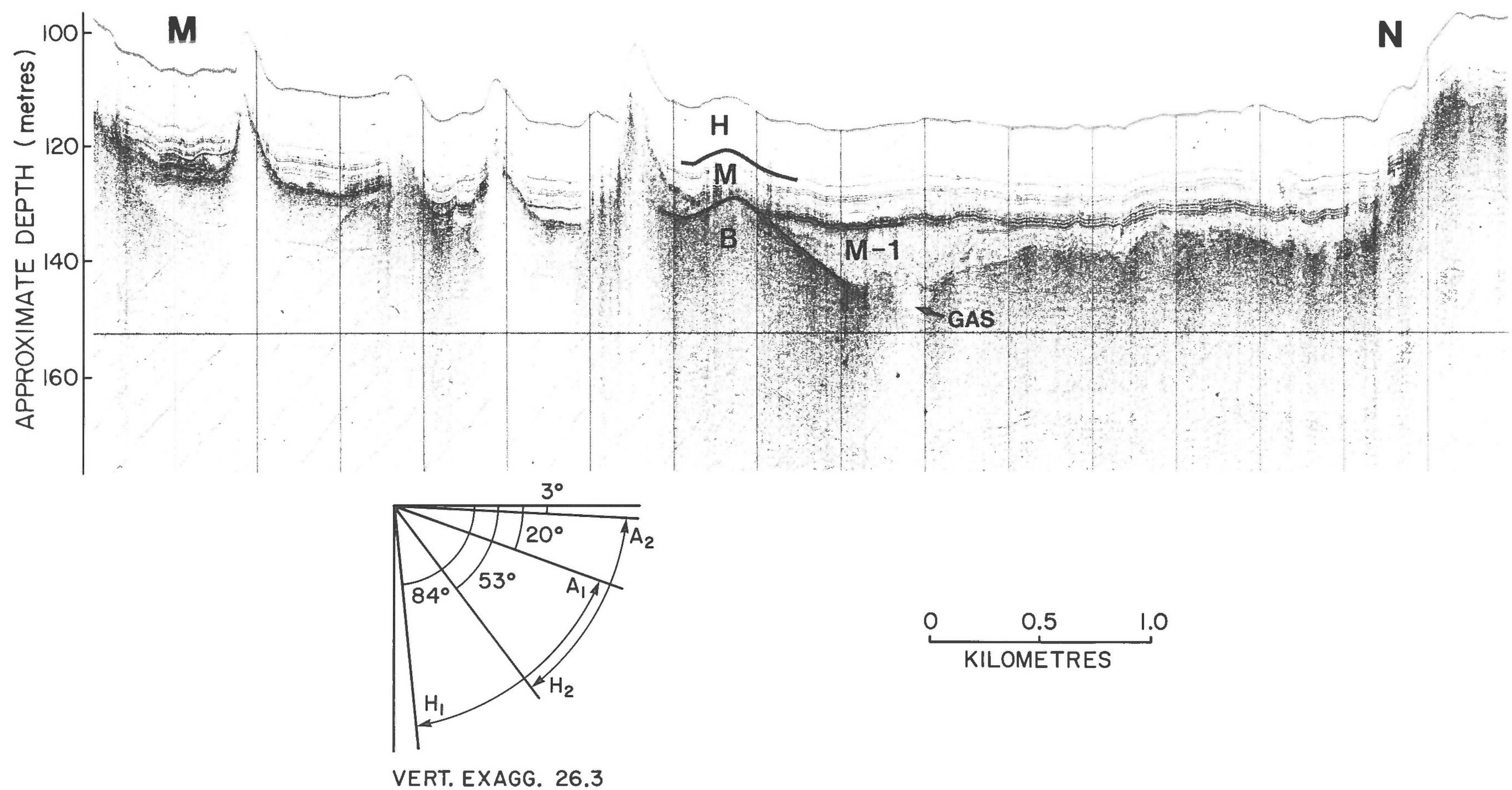


**Figure 17.** Seismic profile M-N.

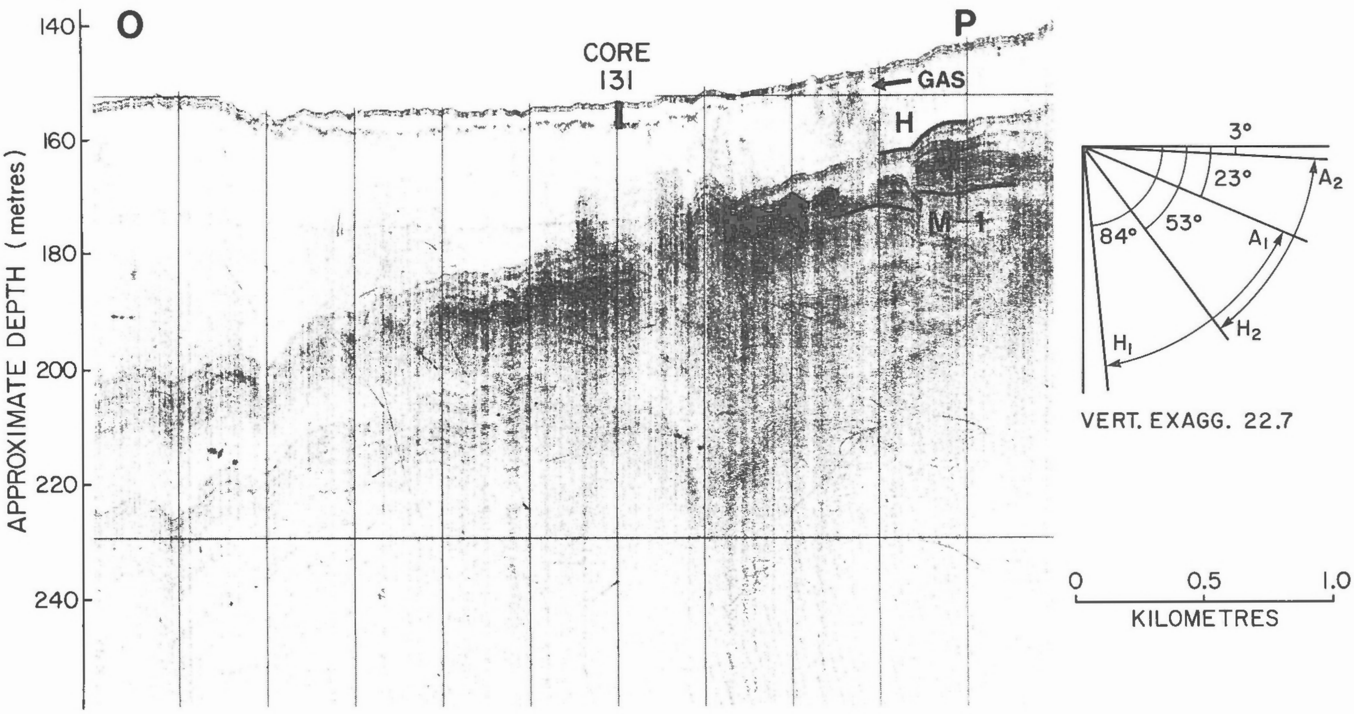


**Figure 18.** Seismic profile O-P.

from Unit M-1 to Unit M cannot be traced over most of the profile. Unit M consists of discontinuous blocks of acoustically laminated deposits separated by lenses and wedges of unstratified sediment. The acoustically transparent sediments of Unit H infills the basin with a maximum thickness of about 45 m near its centre. The zone of enhanced reflectors at about 5 m below the surface does not correspond to a significant lithologic discontinuity in Core 131 (see below).

**Profile Q-R** (Fig. 19)

The profile follows the bottom of a basin slope, approximately three kilometres off Epinette Peninsula in 140 m of water. The acoustic reflectors are irregular and discontinuous. The uneven and intermittent surface of the basal reflector (B) could be bedrock or a reflector surface within the sediment column. It is covered by disturbed sediments showing truncated and folded bedding. The boundaries of the acoustic units are highly speculative.

**Profile S-T** (Fig. 20)

The profile follows along the bottom of a narrow and deep basin which is enclosed by a shallow bank to the north, an escarpment of fine marine deposits off Epinette Peninsula to the south and the Naskaupi-Grand Lake delta to the west. The seafloor and strata rise towards the west, suggesting that the effluent of the Naskaupi River has been a major source of sediment.

The deepest acoustic facies consists of a uniform, dense, grey zone of incoherent reflectors that grade into the laminated reflectors towards the surface. The acoustic character of Unit M alternates between bands of closely stratified, high amplitude reflectors and zones of low amplitude incoherent reflectors. The lenses of unstratified sediment within Unit M are more common towards the top, forming a thick unstratified zone at the boundary with Unit H.

**Profile U-V** (Fig. 21)

The profile transverses the Churchill River prodelta in Goose Bay, and shows more than 40 m of acoustically well stratified deposits. Lying under these are mostly unstratified deposits with frequent intrusive features piercing the laminated beds above. These may represent diapirs. On the basis of the incoherent reflection characteristics, these deposits are interpreted as representing Unit M-1. Unit M is recognized by the dense, evenly spaced, high amplitude reflectors of flat-lying beds. The acoustic banding is less dense in Unit H, where stronger reflectors alternate with weaker ones. Within the upper five metres, there is a zone of acoustically transparent sediment sampled by Core 77 as silty clays changing to sandy clays towards the surface, where the acoustic banding is denser.

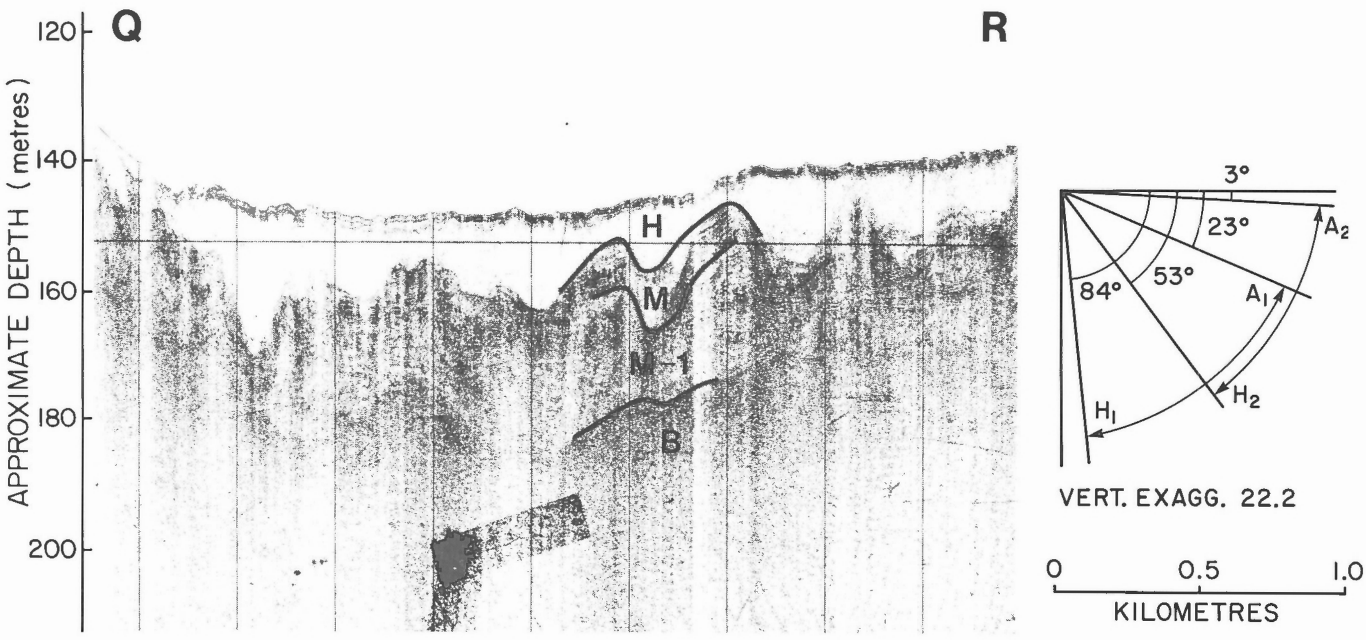


**Figure 19.** Seismic profile Q-R.

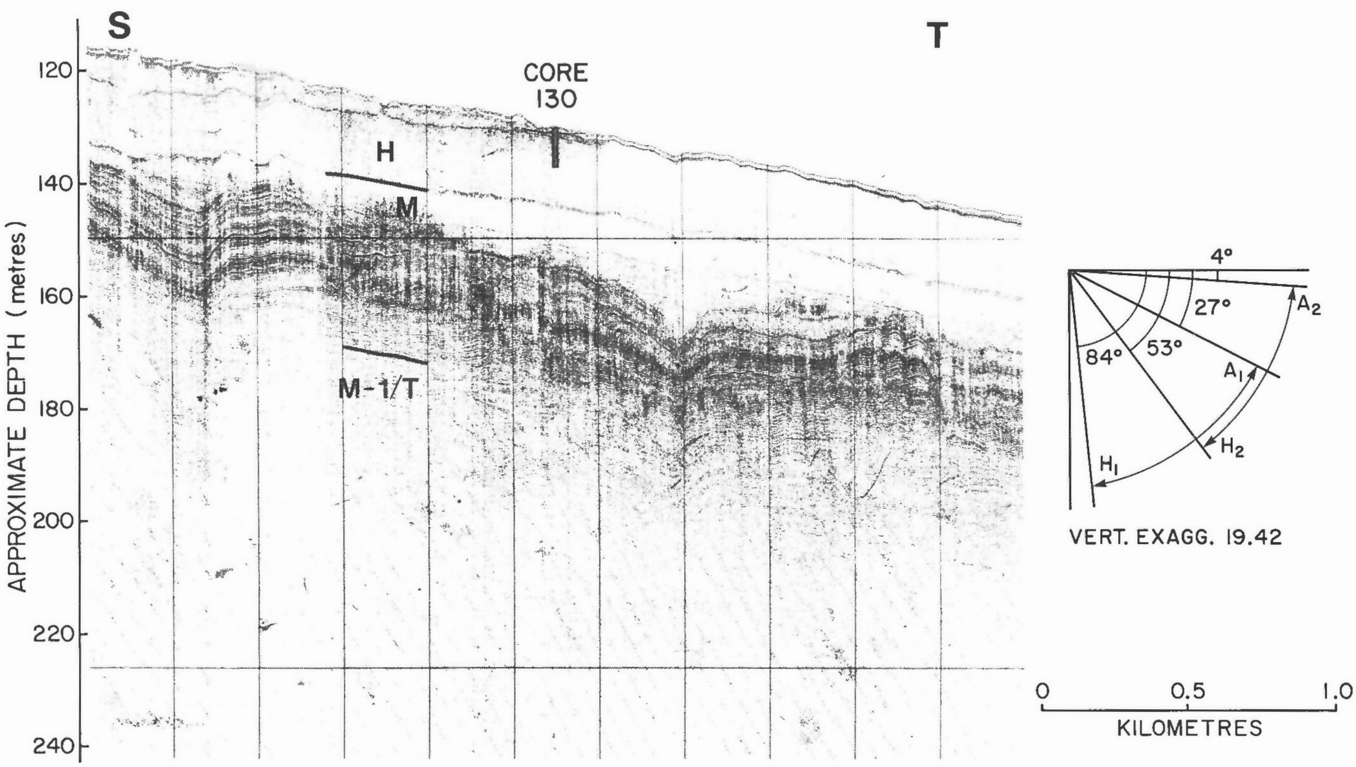


**Figure 20.** Seismic profile S-T.

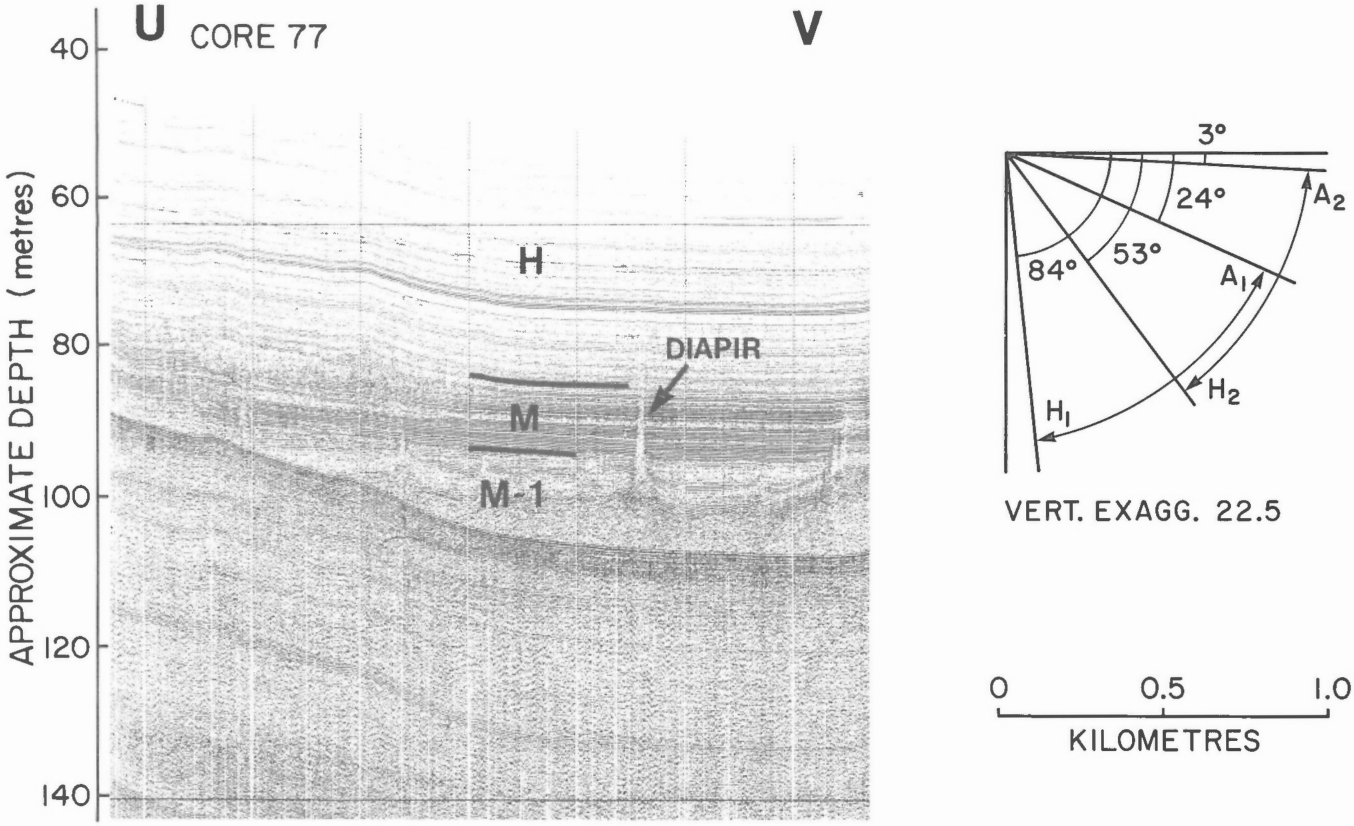


**Figure 21.** Seismic profile U-V.

### *Acoustic units: Summary*

The four acoustic units were defined by a major acoustic signature prominent within each unit: Unit H by transparency, Unit M by high-amplitude continuous acoustic laminae, Unit M-1 by discontinuous reflectors, and till by incoherent acoustic returns. On the basis of these criteria each unit was recognized to a varying degree of certainty in each of the seismic profiles despite the differences in the physiographic setting that the profiles represented. The definition of the units is based entirely on acoustic characteristics and therefore, the units could be time-transgressive.

The surface of the acoustic basement in Lake Melville is highly irregular with deep depressions, probably channels, and steep slopes. Postdepositional movement of sediments overlying the basement is evidenced by the disturbance of the strata in varying intensities, from offsets of linear reflectors to highly disorganized and discontinuous reflectors. The postdepositional reorganization of sediment strata complicates the interpretation of acoustic profiles. Primary or original sedimentary structures are mixed with secondary or postdepositional structures in varying degrees of intensity. In places where the postdepositional movement has been extensive, the boundaries between the stratigraphic units are arbitrary.

### *Acoustic basement*

The basement surface is recognized as bedrock or till. Where the till is less than two metres thick it cannot be identified as a separate unit.

The acoustic basement is seldom discernible below a sediment cover thicker than 100m and therefore the basement is not recognized in the deep basins (Profiles A-B, O-P and U-V, Figures 10, 11, 18 and 21). The acoustic characteristics of the basement surface vary, presumably reflecting the different lithologies of the bedrock and the overlying sediment in contact with it. A smooth and almost solitary reflector is assumed to represent bedrock in contact with waterlain sands or muds, e.g., the bedrock peaks in Profile M-N, Figure 17. A hummocky basement surface formed by tightly overlapping hyperbolae may be due to uneven bedrock surface or may indicate a veneer of coarse sediments with boulders overlying the bedrock (Profile C-D; Figure 12). Till-like deposits masking the bedrock surface could also be indicated by a zone of closely spaced, strong, incoherent reflectors with a diffuse upper boundary (Profiles E-F, G-H, K-L and M-N; Figures 13, 14, 16 and 17).

### *Till*

Most till is in isolated bedrock depressions on top of the ridges and possibly along basin flanks (Profile E-F; Figure 13) or bottom of M-1 on Profile A-B, Figure 11). Discontinuous till deposits recorded along profile K-L (Fig. 16) were sampled at 8.5-9.7 m in Core 132.

### *Unit M-1*

Unit M-1 is in contact with bedrock or till at the bottom of the sediment column. The reflectors in Unit M-1 commonly show abrupt facies changes; acoustically nearly transparent zones change to moderately dense incoherent reflectors (Profile C-D; Figure 12) or blocks of closely spaced parallel reflectors (Profile I-J; Figure 15). Here the lateral change in acoustic signature from closely spaced, parallel reflectors to a dense mass of homogeneous reflectors may be due to the sliding of sediment downslope, in the process disrupting the primary structures of the laminae. Along profiles K-L and M-N (Figs. 16, 17) lenses of low amplitude, homogeneous reflectors of unstratified sediment are separated by intermittent, single, high-amplitude continuous coherent reflectors. In the deep basins Unit M-1 appears in thick sequences of acoustically moderately transparent beds, interspersed with short semiparallel or irregular reflectors (Profiles O-P and S-T, Figures 18 and 20).

### *Unit M*

The relatively irregular acoustic signature of Unit M-1 sediments changes to continuous sequences of closely spaced, strong acoustic reflectors in Unit M. The acoustically stratified beds conform to the topography of underlying surfaces (Profile C-D; Figure 12), except in the deep basins, where the sediment strata are ponded in horizontal sequences (Profiles A-B and G-H; Figures 11 and 14). The acoustic character of the deposits alternates between bands of closely laminated, high-amplitude, continuous reflectors and zones of low-amplitude, incoherent reflectors (Profiles E-F and S-T; Figures 13 and 20). Occasionally it is possible to trace a single reflector or a group of reflectors over considerable distances (Profile C-D; Figure 12). In the basins, the stratified beds of Unit M are frequently separated by wedges of unstratified sediments originating from the flanks of the basins. These may represent gravity flows or slumps.

### *Unit H*

The surface Unit H consists of acoustically transparent sediments containing faint internal reflectors that vary in intensity, depending on depositional setting. In the distal basins of eastern Lake Melville and on the mid-lake ridges, the internal reflectors are subparallel and include occasional small, point-source reflectors, which probably indicate the presence of boulders (Profile M-N; Figure 17). The narrow basin in the western end of Lake Melville is closer to the sediment source and contains mostly unstratified sediments of Unit H with chaotic internal reflectors of basin- fill deposits (Profiles O-P and Q-R; Figures 18 and 19). The Unit H deposits facing the Churchill River delta in Goose Bay consist of a relatively thin sequence of highly stratified deposits (Profile U-V; Figure 21).

The boundary between Units H and M is sharp and occasionally consists of a single, continuous high-amplitude reflector (Profile C-D; Figure 12). Unit H overlies subsurface irregularities conformably (Profile M-N; Figure 17) and follows slopes of up to 4° with undisturbed internal reflectors (Profiles E-F and M-N; Figures 13 and 17). Occasionally at the bottom of major slopes, hummocky seabed surfaces and disturbed internal reflectors suggest sediment slumping (Profiles A-B and O-P; Figures 11 and 18). The Unit H sediments may pinch out exposing the underlying beds on top of a ridge (Profile K-L; Figure 16) or on a slope break (Profile I-J; Figure 15).

### *Sediment volumes*

The thickness of the sediments overlying the acoustic basement was estimated, assuming 1.5 km/s sound velocity. The isopach maps (Figs. 22, 23) show that sediments are thickest in the depressions, where they also are ponded. Outside the larger basins, the conformable sediments are normally less than 10 m thick, although in the smaller depressions the combined thickness could be over 10m. The thickest sections of Unit H are close to the river deltas off Epinette Peninsula, Northwest River and at the entrance to Goose Bay.

Sediment volumes were estimated with the aid of isopach maps. The estimates are minimal, because in the deeper basins the acoustic signals did not reach the basement. We assumed an average thickness of 40 m within those areas mapped with isopachs of more than 30 m. The area of the lake that was surveyed was 1660 $km^2$, thus the volume of the combined Unit M-1 and Unit M sediments is 20.39 x $10^9$ $m^3$ and Unit H sediments 13.66 x $10^9$ $m^3$.

## SEDIMENTS IN PISTON CORES

### *Lithology*

The colour of the mud in freshly cut cores is brown, with hues of grey, light olive grey and yellow. The major variations in the shades of the colour coincide with changes in sediment structures that are discriminated by X-rays. The X-radiographs of each core show an upper layer of bioturbated sediment that grades to laminated sediment towards the bottom, except in the basins where the bioturbated sediments may be too thick for the cores to reach the laminated zone (Figs. 24, 25). The bioturbated sediment also shows outlines of burrows, anastomosing strands of pyrite and molluscan shells. The laminae are

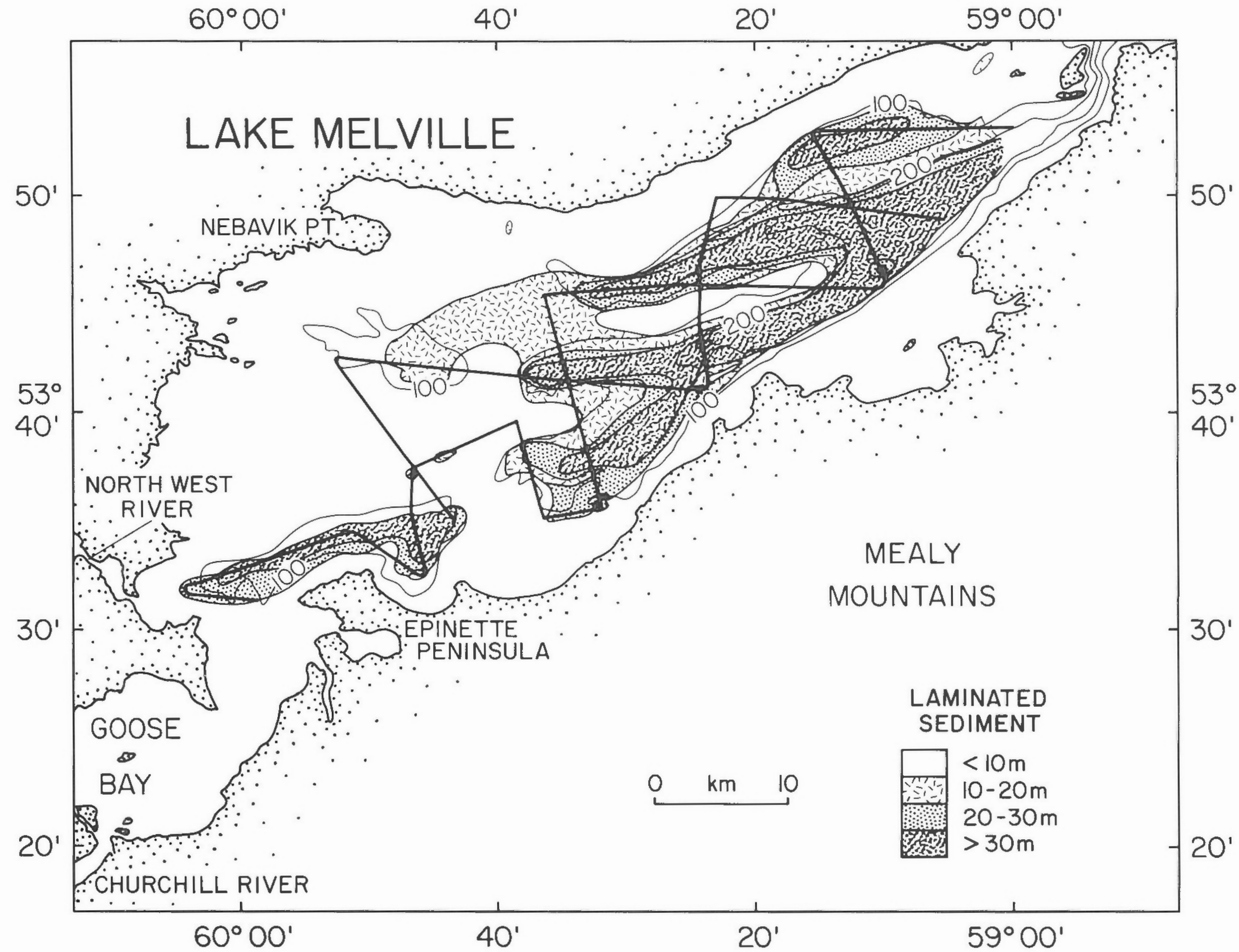


**Figure 22.** Isopack map showing the estimated thickness of the laminated glaciomarine sediment.

sharp or diffuse. The diffuse laminae may be an artifact as a result of the direction of X-rays not being the same as the plane of the laminae. Thus, horizontal laminae are sharp, but fine beds deposited at an angle may not always show a sharp image on X-radiographs. The bottom of core 132 penetrated about one metre of reddish-brown gravel. In addition, pebble-sized clasts are scattered throughout the cores. These pebbles occasionally show evidence in X-radiographs of having sunk through the laminated mud, e.g. Core 132, and are therefore interpreted as dropstones from sea ice or glaciers.

### *Downcore averages and variability of sediment types*

Sediment size analysis was carried out on subsamples at regular intervals downcore and the results averaged in Table 2. Clay dominates, except for Core 77 close to the Churchill River Delta in Goose Bay, where silt is the major sediment type. Sand is highest in Core 1 from a ridge and gravel occurs in amounts greater than 0.1 per cent only in two cores.

The coefficient of variation (CV) estimates the relative downcore variability of the mean for each sediment size fraction. In the two basins (cores 109, 111, 130 and 131), the CV is low for clay and silt, but high for sand (Table 2). In these cores the amount of mud (silt and clay) changes very little downcore. Cores 128 and 2 collected from the central basin show considerably higher CV for all sediment types and it will be shown below that these cores penetrate older strata than the other basin cores. The highest downcore variability was recorded in the ridge Core 1 and Goose Bay Core 77.

### *Downcore averages and variability of size classes*

In most of the basin cores a typical grain size profile at one phi intervals shows progressively increasing mean percentages towards the finer size fractions (Figs. 26, 27, 28); exceptions are Core 109 (Fig. 26) taken next to Core 111 which shows a fine silt mode, and Core 131 (Fig. 28) where a coarse silt mode is prominent between 4 and 5 phi. The standard deviation of the mean at these modes is

**Table 2.** Downcore averages of major sediment size classes.

| Core | % Clay | | | % Silt | | | % Sand | | | % Gravel | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | S | CV | X | S | CV | X | S | CV | X | S | CV |
| 109 | 53.9 | 3.4 | 6 | 43.1 | 3.3 | 7 | 1.1 | 0.6 | 53 | 0 | 0 | 0 |
| 111 | 61.5 | 3.3 | 5 | 37.0 | 3.1 | 8 | 1.4 | 0.4 | 29 | 0 | 0 | 0 |
| 128 | 65.5 | 11.0 | 17 | 31.8 | 10.0 | 31 | 2.4 | 0.8 | 33 | 0.4 | 1.0 | 250 |
| 2 | 69.3 | 8.9 | 13 | 28.7 | 8.2 | 29 | 1.9 | 1.2 | 63 | 0 | 0 | 0 |
| 130 | 64.2 | 2.4 | 4 | 34.0 | 2.5 | 7 | 1.8 | 0.4 | 22 | 0 | 0 | 0 |
| 131 | 52.4 | 3.6 | 7 | 45.3 | 2.3 | 5 | 2.3 | 2.6 | 113 | 0 | 0 | 0 |
| 1 | 57.5 | 21.7 | 38 | 31.2 | 11.9 | 38 | 11.2 | 24.9 | 222 | 0.2 | 0.4 | 200 |
| 77 | 37.3 | 16.5 | 44 | 54.7 | 13.8 | 25 | 8.0 | 4.5 | 56 | 0 | 0 | 0 |

X = mean, S = standard deviation, CV = coefficient of variation.

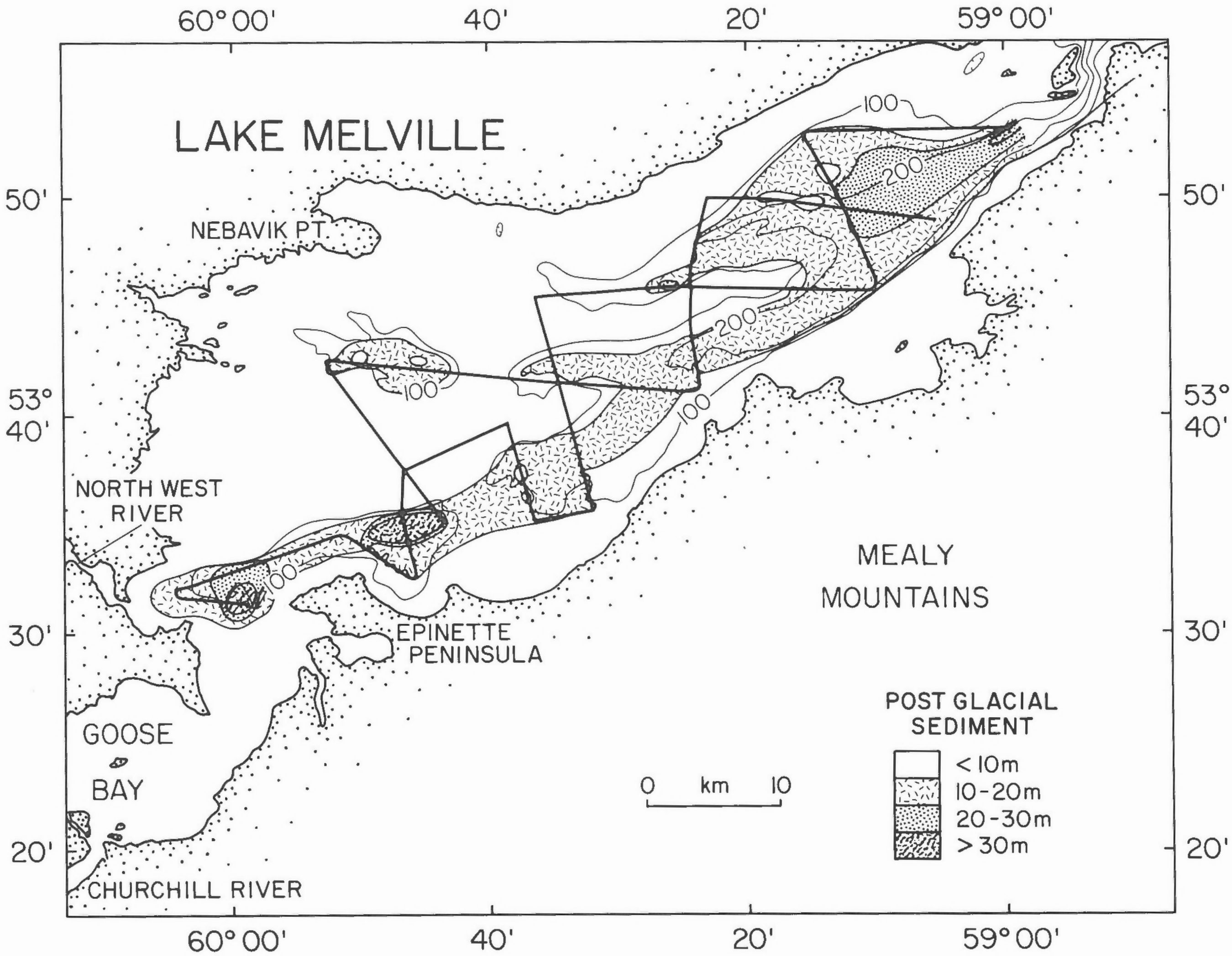


**Figure 23.** Isopack map showing the estimated thickness of postglacial sediment.

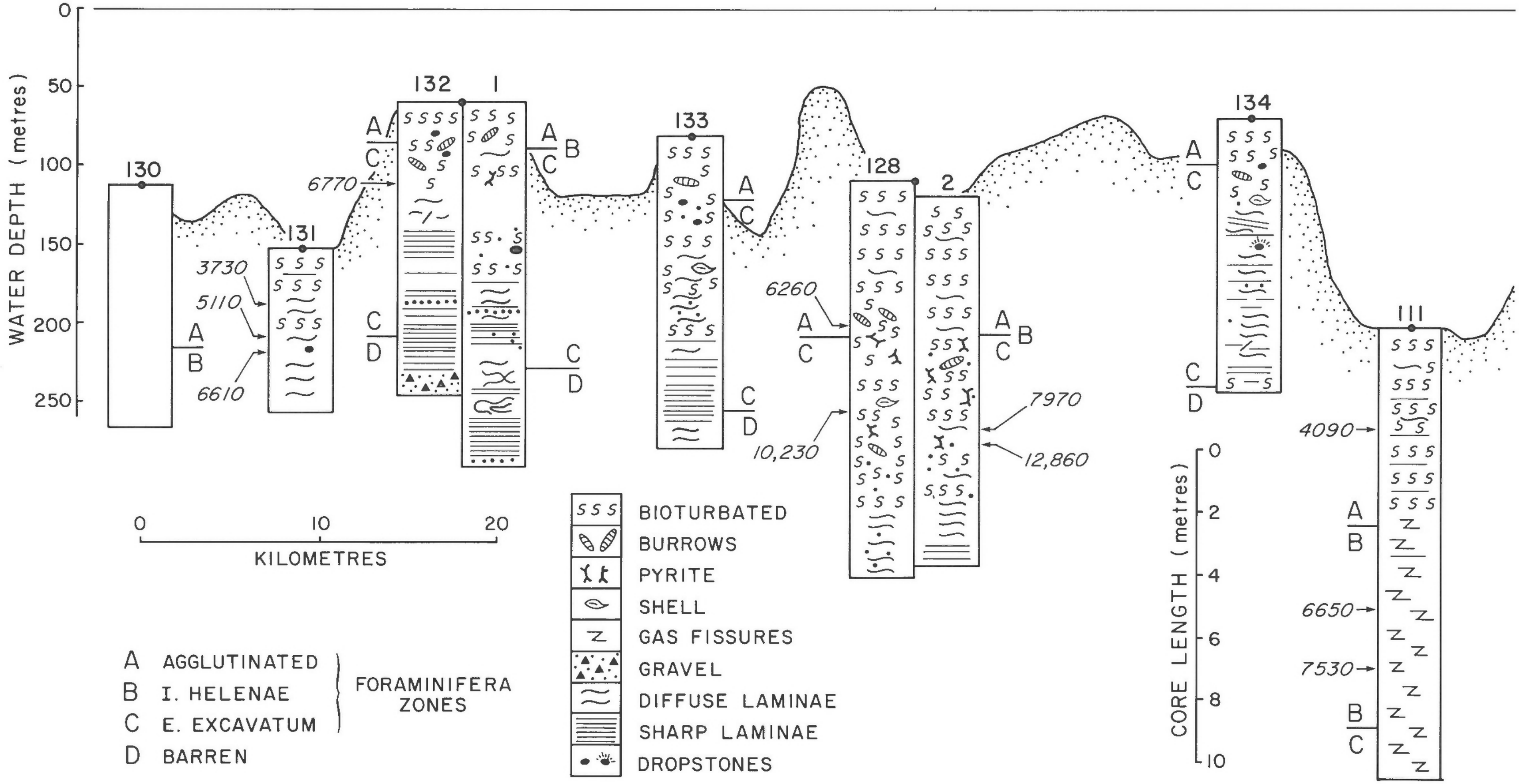


**Figure 24.** Interprettion of core X-rays and radiocarbon dates along a transect through Lake Melville.

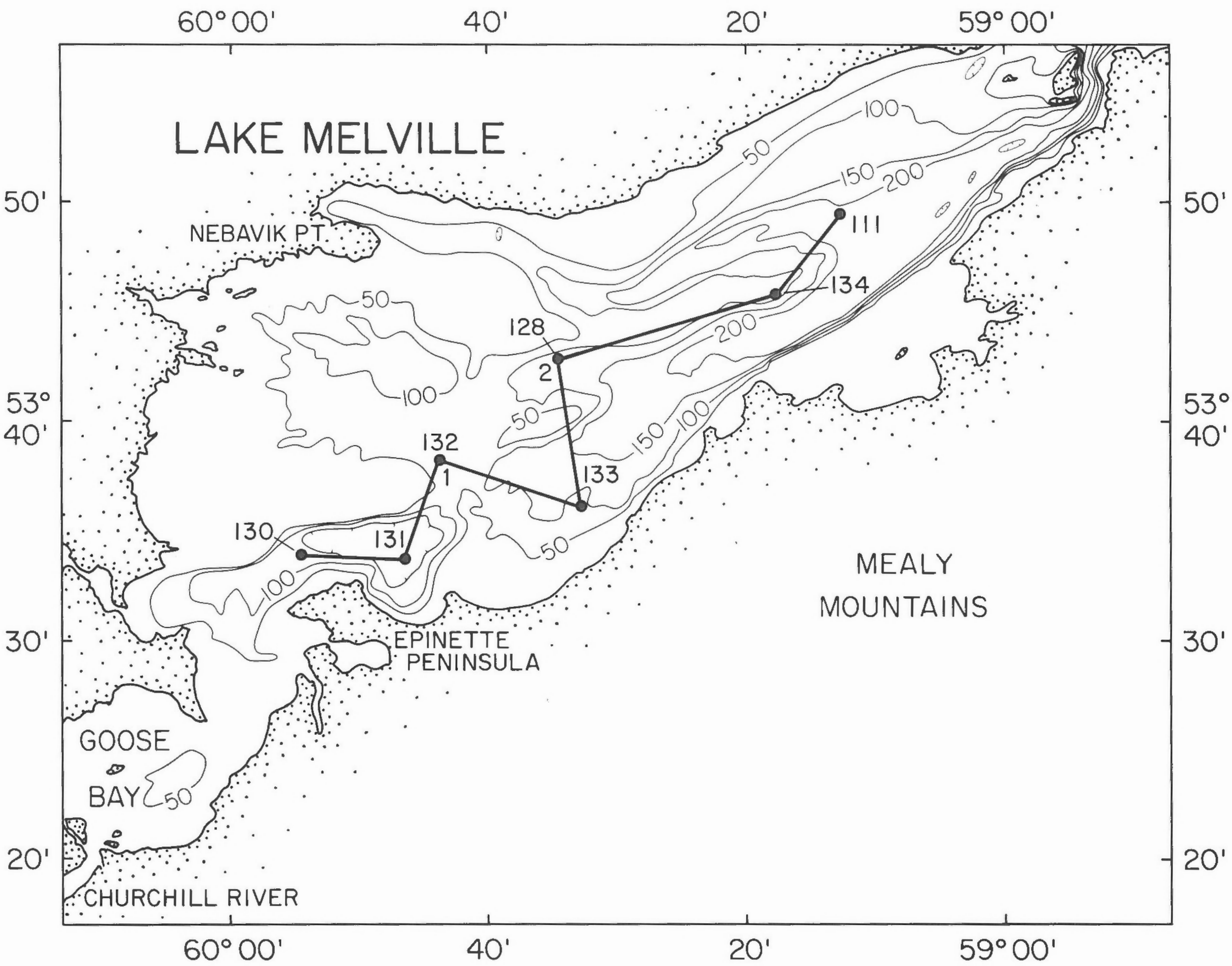


**Figure 25.** Position of the transect.

not high and is smaller in the case of Core 109, indicating that the silt modes are prevalent throughout the cores. The greatest standard deviations in the basin cores are between 4 and 5 phi (cores 2, 109 and 128) or 8 and 9 phi (cores 130 and 111). In Core 131 the greatest variability is in the fraction coarser than 4 phi.

Sediments in the two cores taken outside the basins are coarser with a distinct sand mode between 1 and 2 phi in Core 1 and two silt modes in Core 77 from Goose Bay (Fig. 29). The standard deviations are much larger in each size fraction, indicating a changing sedimentary environment or sediment supply within the time interval represented by the cores.

### *Downcore sediment size spectra*

Core 77 from Goose Bay provides information on grain size distribution in a prodelta environment (Fig. 32). Within the upper 250 cm the mean size of the sediment fluctuates between coarse silt and fine sand and there is an almost total absence of sediments finer than 9 phi. Below 250 cm the sediment becomes finer and the clay content increases, reaching values similar to the basin sediments. The size spectrum also spreads towards the coarse end with increasing percentages of sediment coarser than 2 phi.

Sediments in Core 1 taken from the central ridge alternate between very fine muds similar to those of the basins and well sorted sands (Fig.33). There are three types of distinct grain size spectra: (1) fine clay with total absence of sediment coarser than 3 phi, e.g. 100-275 cm, 675-975 cm and 1100-1125 cm. The two deeper downcore intervals are slightly coarser and may contain a coarse or fine silt mode; (2) fine clay with a sand mode, e.g. 0 cm and 325-450 cm; and (3) well sorted sand with clay component almost totally absent, e.g. 575 cm and 1050-1075 cm.

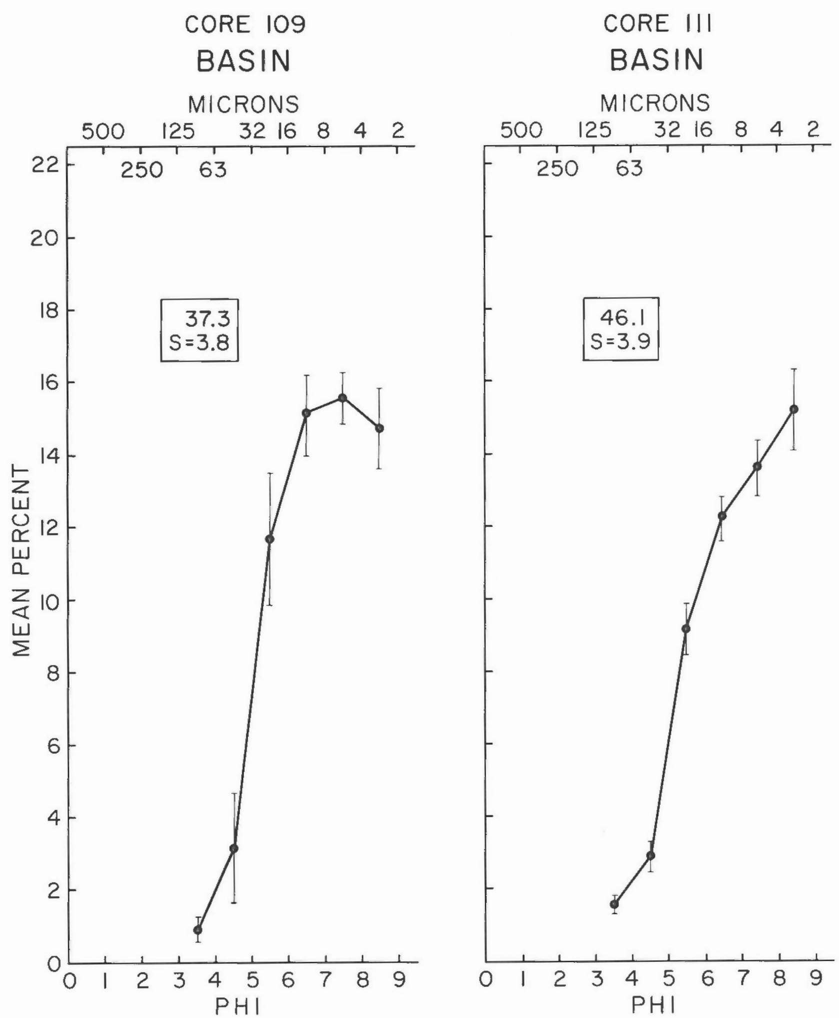


**Figure 26.** Mean grain size distribution in sediment cores 109 and 111 averaged over downcore samples. Vertical bars are standard deviation of the means. The boxed-in numbers are mean percent and standard deviation of the mean for sediments finer than 9 phi.

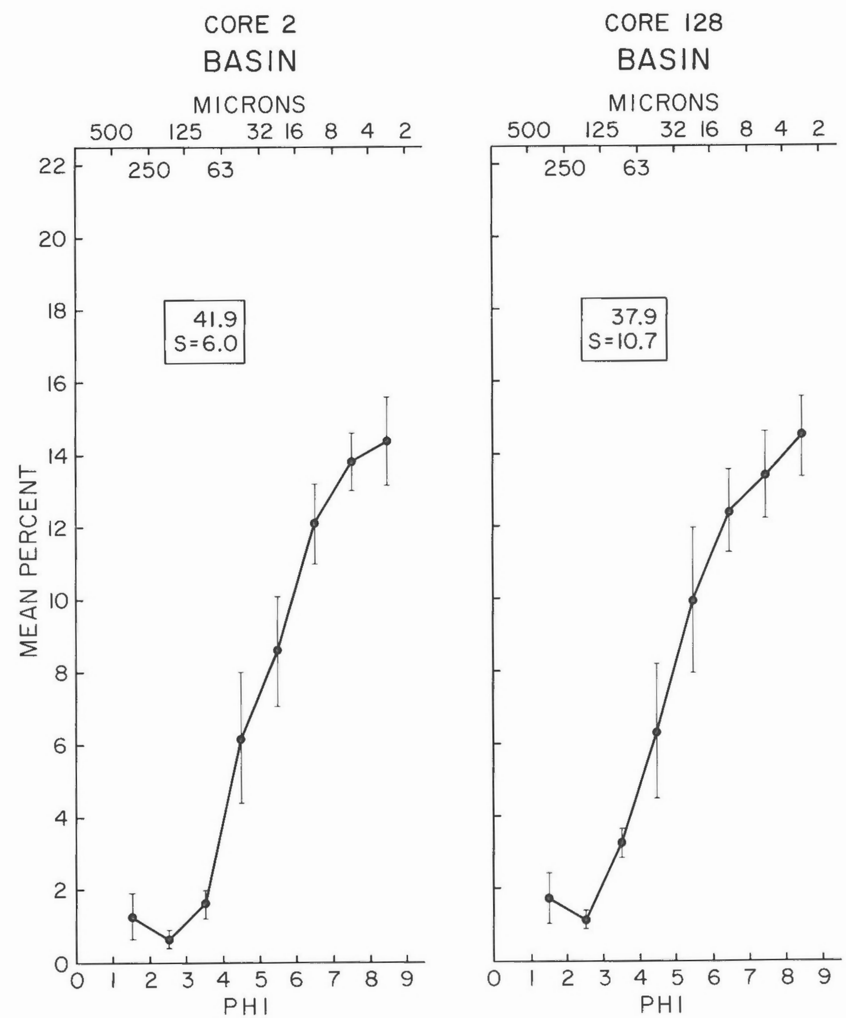


**Figure 27.** Mean grain size distribution in sediment cores 2 and 128.

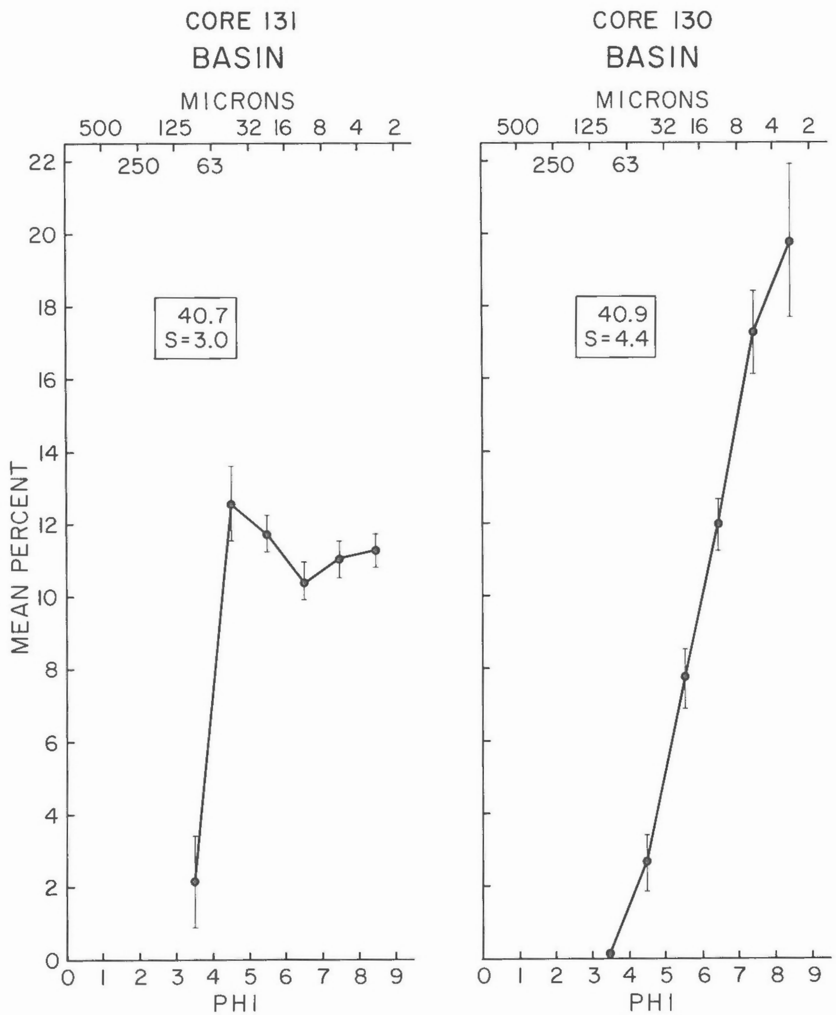


**Figure 28.** Mean grain size distribution in sediment cores 131 and 130.

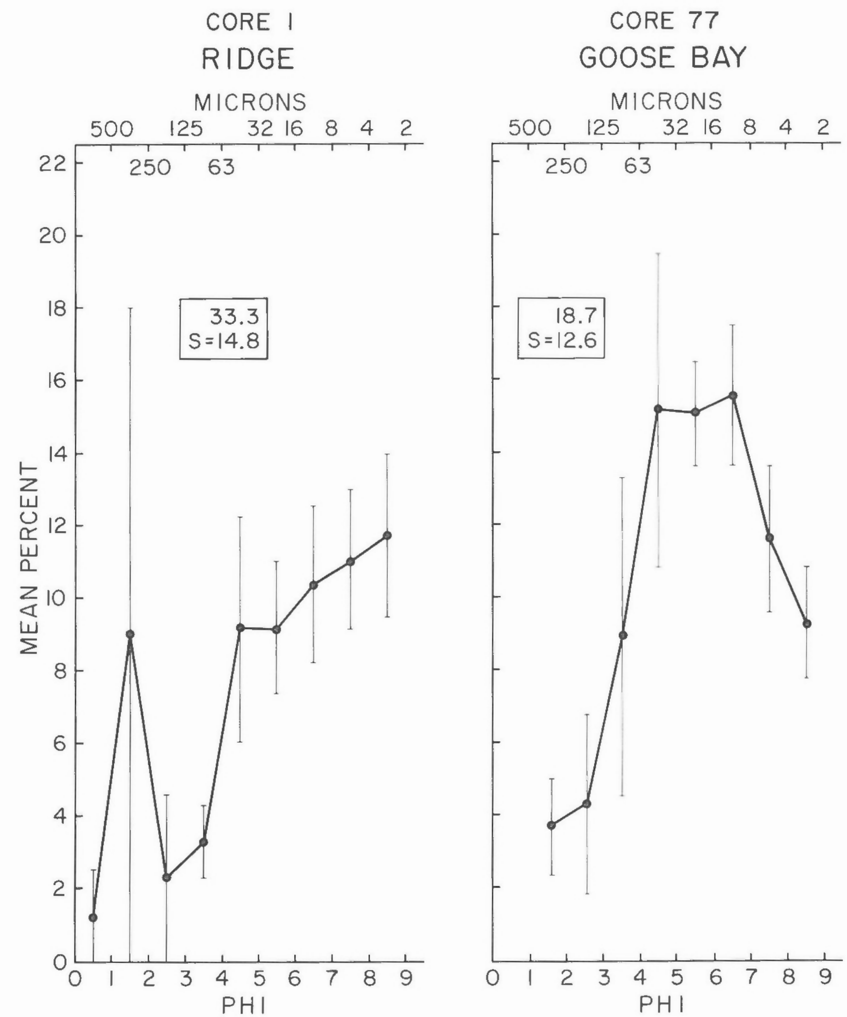


**Figure 29.** Mean grain size distribution in sediment cores 1 and 77.

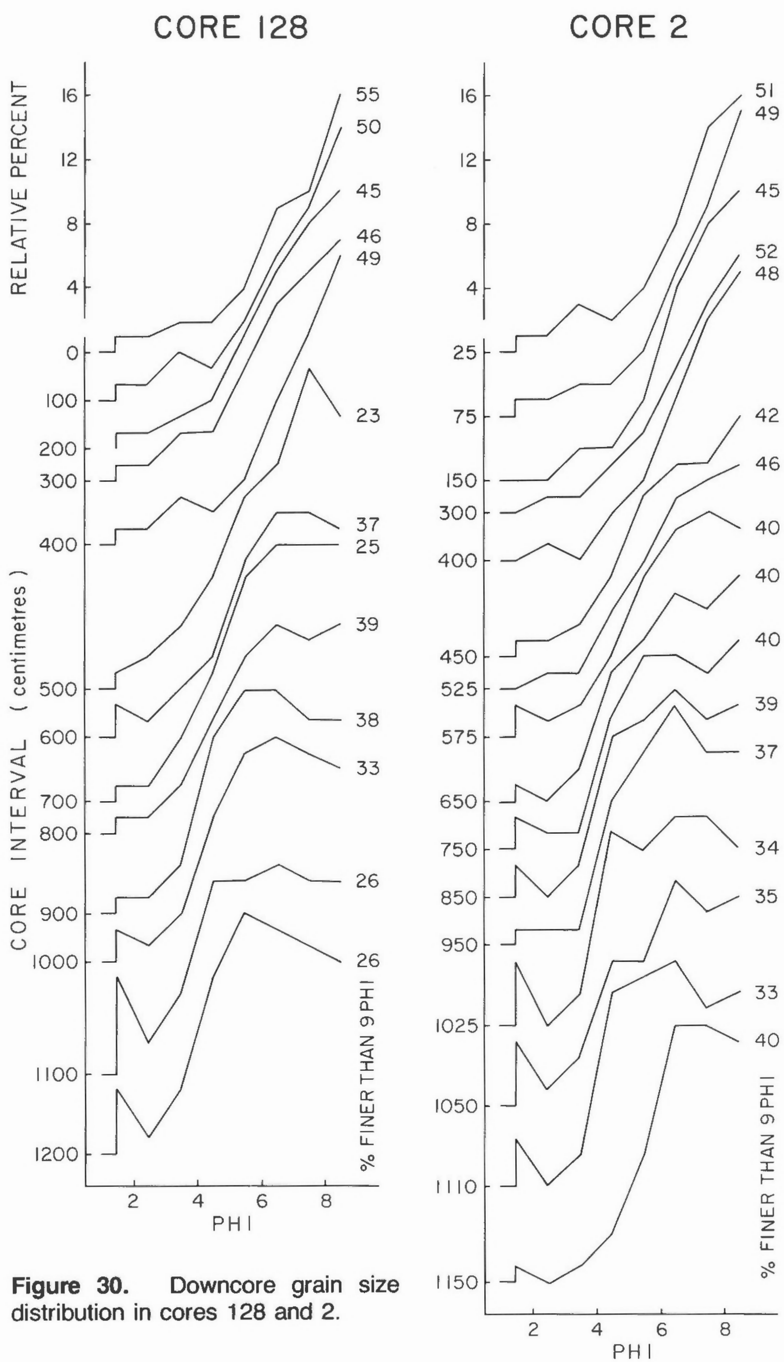


**Figure 30.** Downcore grain size distribution in cores 128 and 2.

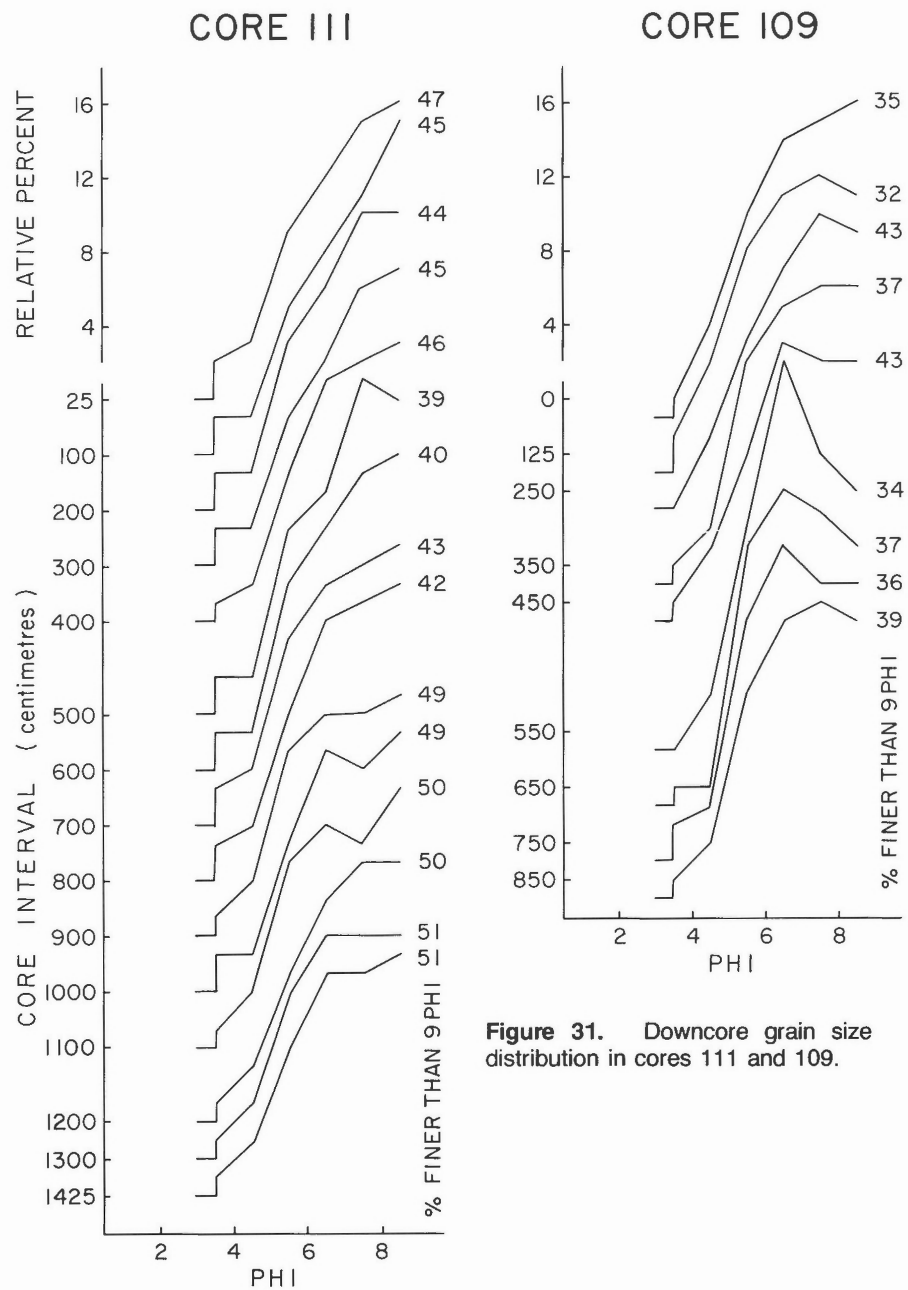


**Figure 31.** Downcore grain size distribution in cores 111 and 109.

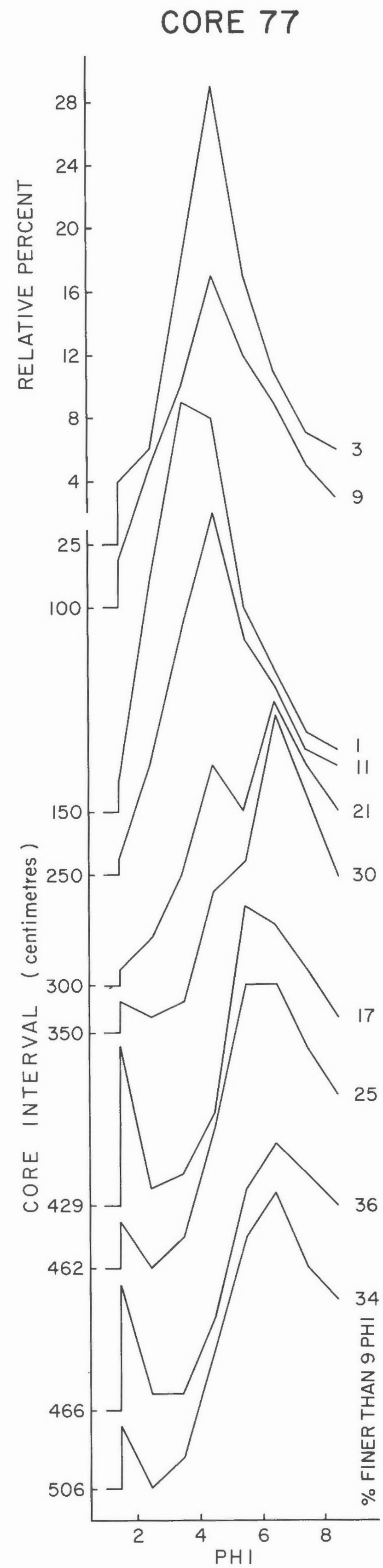


**Figure 32.** Downcore grain size distribution in Core 77.

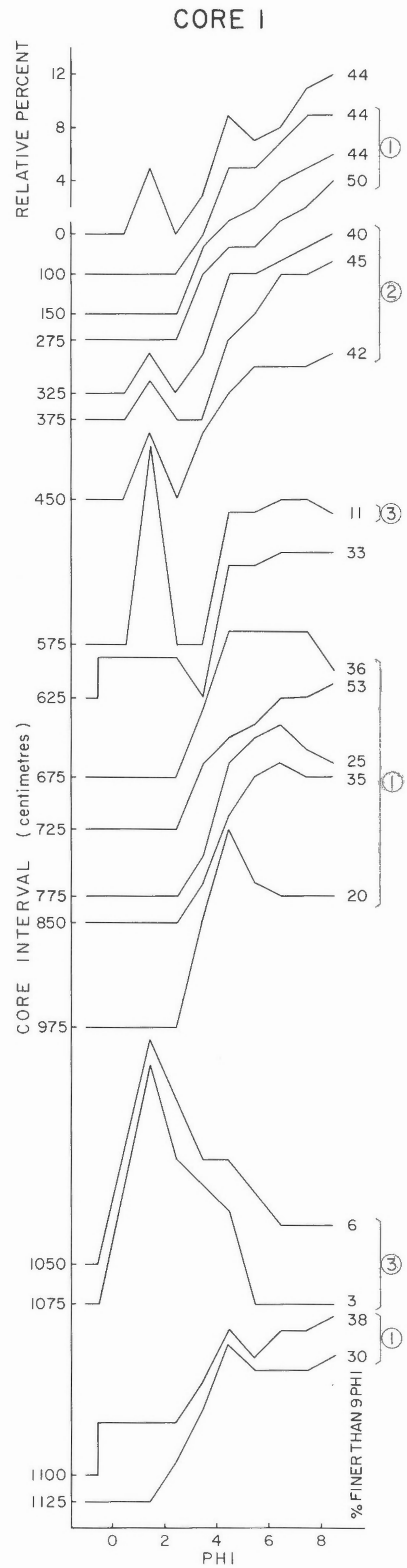


**Figure 33.** Downcore grain size distribution in Core 1. Circled numbers represent sediment facies explained in text.

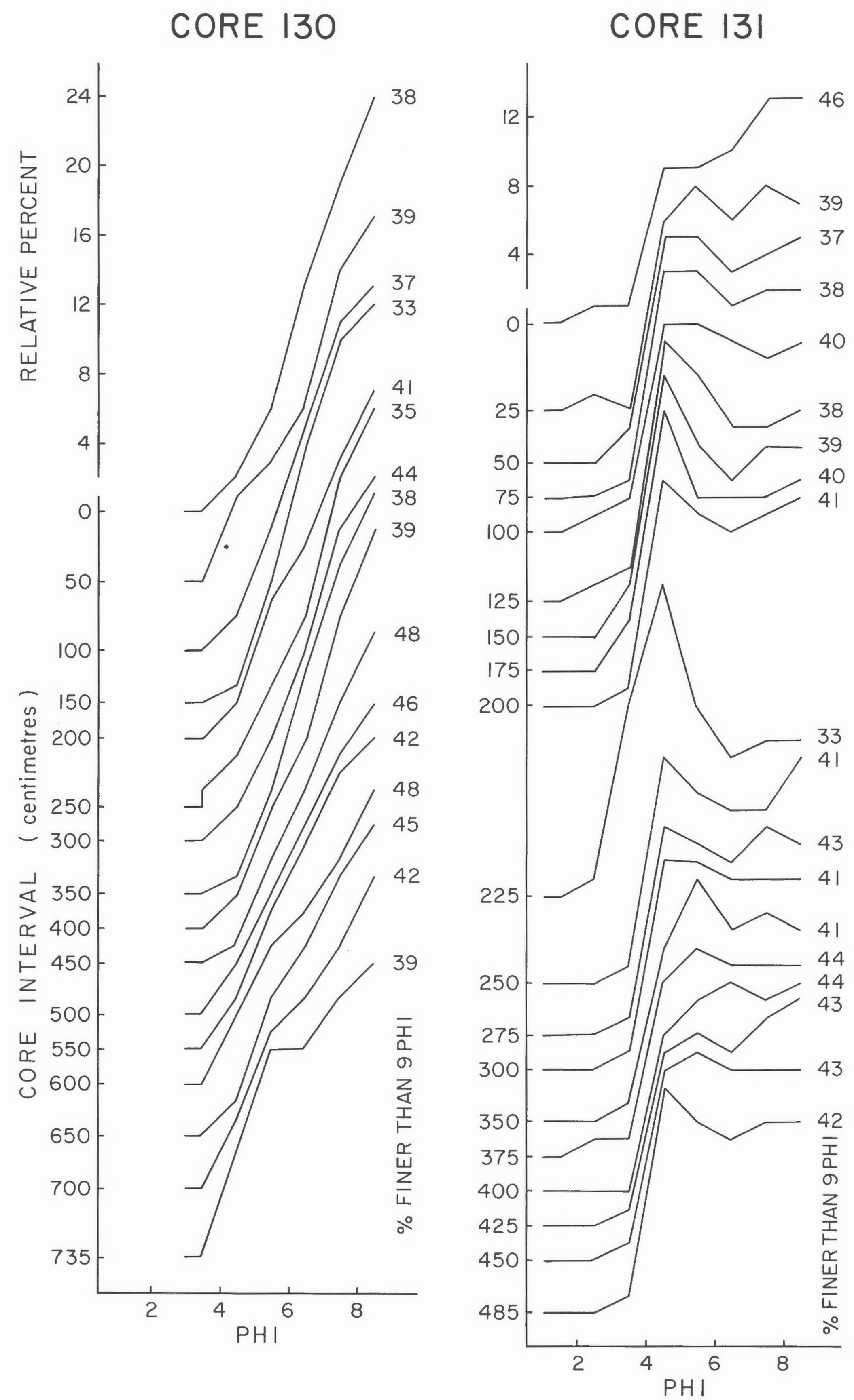


**Figure 34.** Downcore grain size distribution in cores 130 and 131.

In the basins the downcore trend for sediment grain size distribution varies from sediments either becoming coarser with depth or there is no significant change. Cores 128 and 2 were taken close to each other and show similar downcore trends (Fig. 30). The upper 400 cm of each core is very fine clay, but silt percentages increase below 5 metres. Below 10m the percentage of grains coarser than 2 phi also increases. Cores 111 and 109 from the basin show slight differences in grain size distribution downcore, although they were taken within a few kilometres of each other (Fig. 31). In Core 111 only a few intervals show a silt mode, but in Core 109 a silt mode between 6 and 8 phi is present in all intervals analysed below 125 cm. A persistent coarse silt mode is also present throughout Core 131, but very fine clay dominates the sediments in Core 130 (Fig. 34).

## FORAMINIFERA

### *Accuracy of foraminiferal data*

Species response to the environment is the primary factor assumed to be responsible for the specific characteristics of foraminiferal assemblages in the sediment. Other factors are recognized, such as post-mortem redistribution of tests on the seafloor and dissolution of tests in the natural environment or in sample storage. These "error" factors are assumed to be negligible, because in most cases there is no evidence to the contrary. Complicated sampling and analytical procedures are required to test the magnitude of the error factors. Often this is not practical or possible.

Schnitker et al. (1980) reported that foraminifera were destroyed in sediment samples allowed to dry slowly for three months at room temperature. The process dissolves carbonate and forms gypsum. The same experiment also recorded the loss of agglutinated tests and it was suggested that bacterial action on the test linings was responsible. We are discussing error factors in our foraminiferal data due to a possible destruction of tests in storage as a result of chemical reactions, errors introduced by the difference in the handling of samples and the patchiness of foraminifera on the seafloor.

Patchiness in foraminiferal numbers in the sediment is demonstrated by the comparison of cores 109 and 111. According to the seismic records, the two cores were collected approximately 0.5 km apart in a similar environment. Both had been in storage for 81 days under controlled humidity and a temperature of 4°C. Sediment washing and picking of foraminifera was carried out by the same people under similar circumstances. Because the two cores were sampled at the same time and subsequently handled under similar conditions, the considerable difference between the total numbers in each of the core intervals (Figs. 35, 36) is most likely due to patchy distribution of foraminifera in the sediment.

The extent of errors due to poor preservation of foraminifera in storage or due to differences in handling is demonstrated in Table 3. Cores 1 and 132 and 2 and 128 are two pairs, each retrieved at the same localities on the basis of radar fixes with accuracy of 200 m. Cores 1 and 2 were subsampled twice (I and II) at the same interval: I 24 hours after coring and II six months later. Subsamples I were washed and dried on board *CSS Hudson* and II were washed in the laboratories at the Bedford Institute of Oceanography by different personnel. The counts of calcareous (C) and agglutinated (A) foraminifera are compared between subsamples I and II of Core 1 and between Core 132, which had been in storage for 3.5 years. Similar comparisons are made between I and II of Core 2 and Core 128, which had been in storage for 2.5 years.

The results in Table 3 show that in Core 1 both the calcareous and arenaceous foraminifera were more abundant in subsamples that had been stored for six months. In Core 2 the comparison between subsamples I and II are inconclusive. The numbers suggest that there is no evidence for the destruction of foraminifera during the six months storage and that the II samples were washed more carefully at BIO. In this case the handling error overrode any possible error due to dissolution.

The comparison of counts between cores 1 and 132 suggests that dissolution could have taken place in Core 132 during the 3.5 years of storage. Both the calcareous and agglutinated numbers are significantly lower than the largest counts in Core 1. However, dissolution is not demonstrated by the comparison of counts between cores 2 and 128. In the upper half of Core 128 the numbers are significantly lower than in Core 2, but in the lower half the numbers are significantly higher. The lack of consistency in these comparisons suggests that local patchiness of foraminifera in the sediments is a larger source of error than dissolution or sample handling.

### *Faunal zones*

Foraminifera are represented by 33 major species from the eleven cores inspected (Table 4). Major species are those that rank up to at least 75% of species present in a sample or occur at least at the 2% level. Relative percentages of species were not calculated in samples where foraminifera occur less than one test per gram of sediment. Most sample intervals contain 3 or 4 major species. The major species present may change downcore (Figs.35 to 45).

Faunal zones were defined by the dominance of species. The upper Zone A is dominated by the agglutinated species *Reophax fusiformis*, *Spiroplectammina biformis*, *Saccammina atlantica*, *Cribrostomoides crassimargo* and the calcareous species *Cassidulina reniforme*. Zone B species are dominated by the calcareous *Islandiella helenae*, *Buccella frigida* and *Protelphidium orbiculare*. Towards the bottom of Zone B, *Elphidium excavatum* f. *clavata* also appears as a major species and the Zone B/C boundary is placed where *E. excavatum* becomes dominant. Zone D is defined by the absence of foraminifera.

## Basins

Cores 111 and 109 were collected from the eastern basin approximately 500 m apart and are similar in terms of major faunal characteristics (Figs. 35, 36), although the absolute numbers are different. The bottom of Zone A is placed at 600 cm in Core 111 and at 450 cm in Core 109. The B/C boundary is at 1250 cm in Core 111. However, as the numbers of foraminifera per sample are reduced, *Triloculina oblonga* becomes a dominant species towards the bottom of Core 111. The base of Core 109 is close to the top of Zone C.

Cores 128 and 2 were taken in the central basin of Lake Melville and are considered as a pair (Figs. 38, 39). The cores are similar in terms of major faunal characteristics, except that Core 2 contains relatively high ratios of *I. helenae* between 150 and 275 cm. Thus, there are traces of Zone B characteristics between Zones A and C in Core 2, which are not present in Core 128. Zone A in

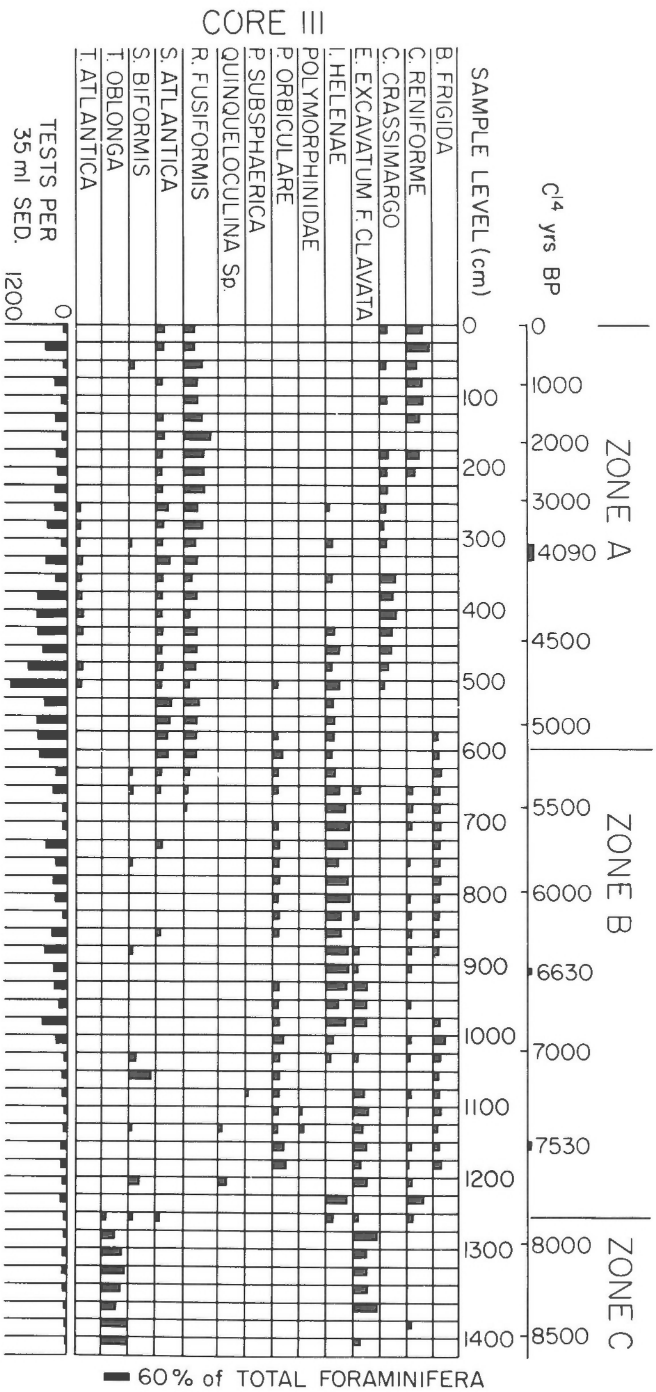


Figure 35. Foraminifera in Core 111. Zones A, B, C and D are defined in text.

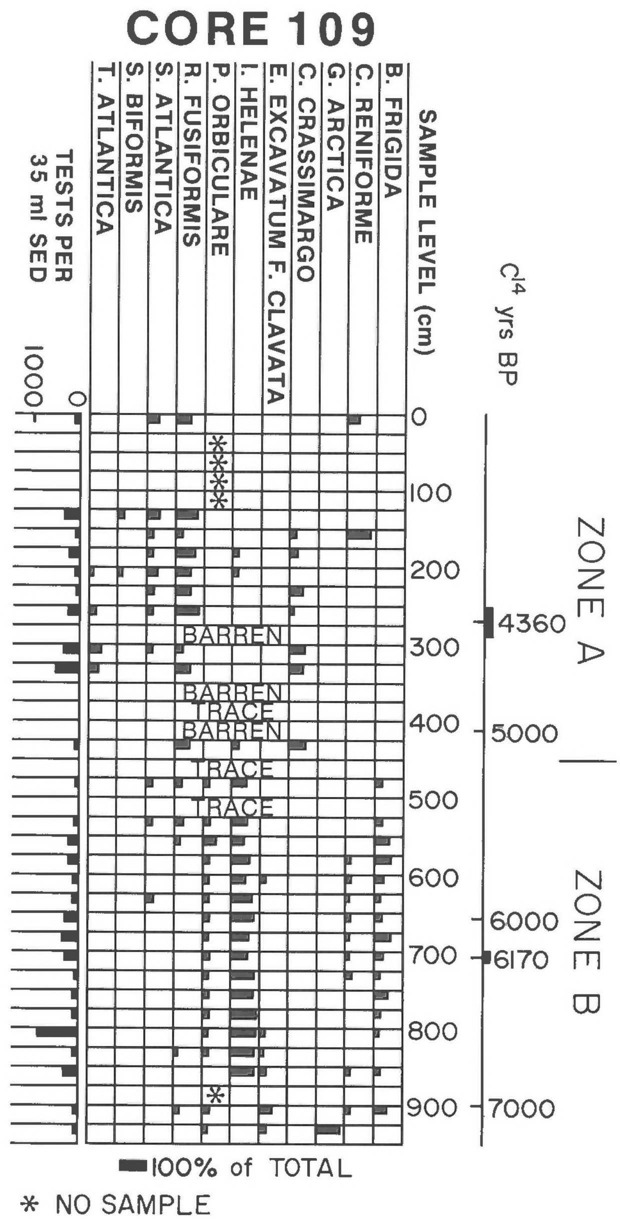


Figure 36. Foraminifera in Core 109.

**Table 3.** Calcareous (C) and arenaceous (A) Foraminifera (Tests/ml) in cores 1 and 2 subsampled within 24 hours (I) and six months (II). Core 128 was sampled after 2.5 years and Core 132 after 3.5 years in storage.

| | Core 1 | | | | Core 132 | | Core 2 | | | | Core 128 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Interval | I | | II | | | | I | | II | | | |
| (cm) | C | A | C | A | C | A | C | A | C | A | C | A |
| 0 | 0 | 2 | 4 | 61 | 0 | 6 | — | — | 4 | 10 | 1 | 1 |
| 25 | 5 | 25 | 5 | 82 | 0 | 21 | 4 | 11 | 7 | 61 | 0 | 1 |
| 50 | 2 | 1 | 13 | 87 | 0 | 8 | 4 | 11 | 1 | 8 | 0 | 1 |
| 75 | 10 | 24 | 6 | 48 | 0 | 14 | 4 | 26 | 2 | 12 | 0 | 0 |
| 100 | 15 | 9 | 13 | 41 | 0 | 16 | | | | | | |
| 125 | 17 | 9 | 25 | 12 | 0 | 2 | 3 | 11 | 2 | 10 | 0 | 0 |
| 150 | 24 | 6 | 25 | 16 | 0 | 0 | 3 | 13 | 5 | 12 | 1 | 1 |
| 175 | 14 | 2 | 10 | 5 | 1 | 0 | 8 | 7 | 9 | 25 | 0 | 1 |
| 200 | 16 | 5 | 20 | 9 | 17 | 2 | 10 | 8 | 3 | 10 | 0 | 0 |
| 225 | 24 | 5 | 40 | 10 | 8 | 0 | 17 | 7 | 7 | 4 | 0 | 0 |
| 250 | 9 | 7 | 9 | 9 | | | 12 | 5 | 8 | 3 | 1 | 4 |
| 275 | 12 | 2 | 20 | 3 | 4 | 0 | 13 | 2 | 7 | 3 | 0 | 1 |
| 300 | 3 | 8 | 4 | 22 | 0 | 0 | | | | | | |
| 325 | 10 | 8 | 32 | 66 | 0 | 0 | 13 | 7 | 10 | 16 | 0 | 0 |
| 350 | 3 | 1 | 8 | 6 | 0 | 0 | 23 | 0 | 7 | 0 | 0 | 1 |
| 375 | 8 | 0 | 10 | 2 | 0 | 0 | 6 | 0 | 5 | 1 | 0 | 0 |
| 400 | 1 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 2 | 9 | 0 | 0 |
| 425 | 9 | 0 | 7 | 2 | 0 | 0 | 5 | 2 | 3 | 5 | 0 | 0 |
| 450 | 7 | 0 | 23 | 4 | 0 | 0 | 7 | 3 | 9 | 1 | 0 | 3 |
| 475 | 4 | 0 | 18 | 2 | 0 | 0 | 17 | 2 | 3 | 1 | 1 | 5 |
| 500 | 3 | 0 | 4 | 0 | 0 | 0 | | | | | | |
| 525 | 11 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 1 | 0 | 9 | 0 |
| 550 | 3 | 0 | 4 | 0 | 0 | 0 | 3 | 0 | 6 | 1 | 10 | 0 |
| 575 | | | | | | | 16 | 1 | 12 | 1 | 7 | 2 |
| 600 | 1 | 0 | 0 | 0 | 0 | 0 | 20 | 1 | 5 | 0 | 27 | 1 |
| 625 | 3 | 0 | 2 | 0 | 0 | 0 | 8 | 1 | 4 | 0 | 30 | 4 |
| 650 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | | | 32 | 0 |
| 675 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 1 | 6 | 0 | 13 | 1 |
| 700 | 1 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 4 | 0 | 18 | 1 |
| 725 | 0 | 0 | 1 | 0 | 1 | 0 | 7 | 0 | 3 | 0 | 13 | 0 |
| 750 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 5 | 0 | 12 | 0 |
| 775 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| 800 | | | | | | | 63 | 0 | 18 | 1 | 30 | 0 |
| 825 | | | | | | | 9 | 0 | 13 | 1 | 24 | 0 |
| 850 | | | | | | | 12 | 1 | 7 | 1 | 30 | 0 |
| 900 | | | | | | | 1 | 0 | 4 | 1 | 12 | 0 |
| 925 | | | | | | | 5 | 0 | 2 | 0 | 9 | 0 |
| 950 | | | | | | | 14 | 0 | 10 | 0 | 9 | 0 |
| 975 | | | | | | | 7 | 0 | 4 | 0 | 9 | 0 |
| 1000 | | | | | | | 4 | 0 | 3 | 0 | 8 | 0 |
| 1025 | | | | | | | 6 | 0 | 2 | 0 | 9 | 0 |
| 1050 | | | | | | | 0 | 0 | 1 | 0 | 3 | 0 |
| 1075 | | | | | | | 0 | 0 | 0 | 0 | 1 | 0 |
| 1100 | | | | | | | 0 | 0 | 0 | 0 | 1 | 0 |
| 1125 | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 |
| 1150 | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 4.** List of major species.

| | | | |
|---|---|---|---|
| 1 | *Ammotium cassis* (Parker) | 19 | *P. orbiculare* (Brady) |
| 2 | *Bucella frigida* (Cushman) | 20 | *Pyrgo subsphaerica* (d'Orbigny) |
| 3 | *Cassidulina reniforme* Norvang | 21 | *P. williamsoni* (Silvestri) |
| 4 | *Cibicides lobatulus* (Walker and Jacob) | 22 | *Quinqueloculina elongata* Natland |
| 5 | *Cribrostomoides crassimargo* | 23 | *Q. seminulum* (Linne) |
| 6 | *C. jeffreyssi* (Williamson) | 24 | *Q. stalkeri* Loeblich and Tappan |
| 7 | *Eggerella advena* (Cushman) | 25 | *Reophax arctica* Brady |
| 8 | *Elphidium bartletti* Cushman | 26 | *R. fusiformis* (Williamson) |
| 9 | *E. excavatum* f. *clavata* Cushman | 27 | *Saccammina atlantica* (Cushman) |
| 10 | *E. frigidum* Cushman | 28 | *Scutuloris tegminis* Loeblich and Tappan |
| 11 | *E. subarcticum* Cushman | 29 | *Spiropletammina biformis* (Parker and Jones) |
| 12 | *Eoeponidella pulchella* (F. Parker) | 30 | *Textularia torquata* F. Parker |
| 13 | *Epistominella takayanagii* Iwasa | 31 | *Triloculina oblonga* (Montagu) |
| 14 | *Glabratella wrightii* (Brady) | 32 | *Tritaxis atlantica* (F. Parker) |
| 15 | *Glomospira gordialis* (Jones and Parker) | 33 | *Virgulina loeblichi* Feyling-Hanssen |
| 16 | *Islandiella helenae* Feyling — Hanssen and Buzas | | |
| 17 | *Protelphidium niveum* (Lafrenz) | | |

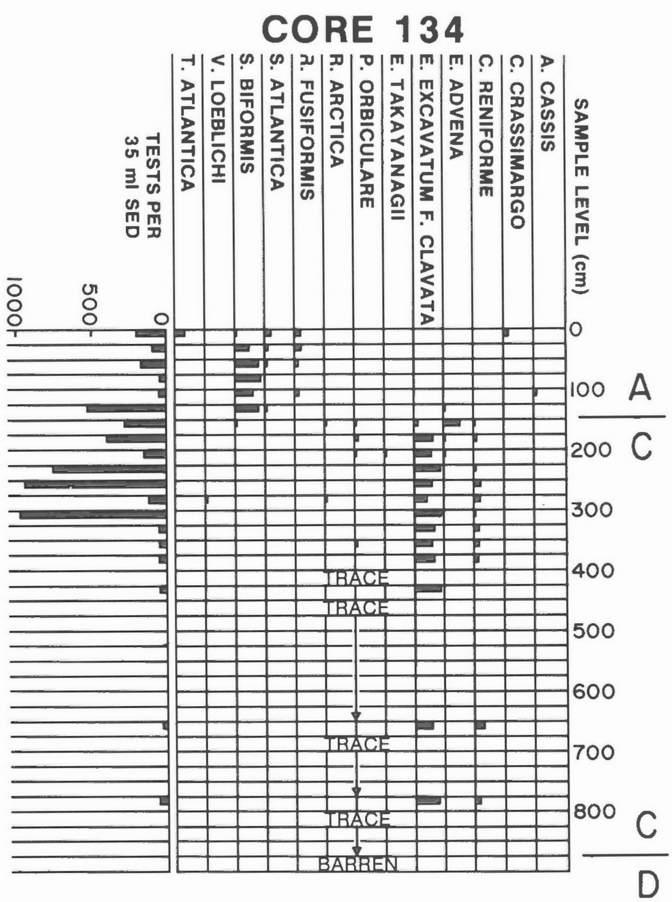


Figure 37. Foraminifera in Core 134.

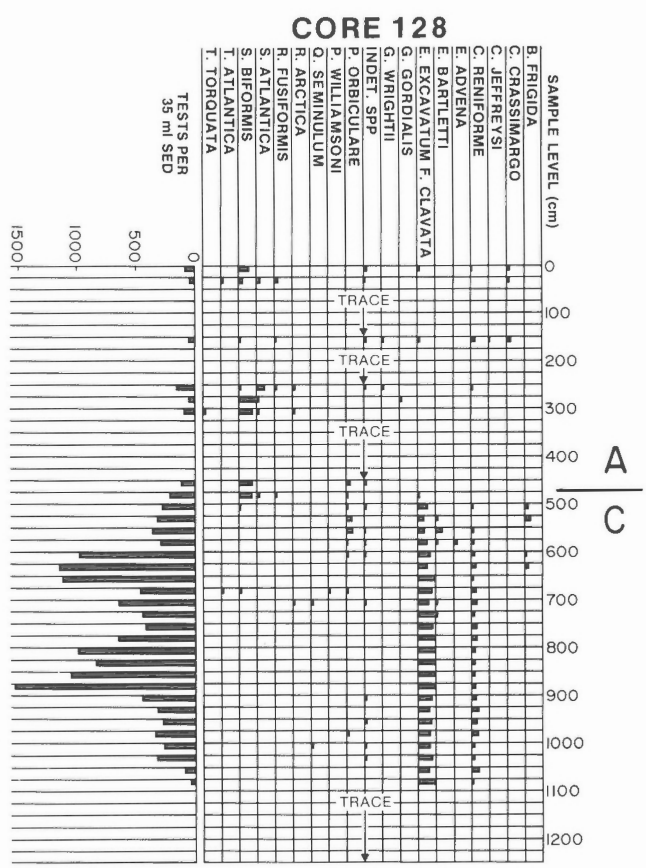


Figure 38. Foraminifera in Core 128.

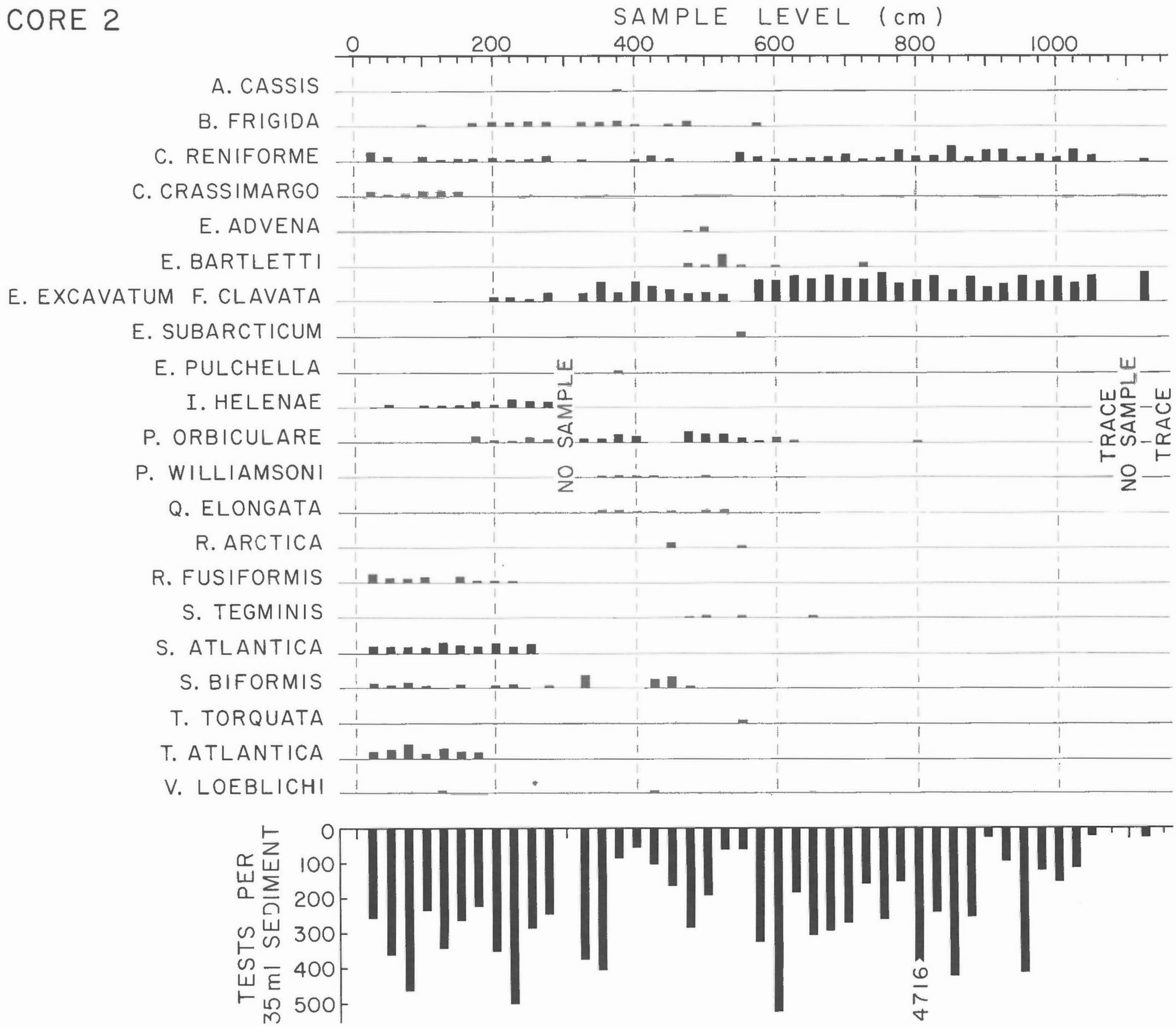


**Figure 39.** Foraminifera in Core 2.

Core 128 contains thick sequences of tests in trace numbers, but in Zone C the foraminiferal numbers are considerably higher in Core 128 than in Core 2. Patchy distribution of foraminifera in sediments is the most likely explanation for these differences.

Cores 130 and 131 were collected from a small basin at the western extremity of Lake Melville (Figs. 41, 44). The species of foraminifera in Core 130 are separated downcore in Zones A and B (Fig. 41), which are similar to the zones in the basin cores to the east. The same Zone A and B species are mixed throughout Core 131 (Fig. 44). Because of the relatively sharp separation of Zone A and B species in the nearby Core 130 and cores from the other basins, sediment redeposition is the most likely explanation for the mixed faunas in Core 131. In the process of redeposition, Zone B species have been added to the in situ Zone A species. The redeposited sediments were derived by shore erosion of raised marine deposits off Epinette Peninsula about 5 km to the south of Core 131 (Fig. 10).

**Ridges**

Core 134 was taken on top of a ridge seven kilometres to the west of a ridge break and contains a less complete sequence of foraminiferal zones (Fig. 37). Zone A is dominated by *Spiroplectammina biformis*, but Zone B is absent. The foraminifera occur in alternating high and low numbers with thick sequences of almost barren sediments below 400 cm.

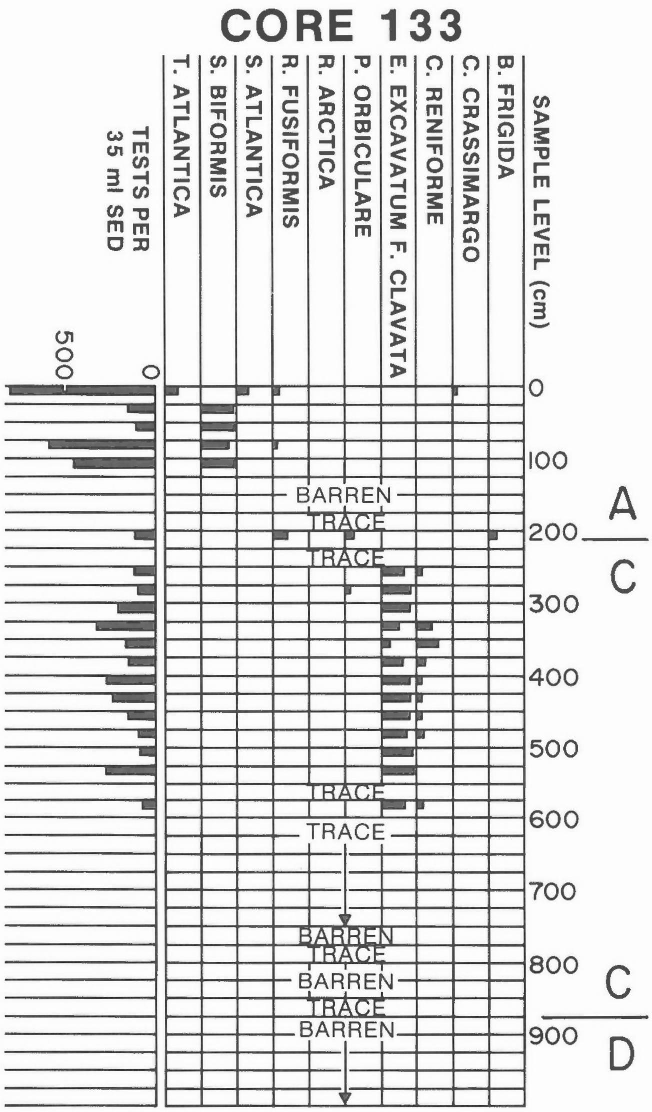


**Figure 40.** Foraminifera in Core 133.

The zonation in Core 133 (Fig. 40) taken at the edge of a shelf is similar to Core 134. Zone A is dominated by *S. biformis*, Zone B is missing and Zone C is dominated by *E. excavatum* f. *clavata* and *Cassidulina reniforme*. Core 133 contains over one metre of sediments barren of foraminifera at the bottom (Zone D).

Cores 132 and 1 (Figs. 42, 43) were retrieved from the same locality on a central ridge. Major characteristics of foraminiferal zones in these two cores are similar, except Core 1 contains sufficient numbers of *I. helenae* to be included as a major species, thus the Zone A/B boundary is recognized between 150 and 200 cm. *I. helenae* is also present in Core 132 in trace amounts between 200 and 375 cm. The more extensive trace and barren intervals in Core 132 could be due to late subsampling (Table 3). Thus, there is a possibility that some of the differences between the two cores result from test destruction in Core 132 while in storage.

**Goose Bay**

Core 77, collected from Goose Bay, contains similar major species similar to those in the Lake Melville cores, but in lower numbers and diversity (Fig. 45). The down-core faunal trends lack distinct zonation, but two boundaries could reflect environmental fluctuations within Goose Bay. The upper boundary at 175 cm separates sediments dominated by *Reophax fusiformis* from sediments dominated by *Spiroplectammina biformis* between 175 and 375 cm. Below 375 cm *Protelphidium orbiculare*, which is one of Zone B species in Lake Melville becomes dominant. However, below 475 cm *S. biformis* reoccurs in large numbers. The fluctuations in species dominance and the frequent unfossiliferous intervals down-core, reflect the nearness of the prodelta environment, where variability in sedimentation and watermass properties are to be expected.

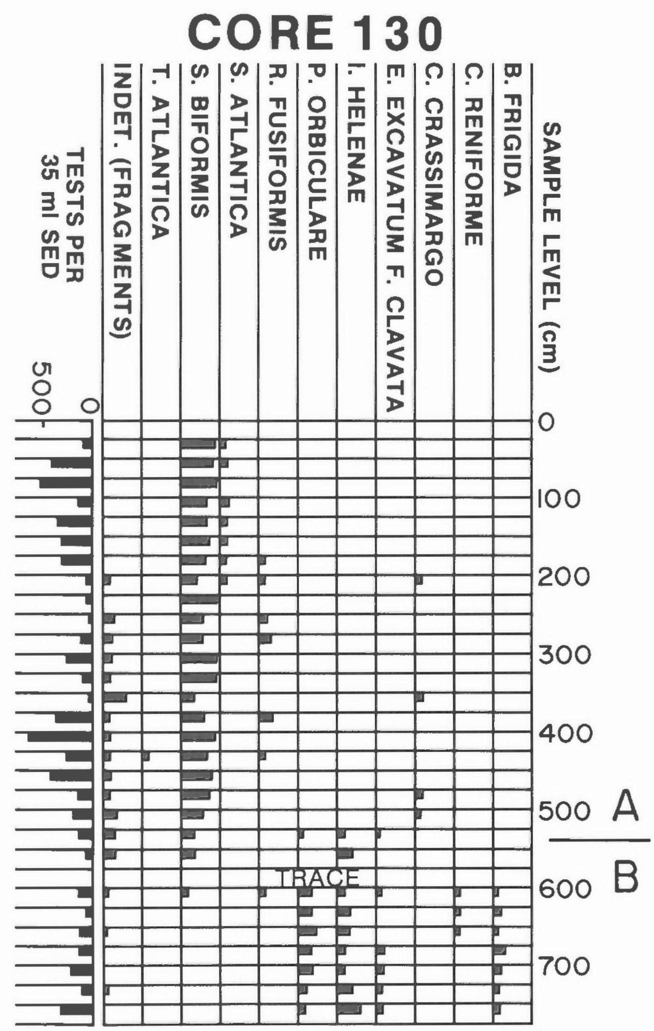


**Figure 41.** Foraminifera in Core 130.

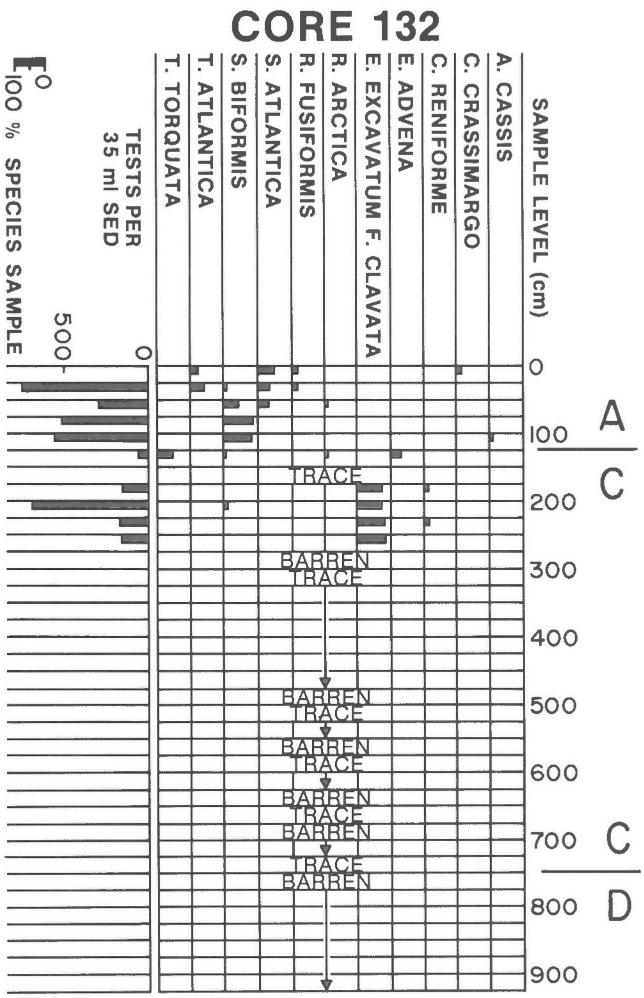


**Figure 42.** Foraminifera in Core 132.

**Summary**

Due to predominantly hemipelagic sedimentation of the fossiliferous intervals, foraminifera in most of the cores of Lake Melville were present in distinct down-core zones. The mixed faunas in Core 131 could be explained by redeposition of sediments derived from shoreline erosion. Cyclic fluctuations of faunas in Core 77 are most likely due to its proximity to the Churchill River Delta. Repeated subsampling and paired cores showed unexpected variability in terms of foraminiferal numbers and downcore levels of zonal boundaries. From the three possible causes of variability, patchy foraminiferal distribution in sediments is most likely the most important, followed by difference in analytical treatment and dissolution during the three years of storage in the case of Core 132.

## SUMMARY AND DISCUSSION

The airgun and Huntec DTS seismic surveys show thick sequences of unconsolidated sediment filling the basins of Lake Melville. Most of the sediment is acoustically stratified with a transparent surface zone. In piston cores the sediments of the surface zone are very fine grained and dominated by clay-sized particles. Towards the bottom of the cores the percentage of the silt-sized particles increases and sand occurs in cores that penetrate the acoustically stratified sediments. Due to the large scatter in foraminiferal data only major faunal boundaries downcore are used for paleoenvironmental interpretations. These will be discussed in the context of the sedimentary and acoustic evidence.

### *Contemporary sedimentation*

The present major source of sediment in Lake Melville is fluvial, although coastal escarpments of raised marine deposits in a few places could also supply a limited amount of sediment from coastal erosion. Churchill, Goose, Naskaupi and Kenamu are the four major rivers entering the west end of the Lake Melville basin (Fig. 4). Churchill and Goose rivers drain into Goose Bay, whereas the Naskaupi River system enters Grand Lake, which attains a maximum depth of over 200 m. Both basins are separated from Lake Melville by shallow sills. Thus the sediment from these rivers can enter Lake Melville only in suspension in the runoff plume.

Except for the western end, the concentrations of suspended particulate matter (SPM) in the surface water of Lake Melville are not higher than 1mg/L (Fig. 8). During August of 1979 a concentration of 1.8 mg/L was recorded at the western entrance to Lake Melville from Goose Bay. A concentration of 0.6 mg/L was recorded at the eastern end. The corresponding fall values are 0.9 and 0.4 mg/L. Thus, during all seasons less than 50% of the SPM was transported to the east end of Lake Melville and on the average, 0.7 mg of SPM per litre settle in Lake Melville at the present time. Slightly higher concentrations of SPM at the Narrows are due to tidal mixing and resuspension.

The river discharge regime into the Lake Melville basin has been modified by the hydro-electric development of the Churchill River that was completed in December 1971. As a result of the controlled discharge and diversion of some of the rivers, the mean annual flow of water into the Lake Melville basin increased, but the seasonal fluctuations decreased (Bobbitt and Akenhead, 1982). After the development, the mean monthly flow during the winter doubled, but during the freshet of the early summer months the mean flow decreased by about 1000 $m^3 s^{-1}$, with a minimal change during the late summer months.

### *Chronology*

Radiocarbon dating of subarctic Late Quaternary inshore sediments is a contentious issue due to poor preservation of dateable material and difficulties in correlation.

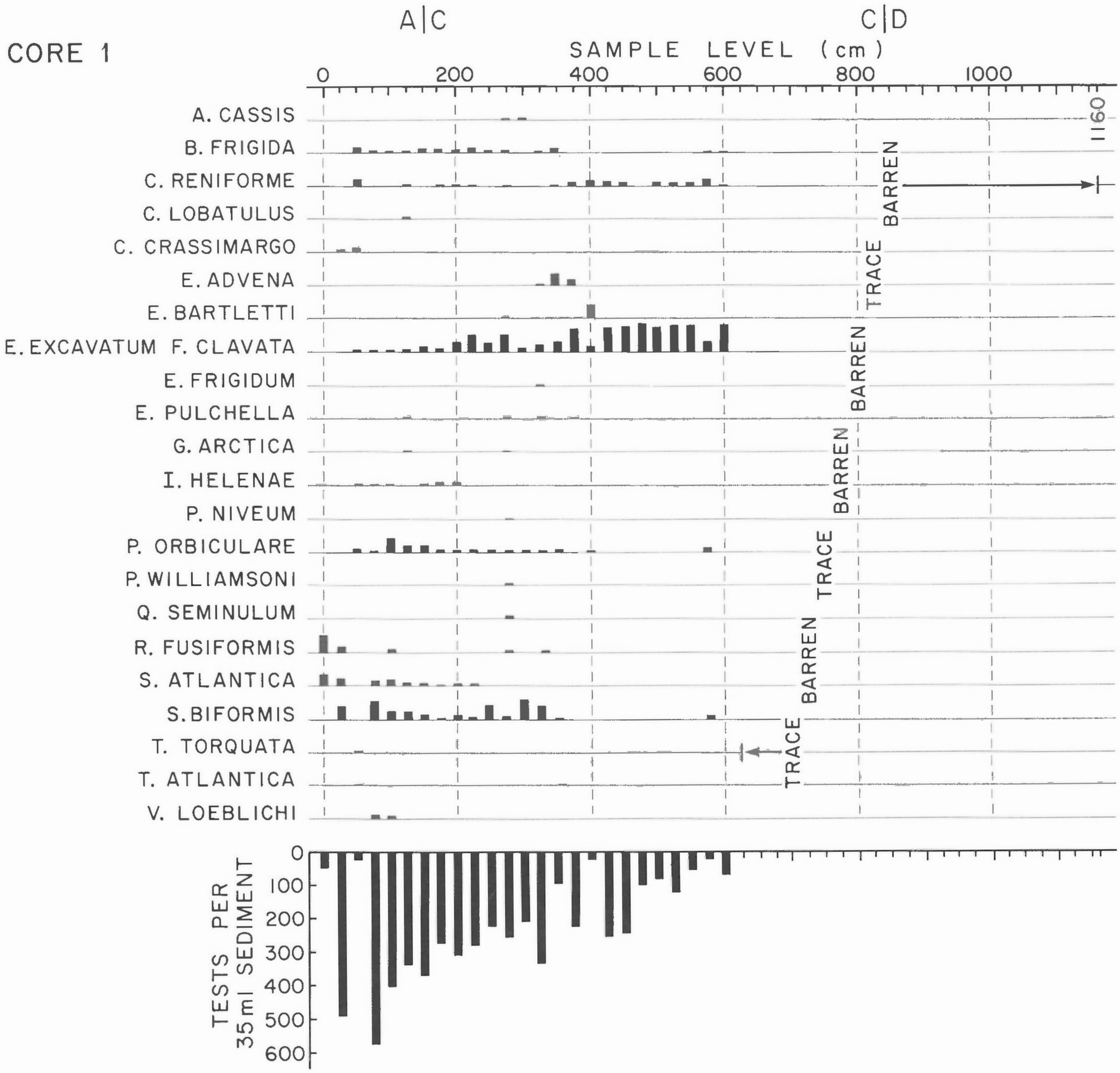


**Figure 43.** Foraminifera in Core 1.

The two commonly used materials for dating are carbonate shells and Total Organic Carbon (TOC). There is commonly a significant disagreement in $^{14}C$ dates between the two carbon sources (Fillon et al., 1981). Andrews et al. (1985) have found a statistical relationship between the consistantly older ages of TOC and molluscan shells. The range of the linear relationship is reliable between 6000 and 28 000 BP.

We have dated 14 samples using carbon from TOC and molluscan shells (Table 5). Unfortunately, samples for the two carbon sources do not overlap, therefore, we cannot make direct comparisons between the TOC and $^{14}C$ dates. Our most reliable date of 7970 BP is based on a pair of *Nuculana minuta* shells using Accelerator Mass Spectrometry (AMS) at the University of Toronto. *N. minuta* is a prosobranch mollusc and does not have a siphon, so that the length of the shell (1.5 cm) is the maximum depth of burial during the lifetime of this species. Less reliable are AMS dates on shell fragments from cores 128 and 132, where the possibility of the contamination by older shells exists. The sample at 725-730 cm interval of Core 128 consisted of one large fragment of *Portlandia intermedia* shell and a number of other unidentifiable bivalve fragments. At the 450-445 cm interval in Core 128, the sample consisted of well preserved, but broken gastropod fragments. The three AMS $^{14}C$

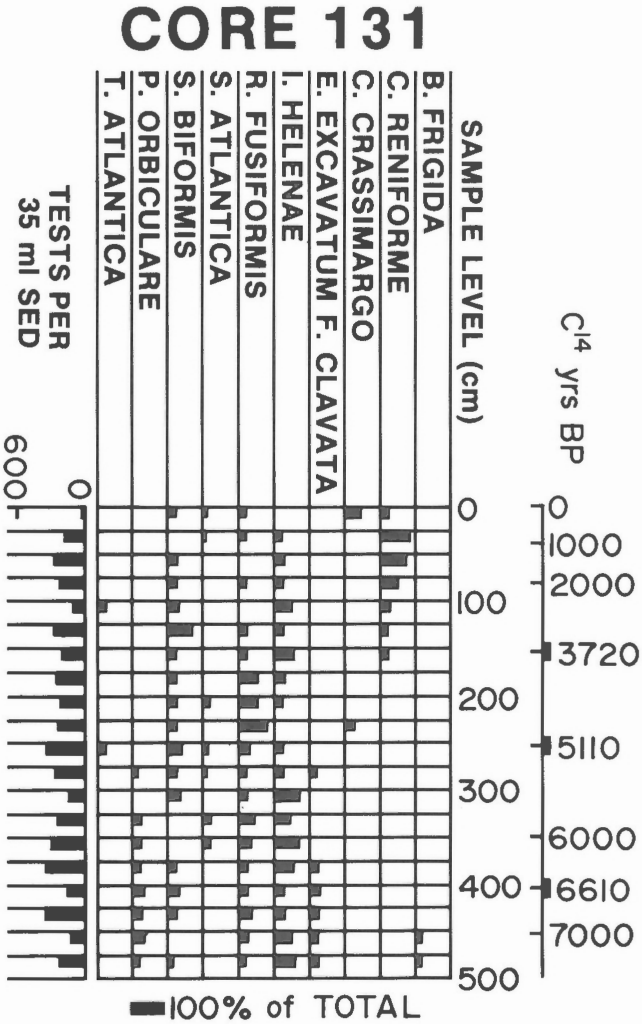


**Figure 44.** Foraminifera in Core 131.

dates from cores 128 and 132 are accepted with caution (Fig. 46).

Two AMS dates on shell fragments are rejected. The 12 620 BP at 429-430 cm of Core 77 from Goose Bay is too old in an area where sedimentation rates are expected to be high. We also reject the 12 860 BP date at 798-803 cm of Core 2, because the date is considerably older than the paired shell date only a few centimetres above (Fig. 46).

A plot of all dates *versus* core intervals shows a trend of TOC dates younger than shell dates, except for Core 131, which contained mixed foraminiferal faunas (Fig. 46). The shell dates, including the sporadically old dates of cores 77 (12 620 BP) and 2 (12 260 BP) may indicate intermittently open marine waters in the Lake Melville basin as early as about 13 000 BP during the early stages of deglaciation, while the surrounding terrain was still covered with glacial ice.

### *Age of boundaries*

On the basis of TOC dates of Core 111 Vilks and Mudie (1983) estimated the A/B boundary at 5200 BP. Because of the good core interval-age correlation in the paired cores 109 and 111 (Fig. 47) and undisturbed faunas, we consider that the 5200 BP date is a good estimate for the bottom of Zone A. Another good estimate is based on an AMS date in Core 128, where the bottom of Zone A is at 6250 BP (Fig. 47). The beginning of Zone A in the other cores is extrapolated from known down-core dates, using 1m/1000 years sedimentation rates from the regression line of $^{14}C$ dates *versus* core intervals in Figure 46. The estimated ages of the beginning of Zone A in Lake Melville vary between 5000 and 6000 BP.

The oldest age for the bottom of Zone B in Core 111 is estimated at approximately 8000 BP (Figs. 35, 47). Zone B is well represented in Core 130 in the westernmost basin, it is weakly developed in the central basin and not present on the ridges (Fig. 24). The bottom of Zone B is not synchronous, because it depends on oceanographic changes, which may vary with the depth of water and the proximity of the counter-flowing marine waters from Labrador Sea.

The dominance of *Elphidium excavatum* in the underlying Zone C suggests that in addition to the paleoceanographic change, there also was a major change in the sedimentary environment, *E. excavatum* and *C. reniforme* are known to dominate sediments that have originated from glacial meltwater (Elverhoi et al., 1980; Vilks, 1981). The glacier margin retreated to the west, therefore the B/C boundary could be considerably younger in the cores to the west of Station 111.

The top of Zone C is dated in Core 128 (Fig. 47) at 6260 BP. The boundary is extrapolated in the other cores using dated horizons and the sedimentation rate of 1m/1000 years. The bottom of Zone C is not dated and is extrapolated in ridge cores where the underlying Zone D was penetrated. These ages vary between 10 000 and 12 000 BP, with the older dates to the east.

### *Sediments in cores and the paleosedimentary environment*

Piston cores sampled the acoustically transparent seismic Unit H in the basins, penetrated the laminated Unit M, sampled gravel or till at one locality on a ridge and sampled the laminated prodelta sediments in Goose Bay. The acoustically transparent Unit H is intensively bioturbated and contains a network of pyritized worm burrows (Fig. 48). Bioturbation decreases down-core and changes to sharply laminated sediments in cores collected from the ridges where the sedimentation rate is lower (Fig. 49). Sediment grain size changes from very fine clay to increased percentages of silt downcore in the basins, but in Core 1 from a ridge, sandy sediments alternate with fine clays or silty clays. The prodelta Core 77 is dominated by fine sand and almost total absence of the fine

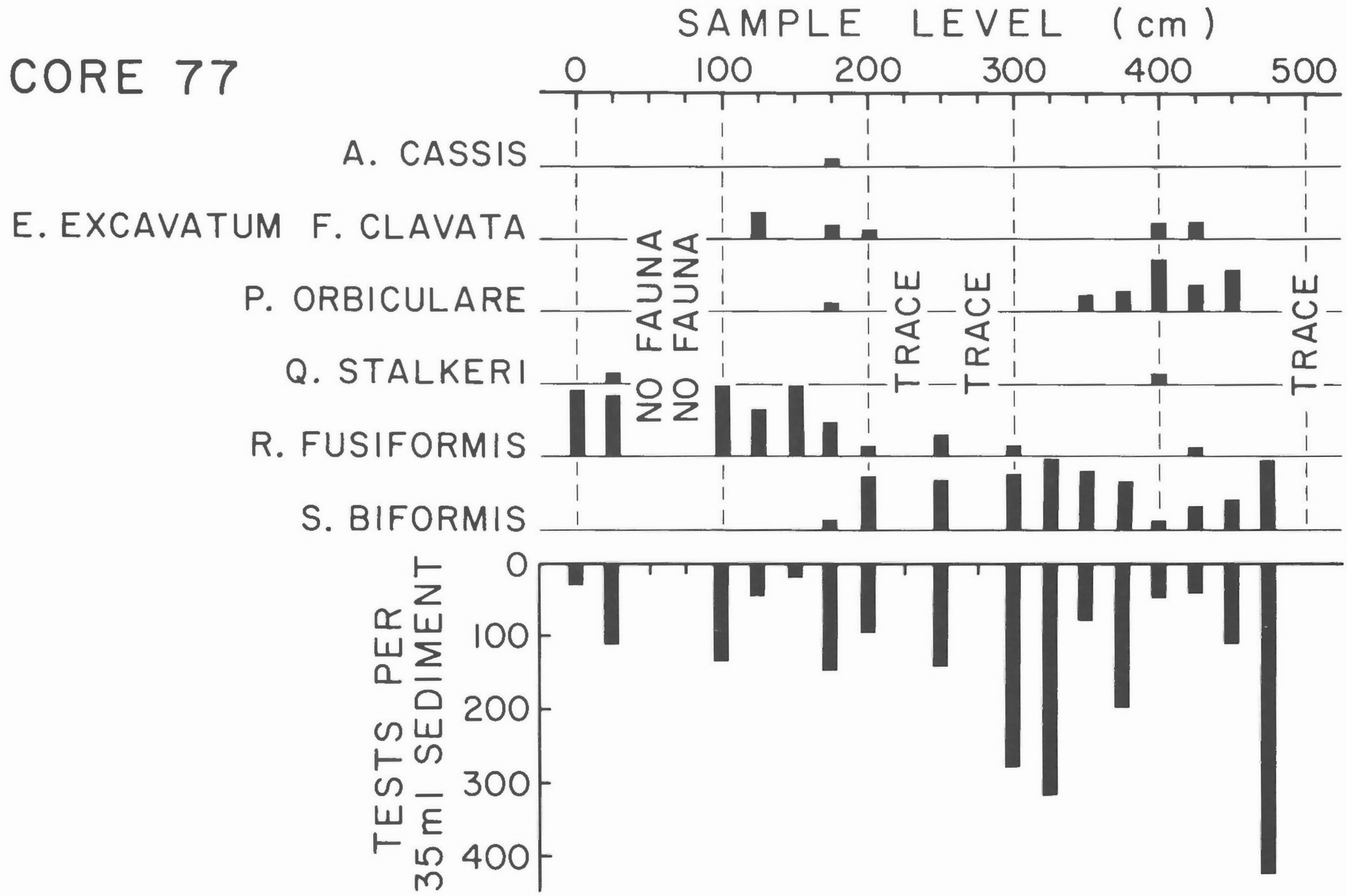


**Figure 45.** Foraminifera in Core 77.

clay in the upper 250 cm, but below this level coarse to fine silt dominates with increasing percentages of fine clay towards the bottom.

Most core lithologies indicate a change in the fluvial discharge characteristics from a setting proximal to discharge points in the early Holocene to a more distal setting at the present time. The proximal setting implies faster sedimentation rates dominated by episodic events, whereas the distal setting is dominated by hemipelagic settling of very fine sediments and much lower sedimentation rates.

The present drainage pattern that includes major intermittent settling basins, such as Goose Bay and Grand Lake, may be relatively recent. During the early Holocene marine maximum these basins were less effective in trapping the coarse fractions of the sediment because of the deeper sills and wider channels. At the present, the sills between Goose Bay, Grand Lake and Lake Melville prevent gravity flows from entering Lake Melville, therefore, only the fine sediments of the effluent plume are deposited in Lake Melville. As the glacier retreated inland, meltwater from the ice and glacial lakes to the northwest entered Lake Melville through valleys now occupied by Sebaskachu and Mulligan rivers (Fig. 4), the headwaters of which now contain abandoned river channels and spillways (Fulton and Hodgson, 1969). During the last stages of deglaciation the Churchill River Valley must have been a major conduit of meltwater from the remnants of the glacial ice to the west. The heavily loaded effluent may have bypassed Goose Bay and entered Lake Melville through the channels presently occupied by the Kenamu River.

The coarser sediments correspond to the foraminiferal Zone D in Lake Melville. They do not contain Foraminifera and in X-radiographs (Fig. 24), are seen to be laminated suggesting an abiotic seafloor or at least very low benthic activity. The extrapolated age for the top of Zone D is 10 000-12 000 BP, thus, the coarser sediments down-core were deposited during the early Holocne when meltwater was still entering the Lake Melville Basin from the west and northwest. According to the regional synthesis of the glacial margin isochrones, the Laurentide Ice Sheet retreated through the Lake Melville Basin between 10 000 and 8000 BP (Fig.4).

**Table 5.** List of $^{14}C$ dates.

| $^{14}C$ date | Core | Interval (cm) | Laboratory No. | Material |
|---|---|---|---|---|
| 4 360 ± 110 | 109 | 250-270 | GSC-3149 | Organic carbon |
| 6 170 ± 130 | | 680-695 | GSC-3160 | Organic carbon |
| 4 090 ± 90 | 111 | 280-300 | GSC-3199 | Organic carbon |
| 6 650 ± 170 | | 880-895 | GSC-3165 | Organic carbon |
| 7 530 ± 120 | | 1030-1050 | GSC-3185 | Organic carbon |
| 3 730 ± 150 | 131 | 130-145 | GSC-3020 | Organic carbon |
| 5 110 ± 220 | | 230-245 | GSC-3063 | Organic carbon |
| 6 610 ± 720 | | 380-395 | GSC-3004 | Organic carbon |
| 6 260 ± 120 | 128 | 450-455 | BETA-12221 | 58 mg shell frag. |
| 10 230 ± 160 | | 725-730 | BETA-12222 | 79 mg shell frag. |
| 7 970 ± 90 | 2 | 770-775 | TO-200 | 83 mg paired shell |
| 12 860 ± 180* | | 798-803 | BETA-12228 | 35 mg shell frag. |
| 6 770 ± 115 | 132 | 263-268 | BETA-12223 | 22 mg shell frag. |
| 12 620 ± 170* | 77 | 429-430 | BETA-12226 | 24 mg shell frag. |

*Dates unreliable because of uncertain quality of material.

## *Foraminifera and paleoecology*

Factor analysis of foraminifera from Core 111 divides the faunas into three factor assemblages (Mudie et al., 1984) that coincide with the assemblage zones estimated by Vilks and Mudie (1983) and Zones A to C in this report (Fig. 50). Zone A coincides with *Saccammina-Reophax* factor assemblage, Zone B with *Islandiella helenae* and Zone C with *Elphidium excavatum* factor assemblage. Fluctuations and trends in fluvial-marine interactions of a cold temperate to subarctic estuary, such as Lake Melville are best described by paleosalinities. Therefore, we characterize our foraminiferal zones by the estimated paleosalinities from the factor analysis of Mudie et al. (1984). The estimated paleosalinities of Zone A vary between 27‰ and 30‰ (Fig. 50), for Zone B between 32‰ and 34‰ and for Zone C between 31‰ and 32‰. Thus, a downcore profile of paleosalinities in Core 111 shows an interval of about 6‰ higher than the present and a trend towards lower paleosalinities at the bottom of the core.

Zone A is present in all the cores as a surface layer, only slightly more than one metre thick on the ridges and up to six metres in the basins (Fig. 24). It reflects the present oceanographic setting in Lake Melville and the different thicknesses are due to different sedimentation rates. The age of the lower boundary of Zone A was estimated to vary between 5000 and 6000 BP throughout the length of the lake. The sediments are thoroughly bioturbated, indicating the presence of burrowing macrobenthos.

Zone B represents an interval of the highest paleosalinity and is not present as a distinct zone in the cores collected from the ridges. Only traces of *I. helenae* are present at the bottom of Zone A in Core 2 from the shallower central basin and in Core 1 from the central ridge. *I. helenae* is prominent at the bottom of Core 130 and 131 collected from the western basin and closest to the Naskoupi and Churchill River effluents.

The presence of Zone B species in Lake Melville sediments implies higher paleosalinities. On the basis of estimated ages, the interval of higher paleosalinities lasted for about 3000 years, starting about 8000 BP. During the marine maximum, about 6000 BP, the shoreline was 110 m above the present datum at the west end of Lake Melville and 13 m higher in outer Hamilton Inlet (Peltier and Andrews, 1983). In the Narrows, the sill depth may have been about 28 m deeper 6000 BP than at the present, according to an estimated paleo-sealevel curve of Vilks and Mudie (1983). The greater sill depth and more open connection between Lake Melville and the waters of Groswater Bay was sufficient to allow the entrance of water at least between 32‰ and 33‰, assuming the August 1979 salinity profile in Hamilton Inlet is representative for the postglacial period. Because of the stratified water and estuarine circulation, greater depths at the sill will let more saline water in the counterflow from Groswater Bay into Lake Melville. Increased river outflow and more vigorous estuarine circulation will not raise salinities in Lake Melville, given a constant sill depth. A wider channel will reduce tidal mixing and also may cause higher salinities in Lake Melville. The absence of Zone B on the ridges suggests that this more saline water was restricted to the basins. Because of the early postglacial tilt of the Lake Melville depression, the western basins were relatively deeper than the eastern, explaining the prominence of Zone B in the western end close to the deltas of the two major rivers.

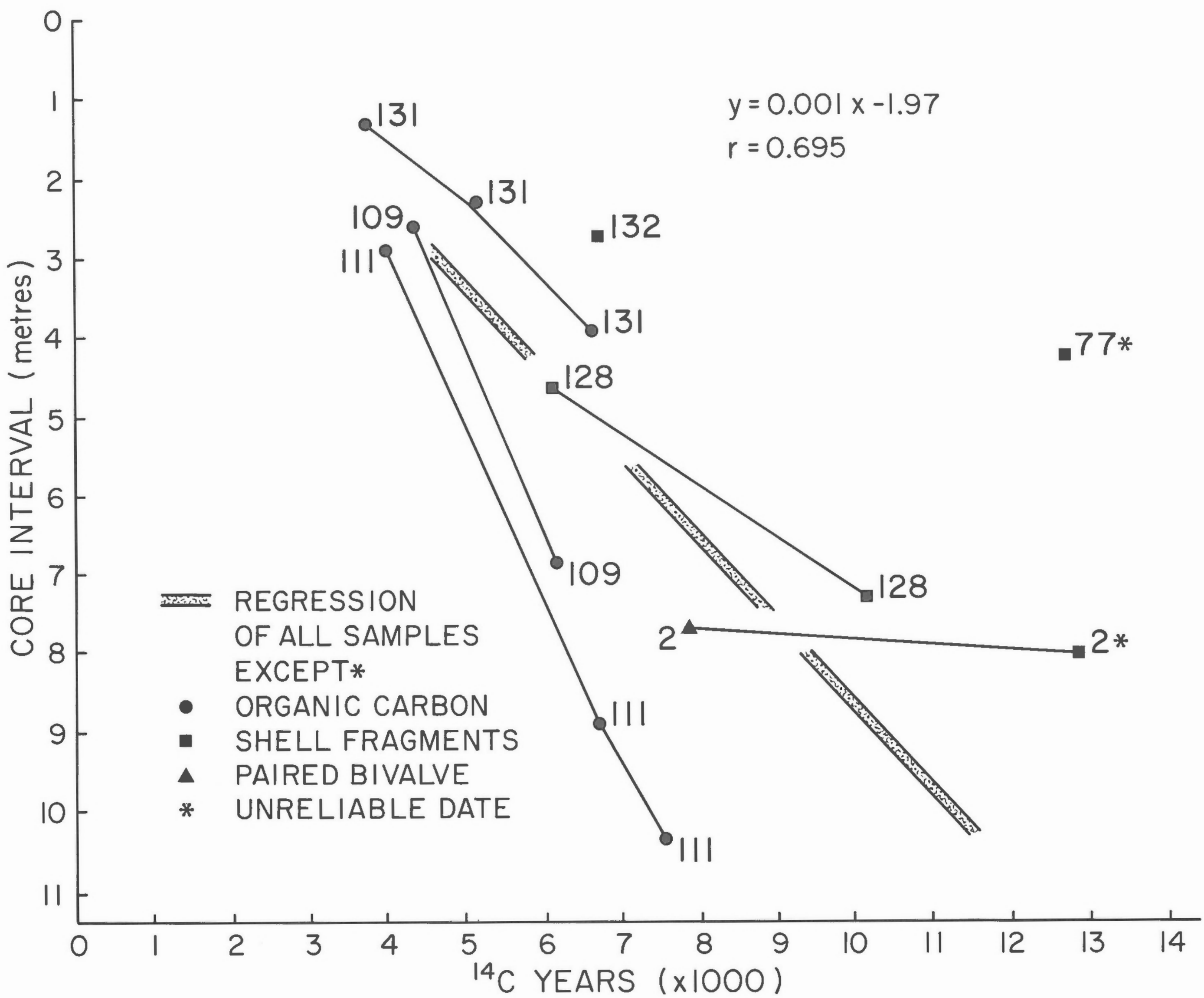


Figure 46. $^{14}C$ dates related to core intervals. The numbers designate cores.

Zone C is the thickest and most extensive zone in Lake Melville and is present both on ridges and in basins. The sediment in the upper half of the Zone is extensively bioturbated and contains abundant pyritized worm burrows and other organic fragments (Figs. 24, 48). The bioturbated sediments grade into laminated sediments towards the bottom of the zone. The numbers of foraminiferal tests is high in the bioturbated zone, but the laminated sediment contains foraminifera in trace numbers and intervals of sediments barren of foraminifera. Zone C is dominated by *Elphidium excavatum* f. *clavata* with *Cassidulina reniforme* as secondary species. The three cores collected from the ridges penetrated Zone C and entered Zone D which consists of laminated sediments and is barren of foraminifera.

The top of Zone C was dated at 6260 BP in the central part of Lake Melville on top of a ridge, but in the basins it is estimated at about 8000 BP. In the context of sediment lithologies, stratigraphic setting and faunal content, Zone C represents an early postglacial environment. The low diversity *E. excavatum* f. *clavata* assemblage has been interpreted by Osterman and Andrews (1983) as proximal glacial marine environment in a Frobisher Bay core. The present day analogue of faunas and sediment facing a calving glacier is in Spitsbergen and is dominated by *Cassidulina reniforme* and *Elphidium excavatum* (Elverhoi et al., 1980).

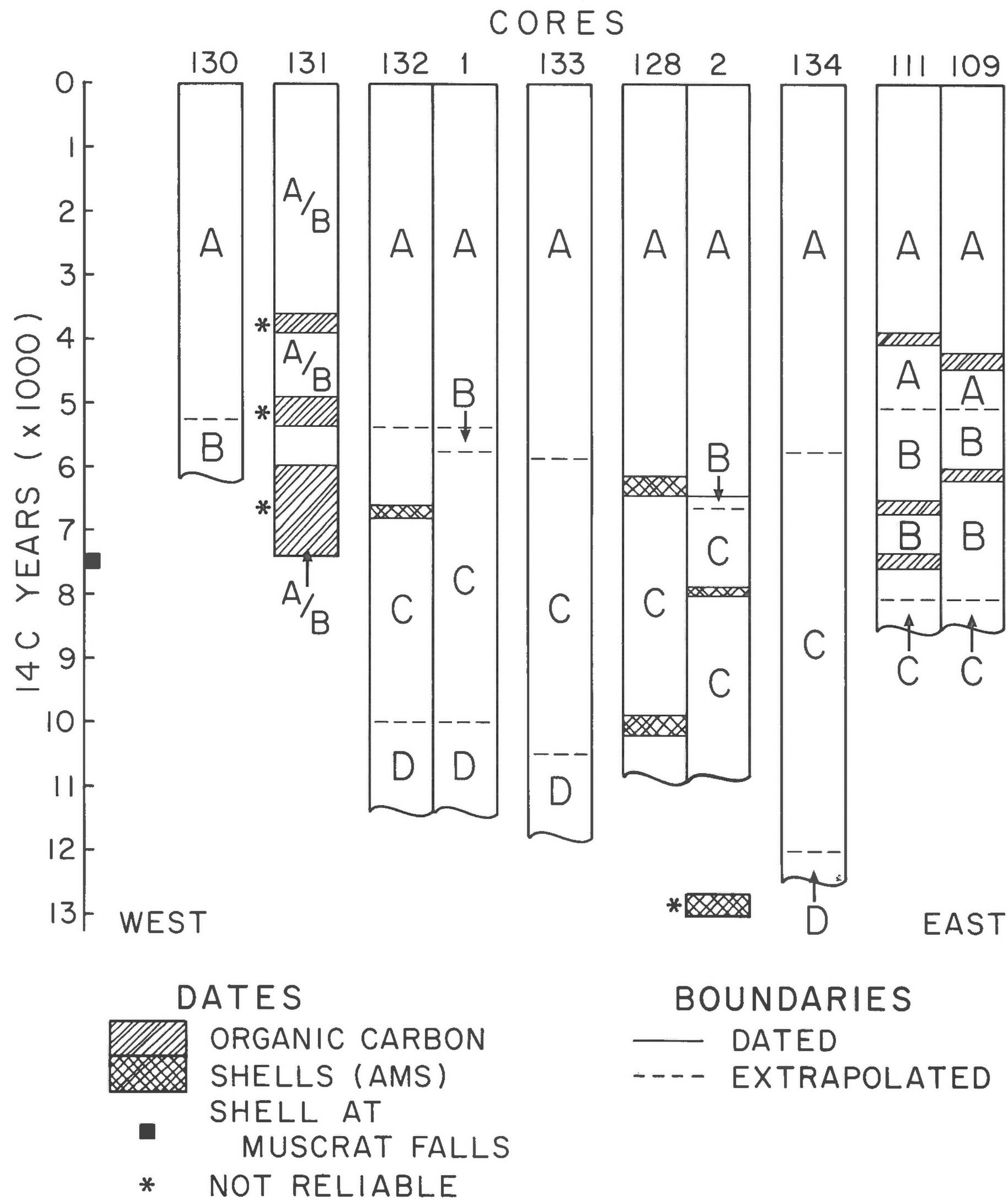


**Figure 47.** Foraminiferal Zones A to D within the framework of $^{14}C$ dates in Lake Melville.

Zone D was encountered by the cores taken from the ridges and the vicinity of Zone D was indicated at the bottom of the basin cores 2 and 128 by the very low numbers of foraminiferal tests. The absence of foraminifera in Zone D and the well preserved sediment laminae suggest an abiotic environment such as underside of a glacier on the ridges and turbidites in the basins.

In summary, piston cores from Lake Melville contain foraminiferal species that indicate a short interval of more saline water than at the present, presumably during the marine maximum. Prior to this period the waters were slightly less saline than during the marine maximum, but more saline than at the present. The environment was presumably proglacial with glacial outwash entering the Lake Melville basin as a surface plume and marine counterflow along the bottom. Nutrients were available for organic production and the seafloor was sufficiently stable for prolific benthos.

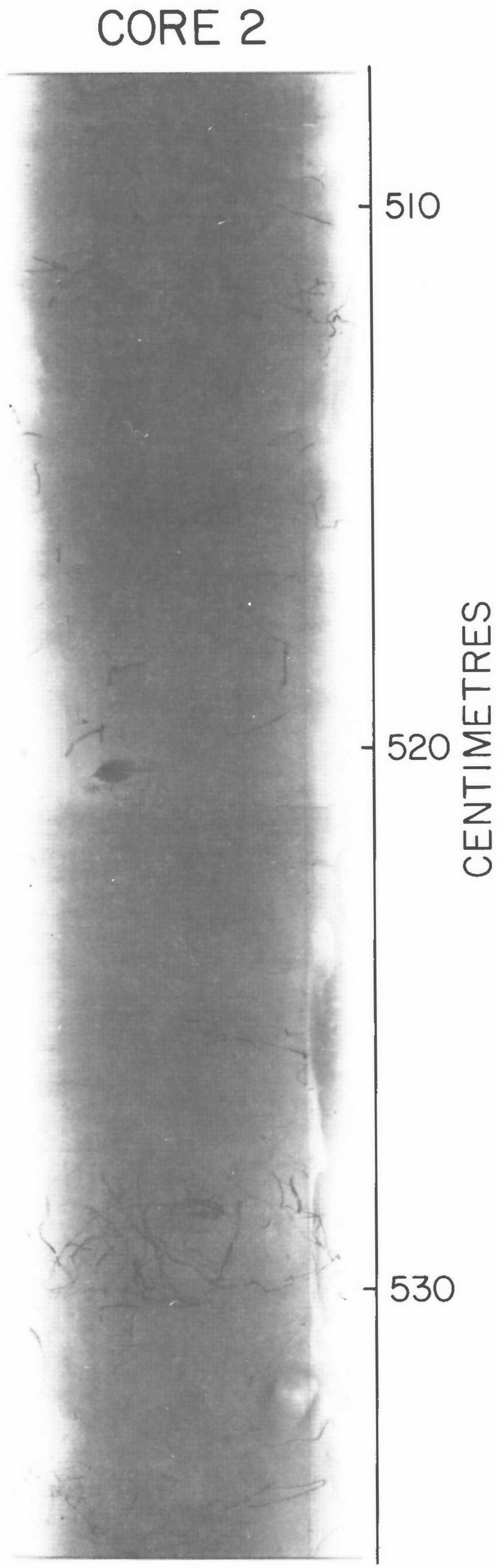


Figure 48. X-radiograph from Core 2 showing pyritized worm tubes in bioturbated sediments.

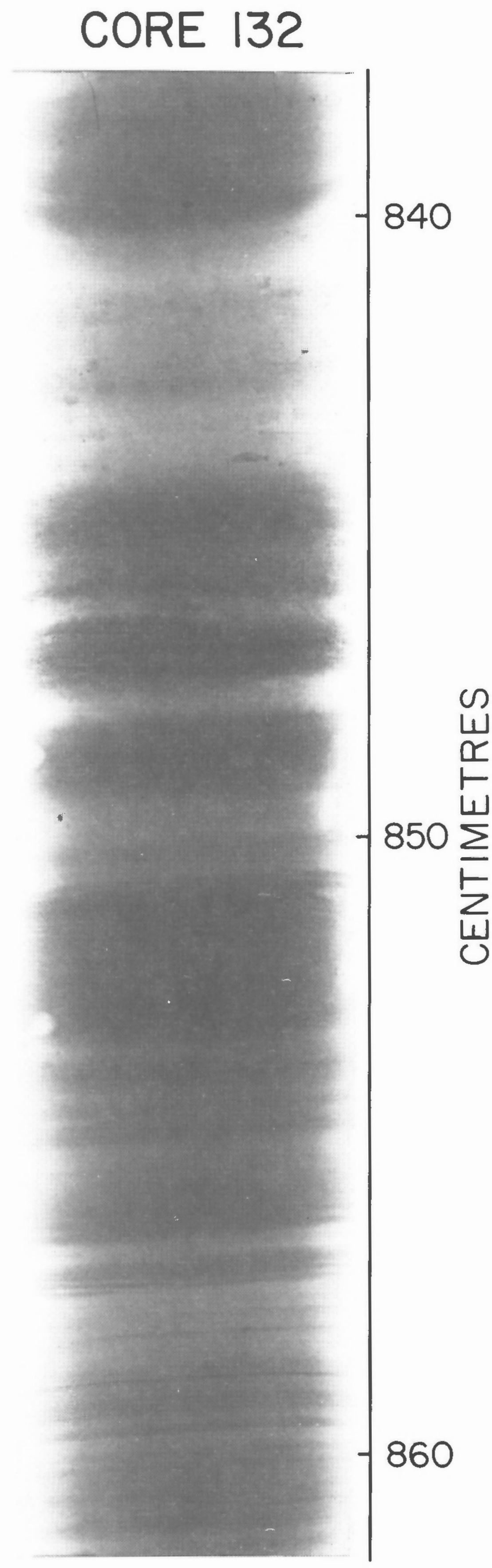


Figure 49. X-radiograph from Core 132 showing sharply laminated sediments.

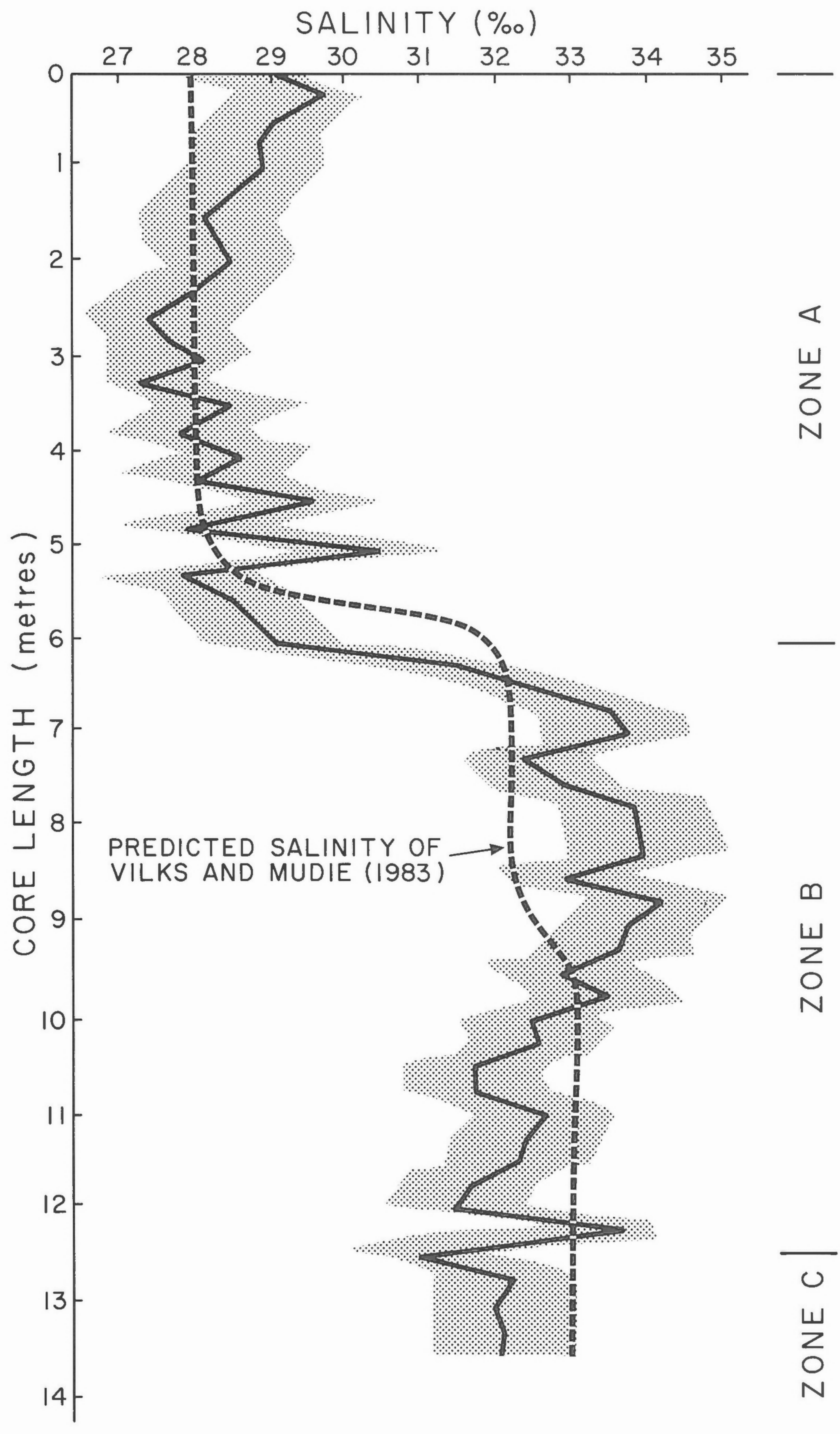


**Figure 50.** Paleosalinity estimates downcore 111 on the basis of factor analysis of Foraminifera — salinity relationships (modified from Mudie et al., 1984).

## *Seismic profiles and Wisconsinan sedimentation*

### Unit H

Huntec DTS profiles show thick sequences of acoustically stratified sediments that are overlain by acoustically transparent and poorly stratified sediments towards the surface. Most of the piston cores sampled the acoustically transparent surface Unit H, which consists of clay (Fig. 11). Sediment and faunal characteristics suggest that Unit H was deposited during the late postglacial period, when sediments were derived mainly from fallout from riverine effluent plumes. The sediments are highly bioturbated as a result of benthic activity and relatively slow sedimentation rates.

Postdepositional redistribution of the Holocene deposits takes place due to slumping on the steep slopes and possibly due to winnowing of the very fine sediment. As a result, Unit H is thickest in the deep basins and thinnest on the ridges and exposed shelf edges. These processes are well illustrated in Profile I-J (Fig. 15). Shore-cliff erosion of the raised marine deposits off Epinette Peninsula and slope instability in the western basin contributed to the thick wedge of Unit H sediments of Profile O-P (Fig. 18). The mixed faunas in Core 131 also indicate sediment redistribution.

### Unit M

Towards the bottom of Unit H the amplitude of acoustic signals increases and the first continuous strong reflector was considered as Unit H/Unit M boundary. The corresponding grain size change in piston cores that penetrated this boundary is towards coarser sediments, e.g. Core 128, Profile G-H (Fig. 14). The extent of bioturbation is considerably lower and X-radiographs show intervals of laminated sediments.

The acoustic H/M boundary does not correspond with the foraminiferal boundaries, and appears somewhere in the foraminiferal Zone C. The poor relationship between acoustics and foraminifera is not surprising considering the various errors involved. The certainty of coring a seismic feature on uneven seafloor and dipping strata is poor due to a navigation accuracy not better than 200 metres. The distribution of foraminifera is patchy and they respond to environmental factors that may have little bearing on acoustic properties of sediment. Foraminifera may respond to a slight change in watermass characteristics, such as salinity, that may not influence sediment lithologies.

Foraminiferal Zone D corresponds to slightly coarser and laminated sediments and because of the absence of faunas, it is assumed to reflect a glacial-late glacial sedimentary environment. The acoustic M/M-1 boundary is in the vicinity of the foraminiferal C/D boundary, e.g. Core 132 (Figs. 16, 42).

The acoustically laminated Unit M is thick and ponded in the basins, but conforms to the underlying topography in relatively thin sequences along slopes and on the ridges. Bands of continuous reflectors alternate with unstratified sediment in parallel beds in the deepest and easternmost basin (Profile A-B; Figure 11) and in lense-shaped sequences in the shallower central basin (Profile G-H; Figure 14). Foraminifera close to top of Zone M are dominated by the proglacial *Elphidium excavatum* assemblage, which decreases downcore to barren sediments. The laminae in X-radiographs are not graded, indicating distinct pulses in sediment supply.

The acoustic, lithologic and faunal information indicates that sediments of the acoustic Unit M are waterlain and glaciogenic. The sediments are distal glaciomarine, and the comparison of glacial margin isochrones of King (1985) with our core data suggest that these sediments were deposited when the ice margin was retreating through the Lake Melville depression. The ponded sediments are turbidites produced by the resedimentation of subaquatic slope deposits. The conforming sequences were deposited from fluvial or glacial meltwater plumes that emanated from points within the Lake Melville basin. The alternating ponded beds reflect single events or a series of turbidity flows; the conforming sequences may reflect pulses in supply.

### Unit M-1

The reflectors in the basin Unit M-1 are discontinuous in a matrix of massive beds or deposits with chaotic acoustic reflectors. The units lacking reflectors are acoustically transparent, indicating lack of internal reflectors, which may be due to fine sediments and high water content. The acoustic signature of this zone suggests a sedimentary structural equivalent of subaquatic meltout till (Dreimanis and Lundquist, 1984) or undermelt diamicton (Gravenor et al., 1984). According to the above authors, undermelt sediments are deposited under active floating or partially floating ice near a grounding line from advancing glaciers, or possibly during the retreat of active ice. The subaquatic meltout till is formed by debris falling a short distance through subglacial water only a few metres deep and as a result, may form massive to laminated diamicton (Dreimanis and Lundquist, 1984).

The massive bed labelled M-1 in Figure 11 extends throughout the basin, becomes thinner towards the west and is not present in waters shallower than 150m or in the deeper western basins. The strong acoustic returns from the laminated sequences underlying these beds, suggest that they consist of fine sediments that may not be coarser than sand.

Units M and M-1 could be stacked on top of each other in an ice marginal setting where calving takes place (Fig. 11). The stacking may be more common than illustrated in the profiles, where in many cases the M/M-1 boundaries are ambiguous.

Fast sedimentation rates in a glacial margin environment are demonstrated by post-depositional movement of sediment that has taken place as a result of slope failures. Initially conforming laminae may be disrupted, creating blocks of chaotic acoustic reflectors (Profiles I-J, Q-R; Figures 15, 19). Confused reflectors of Profile O-P (Fig. 18) may be partly due to mud flows from slopes nearby or partly dissolved methane. Sporadically poor coherence of acoustic returns in Profile S-T (Fig. 20) is due to partly dissolved gasses and very little sediment disturance, because of the well preserved faunal boundaries in Core 130. The M-1 sediment of the bottomset deposits of the Churchill River Delta may have formed mud diapirs through the laminated sediment in response to pressure (Profile U-V; Figure 21).

## GLACIAL AND POSTGLACIAL SEDIMENTATION IN LAKE MELVILLE: A MODEL

The Lake Melville Basin contains thick sequences of ponded and conformable stratified sediments overlain by hemipelagic muds. The former were deposited in a glacial setting, the latter in the existing fluvial mode of sediment transport. Some of the till-like deposits at the base could be sediment slumps or subaquatic meltout tills or undermelt diamicton deposited from a partly floating glacial ice sheet and close to an active margin. The Lake Melville depression may have acted as a calving bay, as suggested by Fulton and Hodgson (1979), while great thicknesses of subglacial or glaciomarine sediments were trapped in the Lake Melville basin.

Glacial margin isochrones in the southeastern Labrador (King, 1985) (Fig. 4) suggest that the glacial ice retreated through the Lake Melville basin between 8000 and 10 000 BP. Our most reliable date is 7970 BP in Core 2 at 770-775 cm below seafloor in the central part of Lake Melville. This is a minimum age for Zone C, described previously as representing proximal glaciomarine environment. The Zone C faunas extend at least 2.5 m below the dated horizon and on the basis of sedimentation rate of one metre per 1000 years, we suggest that the glacier had retreated past the coring site by at least 10 000 BP. King (1985) places a 9000 BP isochrone through the Core 2 site. Dates on molluscan fragments close to 13 000 BP suggest that earlier open marine conditions may have existed.

There may have been a major glacial stillstand at Northwest River, where morainal deposits are dated at 7500 BP (Lowdon and Blake, 1975), which are considered to be of the same age as the Sebaskachu Moraine to the northeast (King, 1985). During the stillstand, the outwash deltas at Northwest River were in more direct contact with Lake Melville than the fluvial deltas of the present time. Coarser sediments were deposited in the basins and at a much faster rate than at the present. As the ice retreated to the west, large volumes of glaciofluvial/lacustrine waters drained to the Labrador Sea through Hamilton Inlet. Although the Lake Melville Basin was deeper and more open to the marine environment during early postglacial time than at the present, foraminfera in piston cores suggest only slightly higher paleosalinities than at the present. Except for the deeper basins, the commonly proglacial *Elphidium excavatum* faunas dominate sediments as late as about 5000 BP.

In the deep eastern basin the inner Labrador shelf faunas dominated by *I. helenae* appear at about 8000 BP and end the dominance close to 5000 BP. At this time the agglutinated species take over the bottom assemblages throughout Lake Melville, regardless of water depth, signifying the beginning of the present day oceanographic marginal marine setting. The marine maximum faunas occupied only the deep basins.

At present, Lake Melville is an estuary in a physiographic setting of a fiord. The water column consists of a thin and diluted surface layer, that also carries the runoff plume. The more saline water below is well mixed and is about 6 ‰ less saline than the water in Groswater Bay at comparable depths. The exchange of bottom water takes place in fall and winter.

The geometry and depth of the Narrows is important in determining the rate of bottom water exchange in Lake Melville. During the early marine maximum, between 10 000 and 8000 BP, the lower salinity *E. excavatum* reflects the added influence of deglaciation meltwater. At present, tidal mixing and sill depth modify the water spilling over to a salinity of about 28‰. In a simple model, a wider and deeper channel would result in a more saline bottom water. Foraminiferal evidence demonstrates that this happened during the late marine maximum in the deeper basins.

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