

Late Quaternary sedimentation, 50° N, North-East
Newfoundland shelf

Sédimentation tardi-quaternaire au NE de la plate-forme
continentale de Terre-Neuve, par 50°N

Späte Quartär Sedimentation, 50° N, Nord-West Neufundland
Terrasse

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Résumé de l'article

Dix carottes prélevées au nord-est de la plateforme continentale de Terre-Neuve et du talus continental adjacent présentent des corrélations dans leurs séquences marines tardi-quaternaires. Les sédiments holocènes récents consistent en une vase gris-olivâtre comprenant quelques débris glaciels. L'Holocène inférieur est caractérisé par des assemblages de microfossiles d'eaux plus chaudes, par d'abondants débris glaciels de carbonates et par des assemblages de pollen indicateurs d'un milieu de forêts boréales alternant avec des toundras. Les stades glaciaires du Wisconsinien supérieur et moyen montrent des assemblages de microfossiles planctoniques subarctiques, des sources régionales de pollen de toundra, un remaniement de sédiments plus anciens (y compris du till) par des tempêtes et des assemblages de foraminifères benthiques et de diatomées provenant d'eaux moins profondes. On reconnaît deux interstades pendant le Wisconsinien moyen comprenant des microfossiles marins semblables à ceux de l'Holocène inférieur. Cette séquence repose en discontinuité sur des vases plus anciennes (illinoiennes?) pro-glaciaires qui paraissent surmonter le till.

LATE QUATERNARY SEDIMENTATION, 50°N, NORTH-EAST NEWFOUNDLAND SHELF

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ABSTRACT Ten cores from the North-east Newfoundland shelf and adjacent continental slope have correlable late Quaternary marine sequences. Late Holocene sediment is olive grey mud, with some ice-rafted debris. The early Holocene is characterised by warmer water microfossil assemblages, abundant ice-rafted carbonate debris, and pollen assemblages indicating open boreal woodland interspersed with tundra. Late and mid-Wisconsinan glacial stades show subarctic planktonic microfossil assemblages, regional sources of tundra pollen, storm reworking of earlier sediment, including till, and shallower water assemblages of benthonic foraminifera and diatoms. Two mid-Wisconsinan interstades are recognised, with marine microfossils similar to the early Holocene. This sequence rests disconformably on earlier (?Illinoian) pro-glacial muds which appear to overlie till.

RÉSUMÉ *Sédimentation tardi-quaternaire au NE de la plate-forme continentale de Terre-Neuve, par 50°N.* Dix carottes prélevées au nord-est de la plate-forme continentale de Terre-Neuve et du talus continental adjacent présentent des corrélations dans leurs séquences marines tardi-quaternaires. Les sédiments holocènes récents consistent en une vase gris-olivâtre comprenant quelques débris glaciels. L'Holocène inférieur est caractérisé par des assemblages de microfossiles d'eaux plus chaudes, par d'abondants débris glaciels de carbonates et par des assemblages de pollen indicateurs d'un milieu de forêts boréales alternant avec des toundras. Les stades glaciaires du Wisconsinien supérieur et moyen montrent des assemblages de microfossiles planctoniques subarctiques, des sources régionales de pollen de toundra, un remaniement de sédiments plus anciens (y compris du till) par des tempêtes et des assemblages de foraminifères benthiques et de diatomées provenant d'eaux moins profondes. On reconnaît deux interstades pendant le Wisconsinien moyen comprenant des microfossiles marins semblables à ceux de l'Holocène inférieur. Cette séquence repose en discontinuité sur des vases plus anciennes (illinoiennes?) pro-glaciaires qui paraissent surmonter le till.

ZUSAMMENFASSUNG *Späte Quartär Sedimentation, 50° N, Nord-West Newfoundland Terrasse.* Zehn Bohrkern von der nordwestlichen Neufundland Terrasse und dem angrenzenden Kontinentabhang haben verwandte, Spät-Quartäre Seebödenfolgen. Spät-Holozän Sediment ist olivengrüner Schlamm, mit etwas gestrandetem Schutt. Das frühe Holozän charakterisiert sich durch microfossile Ansammlungen wärmeren Wassers, häufigem, gestrandetem Karbonatschutt und Pollenansammlungen, die auf nördliches Waldland, das von Tundra unterbrochen ist, hindeuten. Die Spät- und Hochwisconsin Eiszeiten zeigen subarktische planktonische und microfossile Ansammlungen, regionale Quellen von Tundrapollen, Sturmverschiebungen von früheren Sedimenten, einschliesslich Till und Ansammlungen von bethonischen Foraminifera und Doppelatome flacherer Gewässer. Zwei Wisconsin Zwischenstadien sind erkennbar mit Seemicrofossilien, wie im frühen Holozän. Diese Schicht liegt unkonformerweise über früherem (Illionischem), vorglazialen Schlamm, welcher seinerseits auf Till zu ruhen scheint.

INTRODUCTION

The North-east Newfoundland shelf is several hundred kilometers wide and reaches water depths in excess of 500 m. The outer shelf is underlain by Jurassic-Cretaceous sediments unconformably overlain by a wedge of Cenozoic sediment (CUTT and LAVING, 1977). The outer shelf consists of shallow banks separated by deep channels cut into the Mesozoic-Cenozoic sequence. A veneer of Pleistocene sediments is recognised by seismic reflection profiling (GRANT, 1972), but its lithology and stratigraphy are virtually unknown. As a result, interpretations of Quaternary glacial ice extent on the North-east Newfoundland shelf are presently poorly constrained (e.g. GRANT, 1977, SLATT, 1977).

Deeper water shelf sediment off eastern Canada consists principally of muds winnowed from the shallower banks (KING, 1970), augmented in places by ice-rafting. The North-east Newfoundland shelf is supplied with icebergs by the Labrador current, and the area between 49° and 54°N is one of significant melting and ice-rafted sediment supply at present (FILLON, 1977). The history of the Labrador current is unclear; data from the Labrador shelf suggest it might have been absent prior to 6000 BP (FILLON, 1976), permitting northward extension of warmer Gulf Stream water, but this is not evident in the planktonic foraminifera from Central Labrador shelf cores (VILKS and MUDIE, in press).

We have examined cores from three areas (Fig. 1). There are 5 gravity cores, 80-150 cm in length (numbered BP 103-107) from an area about 2 km square on the southern margin of Bonavista Channel in water depths of about 295 m (Figs. 1, 2), where the regional slope is about 1 in 400. Huntec seismic reflection profiles from this area (Haworth and Dale, pers. comm., 1978) show a hummocky sea floor with a patchy surficial sediment cover never more than 5 m thick (hummocks are typically 1-3 m high and 50-200 m across). We have one piston core (77-014-1) and its trigger gravity core (-1G) from a similar setting on the continental shelf about 50 km further south at 49°14.3'N, 51°06.9'W. The third area is the upper continental slope at about 50°N (Fig. 3), where 5 gravity cores are available (numbered 77-034-49 to -54). All cores have been split in their liners, x-radiographed, and lithological units distinguished. Textural and petrologic analyses have been made by standard techniques at selected intervals in all cores. Detailed micropaleontological investigations have been made in five cores. The silt fraction of two cores have been examined for volcanic ash (following the technique of AKSU, 1977). Paleomagnetic measurements have been made on two cores.

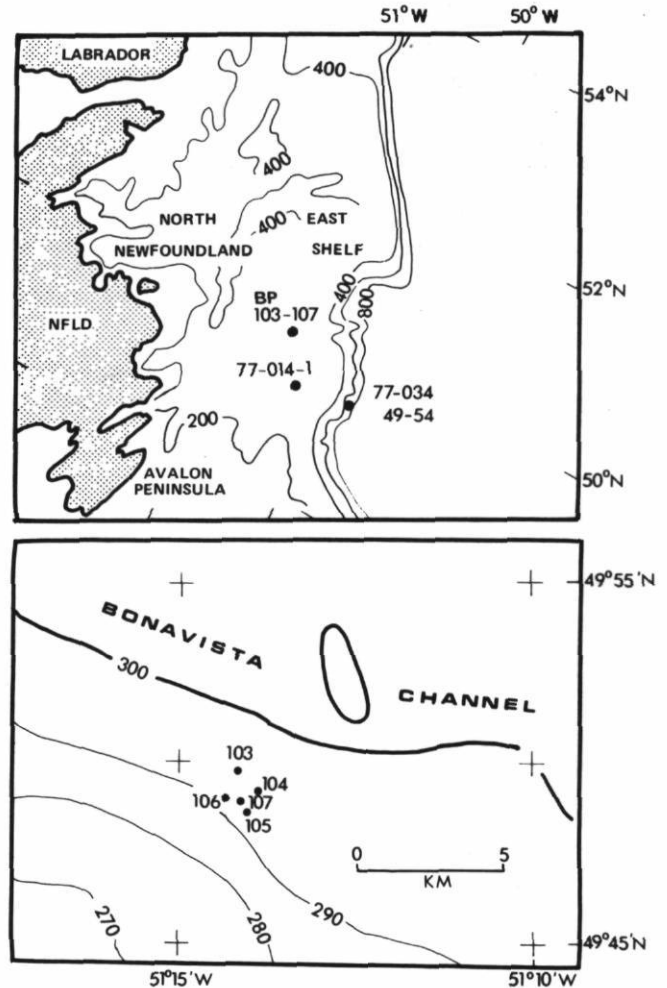


FIGURE 1. Map showing regional location of cores studied and the distribution of the Bonavista Channel (BP) cores (contours based on Natural Resource Series charts).

Cartes montrant la localisation des carottes étudiées ainsi que la répartition des carottes prélevées dans le canal de Bonavista (BP) (courbes selon les cartes des Natural Resource Series).

LITHOSTRATIGRAPHY

Cores BP-103 and 105 from Bonavista Channel have almost identical lithological sequences, and are used as standards with which the other cores are correlated (Figs. 2, 4). The top of the cores consists of a few centimeters of olive grey mud (unit A1). This passes down into several centimeters of olive grey, gravelly sandy mud (unit A2), the additional sand and gravel probably being ice-rafted. This is underlain by a unit (B) of lighter olive grey mud (often gravelly sandy) with a high carbonate content. The carbonate is distributed throughout the range of grain sizes present, includes considerable dolomite, and appears to be predominantly

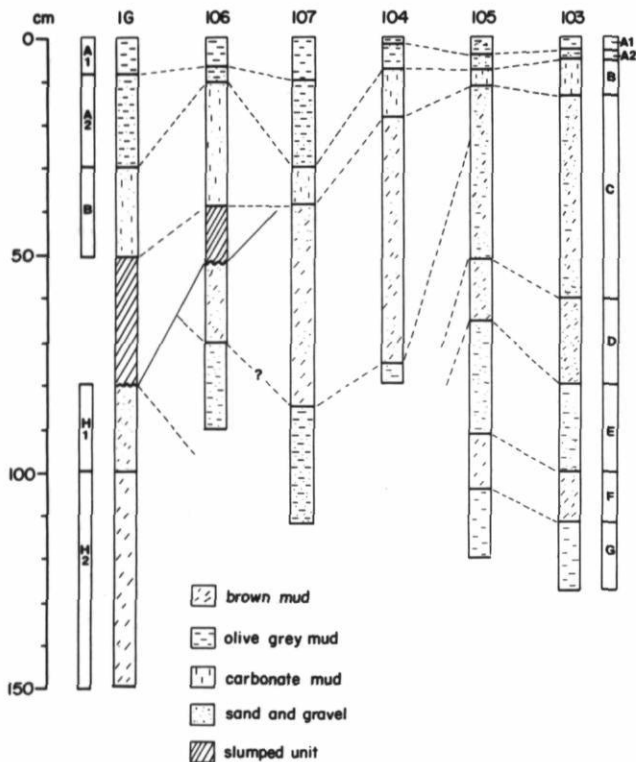


FIGURE 2. Lithologic correlation of cores from north-east Newfoundland Shelf, showing subdivision into units.

Corrélation lithologique entre les différentes carottes provenant du plateau continental au nord-est de Terre-Neuve, ainsi que les unités retenues.

ice-rafted in origin, although the amount of biogenic carbonate is also unusually high. Unit B is about 5 cm thick and its base is marked by the lowest carbonate bed. Unit C (about 40 cm thick) is similar to B, but lacks distinct carbonate beds, and gravel is less abundant. In places, especially in the upper part of the unit, the colour tends towards a dusky yellowish brown. Four sub-units (C1-C4) are distinguished on the basis of colour and grain size distribution (see Fig. 4). Unit D is about 20 cm thick and comprises dusky yellowish brown gravelly sandy mud, distinctly browner and coarser than unit C. Unit E is a 20 cm thick sequence of olive grey gravelly sandy mud, similar to A2. Unit F, 10-14 centimeters thick, is similar to D. Unit G is an olive grey mud with almost no sand or gravel, similar to A1.

The sequence A1-A2-B at the top of these cores is very distinctive, and can be easily correlated to all the adjacent gravity cores (Fig. 2), also to piston core 77-014-1 to the south and the sequence of cores on the continental slope. There is considerable variation in thickness of this sequence, however, with top of unit B

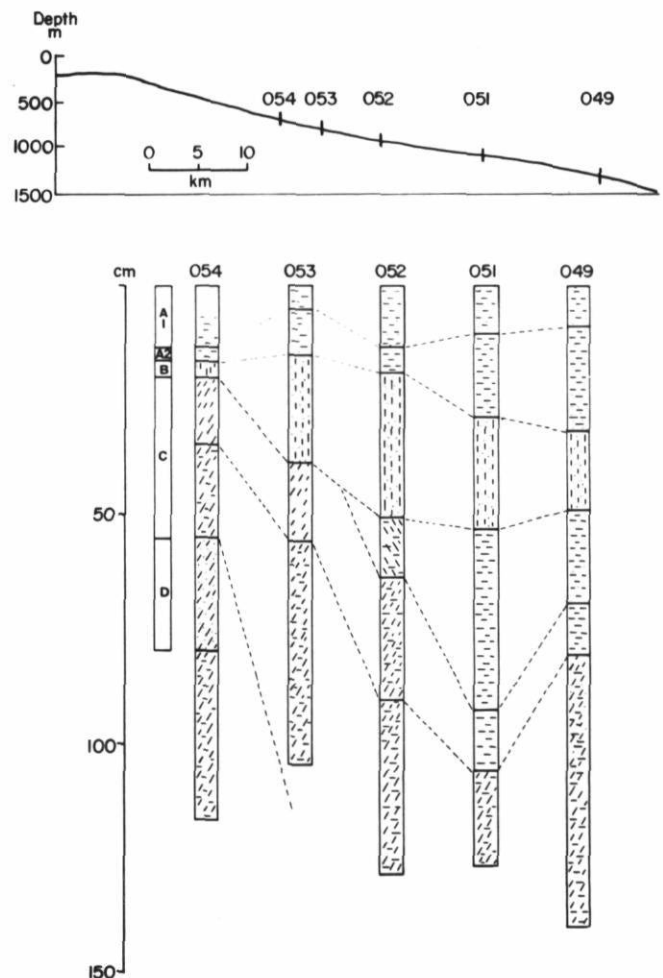


FIGURE 3. Lithologic correlation of cores from North-east Newfoundland slope. Symbols as in Figure 2. Cross section shows bathymetric setting.

Corrélation lithologique entre les différentes carottes provenant du talus continental au nord-est de Terre-Neuve. Les symboles sont les mêmes que ceux de la figure 2. La bathymétrie est montrée en coupe transversale.

as deep as 30 cm in BP-107, 77-014-1G, and 77-034-49. Unit C also appears considerably expanded in cores BP-107 and 104, where an upper browner section and a lower more olive grey section can be distinguished.

In cores 77-014-1G and BP-106, unit B rests on 15-30 cm of apparently slumped material of either unit B or unit C. The base of this slump interval appears to be a disconformity. In BP-106, it rests on a sequence comparable with units D and E. In the gravity core of 77-014-1 it rests on a very thick sequence of compact dusky yellowish brown sediment. The uppermost 20 cm (H1) is a gravelly sandy mud; below this, coarse sediment is rare (H2). The accompanying piston core preserves over 2 m of brown mud (H2), much of it well

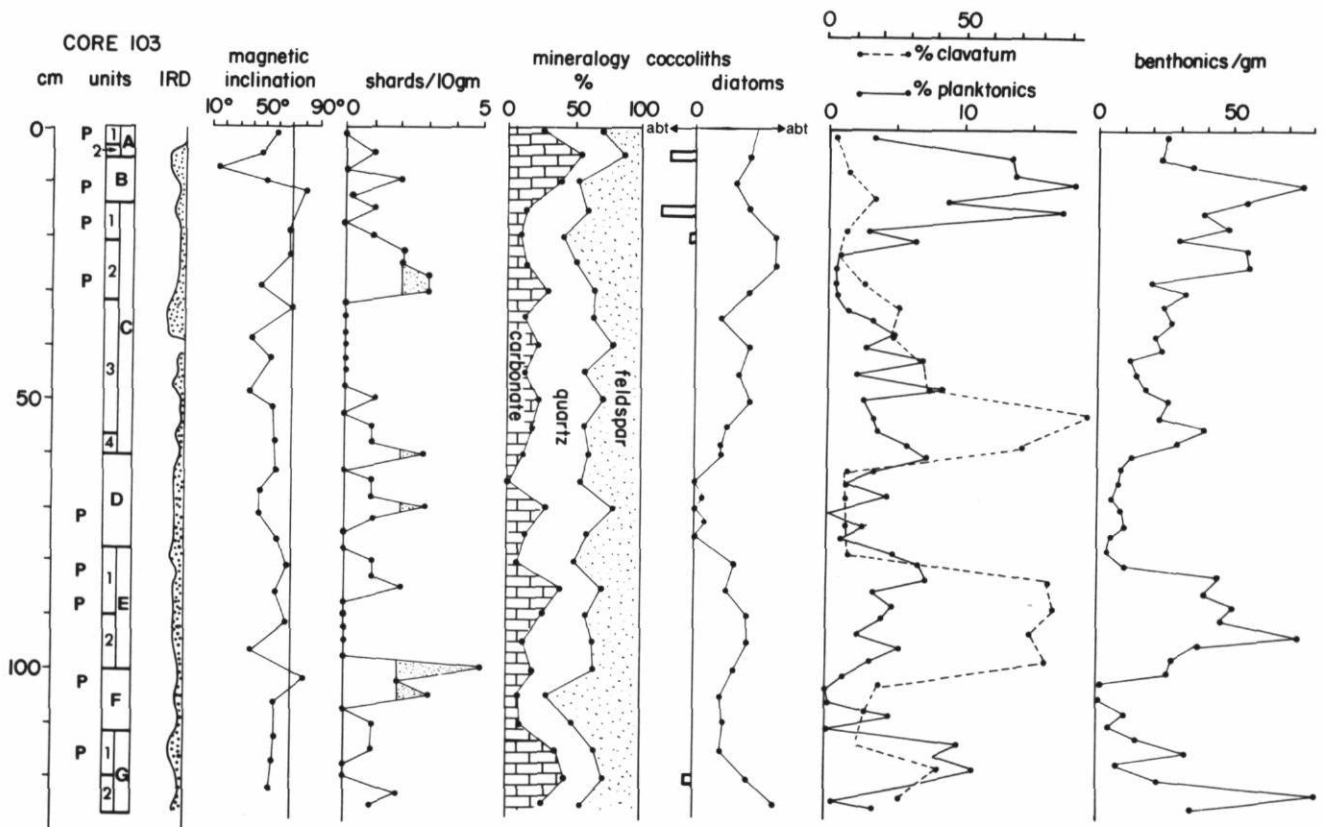


FIGURE 4. Detailed analysis of core BP-103. P = palynological sample; IRD = visual estimation of gravel and very coarse sand in x-radiographs: believed to be mostly ice-rafted debris but may include storm-transported sediment; coccolith and diatoms shown by arbitrary abundance scales estimated from smear slides; % clavatum = *Criboelphidium excavatum clavatum* as a percentage of total benthonic foraminifera; % planktonics = planktonic foraminifera as a percentage of total foraminifera; mineralogy = mineralogy of sand fraction determined by x-ray diffraction.

Analyse détaillée de la carotte BP-103. P = échantillon palynologique; IRD = estimation visuelle du gravier et du sable très grossier d'après les radiographies-x: constitués en grande partie de débris glaciels pouvant contenir des sédiments transportés par des tempêtes; abondance des coccolithes et diatomées évaluée sur lamelles, selon des échelles arbitraires; % clavatum = *Criboelphidium excavatum clavatum* exprimé en pourcentage des foraminifères benthoniques totaux; % planctonique = foraminifère planctonique exprimé en pourcentage des foraminifères totaux; minéralogie = minéralogie de la fraction sableuse d'après la diffraction des rayons-x.

laminated, and with thin interbedded fine sands and scattered gravel (probably ice rafted) in the lower part.

In the continental slope cores (Fig. 3), units A1, A2 and B differ from the shelf cores only in that sand and gravel are more common in A1 on the slope. Unit B is underlain by dusky yellow brown and olive grey muds, generally with low sand and gravel content. These are grossly similar to unit C on the shelf, although correlation in detail has not proved possible. Core 054 on the upper slope has the most condensed sequence, and penetrates a brown sandy mud with very low foraminiferal abundances similar to unit D on the shelf. The other slope cores do not penetrate beyond the apparently extensive C unit.

MICROPALaeontology

1. MARINE MICROFOSSILS

Foraminifera have been examined at 2.5 cm intervals in core BP-103, at 5 cm intervals in 107, and at selected points in other cores (Figs. 4, 5). Coccolith and diatom abundances have been estimated from smear slides (Fig. 4) and diatoms have been determined from core BP-103. Dinoflagellate cysts from core BP-103 are described later (sect. 3).

Planktonic foraminifera are not abundant in the shelf cores (Fig. 4) so that most counts of planktonic species from these cores are not statistically reliable; however, they become increasingly abundant in sediments down

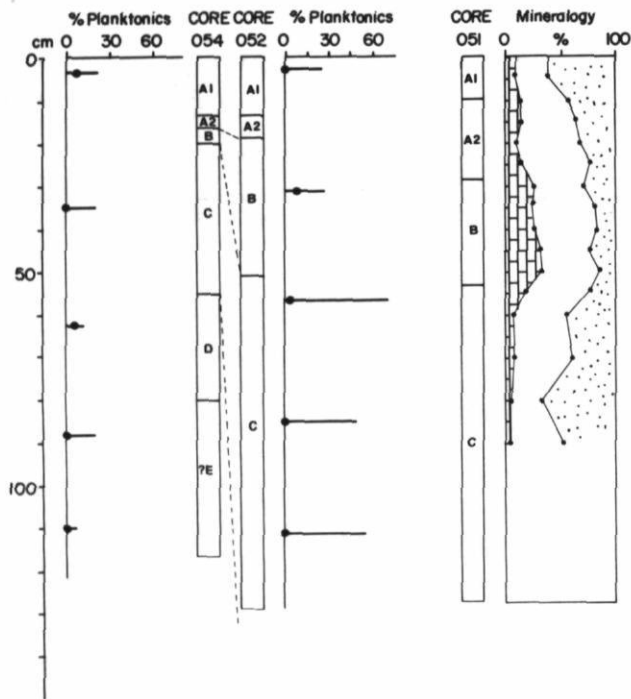


FIGURE 5. Detailed analyses of cores from North-east Newfoundland slope. % Planktonics = total planktonic foraminifera (bar) and *G. bulloides* plus *G. inflata* (circle), both as a percentage of total foraminifera. Mineralogy = mineralogy of sand fraction, symbols and method as in Figure 4. Core location and lithologic units shown in Figure 3.

Analyse détaillée des carottes provenant du talus continental au nord-est de Terre-Neuve. % planctoniques = foraminifères planctoniques totaux (trait horizontal) et *G. bulloides* plus *G. inflata* (cercle) tous étant exprimés en pourcentage des foraminifères totaux. Minéralogie = minéralogie de la fraction sableuse, les symboles et les méthodes étant identiques à ceux de la figure 4. Les localisations et les unités lithologiques des carottes apparaissent sur la figure 3.

the continental slope (Fig. 5). Two types of planktonic foraminiferal assemblages are recognised: "very cold", with more than 98% left-coiling *Globigerina pachyderma* (= *Neogloboquadrina pachyderma*), and "cold" in which left-coiling *G. pachyderma* still predominates but is usually accompanied by 5-10% right-coiling *G. pachyderma* and 15-35% *G. bulloides* and *G. inflata*.

The ratio of planktonic to benthonic foraminifera varies systematically in the cores from Bonavista Channel (Fig. 4). It is low in A1, higher in A2 and reaches a peak of 15-20% in B and the top of C. Lower in the cores, planktonic abundances are low, except toward the base of unit C, in unit E and in unit G, where abundances of up to 8% are found. «Very cold» assemblages are found where planktonic abundances are low. Our limited data show a less regular variation in the slope cores (Fig. 5).

Benthonic foraminifera also vary systematically in their abundance (Fig. 4), being least abundant in units D and F. The assemblage present (Table I) is similar to that described by SEN GUPTA (1971) from the Tail of the Grand Bank. *Criboelphidium excavatum clavatum* is the dominant species in most samples, generally making up between 3 and 20% of the total, but reaching over 80% in the lower part of unit C and in unit E. *Cassidulina crassa* is the dominant species in unit H. The detailed environment significance of changes in benthonic foraminiferal assemblages is unclear. Abundant *C. clavatum* may indicate rather shallower water or a more estuarine circulation than at present. The assemblage in the upper half of unit H2 is similar to that found in the latest Pleistocene Champlain Sea (CRONIN, 1977).

Coccoliths are most abundant in intervals with high planktonic foraminifera abundances. Diatoms are particularly abundant in units A1, the upper part of C, E, and G. In core BP-103, pennate diatoms are particularly diverse and common in the upper part of unit C, suggesting more nearshore conditions. High proportions of warmer water diatoms (*Coscinodiscus centralis*, *C. nodulifer*, *Thalassiosira oestrupii*) are found only in units A and B.

2. POLLEN

Five samples from core BP-106, nine from BP-103 and one from 77-014-1 have been examined for palynomorphs. Results for the latter two cores are summarised in Table II. In most samples interpretation of the assemblage is difficult because of the relatively low concentrations of well-preserved palynomorphs and the presence of redeposited pre-Quaternary pollen and spores (including some distinctive Permo-Carboniferous and Cretaceous-Paleocene forms e.g. *Cicatricosisporites*, *Appendicisporites* and *Podocarpites*). However, counts of at least 100 Quaternary grains were made for all samples except the H2 unit with only 45 grains. The samples fall into 3 groups on the basis of the abundance (% total pollen + spores) of pre-Quaternary taxa: unit A contains < 1%, units B-G have 10-23% and unit H, 49%.

Surface samples (unit A1) from BP-103 and 106 have relatively high pollen concentrations (c. 8000 grains cm^{-3}) which are typical of late Holocene shelf or upper slope marine sediments off boreal regions of North America (VILKS and MUDIE, in press). The pollen composition is characteristic of that found in closed-crown boreal forest areas of Newfoundland today.

Unit B in BP-103 has a lower pollen concentration and larger numbers of redeposited palynomorphs, although the % pre-Quaternary grains is much lower than the abundances (> 20%) considered typical for shelf

TABLE I
Abundance of Foraminifera per 20 ml sediment (D.B. Scott, pers. comm., 1977)

| Cores Depth in cm Unit | BP-103 | | | | | 77-014-1 | | |
|--|---------|----------|---------|----------|----------|--------------|---------------|---------------|
| | 4 A2 | 25 C2 | 70 D | 86 E1 | 105 F | 136(G) H2 | 165 (P) H2 | 240 (P) H2 |
| Planktonic foraminifera | 48 | 18 | 2 | 48 | 4 | 24 | 1 | 1 |
| <i>Criboelphidium excavatum clavatum</i> | 266 | 2064 | 109 | 2384 | 125 | 74 | 30 | 3 |
| <i>Islandiella islandica</i> | 68 | 616 | 120 | 408 | 99 | 2 | — | — |
| <i>Nonionella labradorica</i> | 272 | 168 | 21 | 80 | 13 | 2 | 2 | — |
| <i>Islandiella teretis</i> | 82 | 152 | 57 | 536 | 65 | 134 | — | 1 |
| <i>Buccella frigida</i> | 50 | 24 | 5 | 8 | 6 | — | — | 2 |
| <i>Astrononion gallowayi</i> | 12 | 8 | 2 | — | 21 | — | — | — |
| <i>Nonion barleeianum</i> | 124 | — | 1 | — | 2 | — | — | 2 |
| <i>Protelphidium orbiculare</i> | 6 | — | 16 | 56 | 13 | 116 | 5 | — |
| <i>Protelphidium bartletti</i> | — | — | — | 8 | — | 82 | — | — |
| <i>Cassidulina crassa</i> | — | — | — | — | — | 450 | 20 | 1 |
| <i>Spiroplectammina biformis</i> | — | — | — | — | — | 36 | — | — |
| <i>Reophax nana</i> | — | — | — | — | — | 24 | — | — |
| <i>Eponides wrighti</i> | 4 | — | 20 | 56 | 15 | 44 | 1 | — |
| Others | 94 | — | 20 | 56 | 15 | 16 | 10 | 5 |

sediments deposited during glacial intervals (STANLEY, 1966). The Holocene pollen indicates open boreal woodland interspersed with tundra, similar to that recorded in southeast Labrador lakes 4000-6000 BP (JORDAN, 1975). Unit C1 has a very low concentration of both Holocene and pre-Quaternary palynomorphs, probably indicating a subarctic upland region sparsely vegetated with shrub-tundra. Unit C2 is similar but has higher representation of herb tundra elements and a significantly higher concentration of pre-Quaternary spores. In unit D of core BP-103 there is a relatively high concentration of tundra pollen, including taxa, e.g. *Salix*, *Dryas* Ericaceae, poorly adapted for long-distance dispersal, which suggest a nearby pollen source.

In unit E1 (top and base) the pollen comprises a confusing assemblage of tundra, boreal and deciduous forest elements, notably including some temperate tree genera e.g. *Carya*, *Castanea* and *Ulmus*, which are conspicuous pollen or macrofossil elements of Wisconsinan interstadial or interglacial deposits on the Magdalen Islands (PREST *et al.*, 1976) and at Milford Quarry, Nova Scotia (PREST, 1977). These temperate tree elements are also present in a poorly preserved state (indicative of redeposition) in unit F; however, the well-preserved pollen fraction of unit F clearly indicates the regional presence of an extensive herb tundra.

The assemblage in unit G is similar to that in B, with low pollen concentrations and proximity of herb tundra suggested by relatively high % Cyperaceae. However, the strong representation of boreal forest elements, including *Abies*, probably also indicates the regional presence of forest-covered areas. The sample from the upper part of unit H2 contains a very low concentra-

tion of almost entirely reworked palynomorphs (about 50% pre-Quaternary), including many from a Cretaceous-Tertiary marine sediment source; there is a minor representation of Holocene tundra elements.

3. DINOFLAGELLATE CYSTS

Variable concentrations of Quaternary Dinoflagellate cysts (dinocysts) were found in the palynological preparations (Table II) and may be used as another source of paleoceanographic evidence. The relationship between cyst distributions and oceanography has been determined for modern shelf and deep-sea sediments in the Northwest Atlantic (WALL, *et al.*, 1977; REID and HARLAND, 1977), and the Quaternary dinocysts have been described in cores from the southeast slope of the Grand Banks (HARLAND, 1973). These data show that the outer shelf environment on the northwestern margin of the Gulf Stream is characterised by a "cool temperate" dinocyst assemblage dominated by *Operculodinium centrocarpum* (40-70%) and *Spiniferites* spp. (10-20%), several minor species also usually being present in addition to Peridinium-type cysts. In contrast, *Spiniferites* has not been found in Holocene sediments of the Central Labrador Shelf and Baffin Bay, where subarctic "cold water" cyst assemblages monotonously comprise 3 taxa: *O. centrocarpum* (> 50%), *Peridinium* spp. (> 25%) and an undescribed *Nematospheropsis* sp. (Mudie, unpubl.).

In unit A1 of BP-103 the abundance of *O. centrocarpum* and the absence of spiniferitid cysts indicates the modern dominance of the cold Labrador current. Cyst assemblages in units B, C and D suggest warmer water, with a relatively high representation of thin-

TABLE II

Relative abundance and concentration of palynomorphs in Core BP-103 and the H facies of Core 77-014-1. Relative abundances based on total Quaternary, pre-Quaternary and Dinocyst numbers, respectively. % pre-Quaternary is based on total Quaternary + pre-Quaternary palynomorphs

| SAMPLE Depth (cm). Unit | CORE BP-103 | | | | | | | | | 77-041-1 |
|---|-------------|-------|-------|-------|-------|-------|-------|---------|---------|----------|
| | 0-2 | 10-13 | 17-20 | 27-30 | 70-72 | 80-83 | 87-90 | 102-104 | 113-116 | 137-141 |
| | A1 | B | C1 | C2 | D | E1 | E1 | F | G1 | H2 |
| QUATERNARY : ARBOREAL | | | | | | | | | | |
| <i>Picea</i> | 64 | 29 | 28 | 21 | 29 | 18 | 22 | 18 | 22 | 27* |
| <i>Abies</i> | 10 | 1 | — | 2 | + | — | — | — | 3 | — |
| <i>Pinus</i> | 16 | 3 | 6 | 6 | 11 | 3 | 9 | 2 | 6 | 27* |
| <i>Tsuga</i> | + | — | — | + | — | 3 | — | — | — | — |
| <i>Betula</i> ¹ | +,— | 6,2 | 13,6 | 5,4 | 2,3 | 5,— | 2,3 | 3,— | 2,4 | — |
| <i>Carya</i> | — | — | — | — | + | — | 2 | 2* | — | — |
| <i>Quercus</i> | 2 | 2* | 2 | 2* | 2* | 5 | 5* | 6* | — | — |
| <i>Fagus</i> | — | — | — | — | — | — | 2 | + | — | — |
| <i>Ulmus</i> | — | — | — | — | + | 3 | 3* | 1 | 1 | — |
| <i>Acer</i> | — | — | — | — | 3* | 5 | — | — | — | — |
| <i>Castanea</i> | — | + | — | — | — | 5 | — | 1* | — | — |
| <i>Alnus</i> | — | 1 | 2 | 2 | + | 10 | 2 | 3 | 4 | — |
| Other | 2 | + | 2 | + | 10 | 3 | 6 | 5 | 7 | 7 |
| QUATERNARY : HERBACEOUS | | | | | | | | | | |
| <i>Salix</i> | — | — | 2 | 3 | 2 | 3 | 2 | 4 | 3 | 7* |
| <i>Dryas</i> | — | 2 | — | + | 3 | — | 3* | 3* | — | — |
| Ericaceae | — | + | 2 | — | 2 | — | 3 | 2 | — | 7 |
| Gramineae | — | 3 | — | 2 | 2 | — | — | + | 3 | — |
| Cyperaceae | + | 3 | — | 3 | 1 | 3 | 3 | + | 6 | — |
| <i>Sphagnum</i> | + | 1 | — | — | + | 8 | 2 | 2 | — | — |
| Moss | + | 5 | — | 6 | 4 | 10 | 3 | 8 | 1 | — |
| <i>Selaginella</i> | 2 | 13 | 8 | + | — | 3 | — | + | 4 | — |
| <i>Lycopodium</i> | — | + | 2 | 3 | — | — | — | + | 3 | — |
| Fern | 4 | 7 | 9 | 6 | — | 8 | 6 | 9 | 10 | 7 |
| Other | 6 | 10 | 8 | 19 | 15 | 10 | 13 | 14 | 10 | 13 |
| INDET. | 2 | 9 | 5 | 14 | 8 | 13 | 8 | 14 | 9 | 7 |
| CONC. cm ⁻³ x 10 ³ | 7.81 | 2.04 | 1.43 | 3.34 | 2.37 | 2.45 | 2.58 | 5.13 | 2.14 | 0.38 |
| PRE-QUATERNARY POLLEN-SPORES | | | | | | | | | | |
| Palaeozoic | 100 | 38 | 17 | 58 | 21 | 86 | 69 | 77 | 32 | 21 |
| Podocarp | — | 11 | 17 | — | — | — | — | — | 5 | — |
| Bisaccate | — | 31 | 50 | 24 | 37 | 14 | 14 | 14 | 21 | 36 |
| Appendisp. | — | — | 17 | — | — | — | — | 5 | — | 7 |
| Cicatrico. | — | 8 | — | — | — | — | 7 | 5 | 5 | — |
| CONC. cm ⁻³ | 63 | 263 | 162 | 1011 | 436 | 429 | 427 | 631 | 192 | 360 |
| % PRE-QUAT. | 0.8 | 11.4 | 10.2 | 23.7 | 15.5 | 15.1 | 14.2 | 11.0 | 8.2 | 48.6 |
| DINOCYSTS | | | | | | | | | | |
| Operculodin. | 7 | 64 | 37 | 30 | 42 | — | 50 | 43 | 10 | — |
| Spiniferites | — | 11 | 21 | 12 | 17 | — | — | 4 | — | 25 |
| Peridinium | 26 | 4 | 21 | 48 | 25 | 89 | — | 4 | 67 | — |
| Pre-Quatern. | 6 | 21 | 21 | 18 | 25 | 11 | 50 | 54 | 13 | 50 |
| CONC. cm ⁻³ | 1940 | 263 | 162 | 1011 | 275 | 552 | 427 | 631 | 212 | 303 |

1. % with grain diameter > 20 μm, < μm; + pollen present at < 1%; * stain intensity indicates redeposition.

walled *Peridinium* Type-C cysts (NORRIS and McANDREWS, 1970) in units C2 probably indicating low salinity nearshore water. The sample from the top of unit E1 is entirely dominated by similar *Peridinium* cysts, while the assemblage at the base of E2 suggests conditions slightly warmer than at present, continuing through to the top of unit F. *Peridinium*-type dinocysts again predominate in the upper part of unit G.

PETROLOGY

The petrology of some twenty samples has been examined in detail by standard microscope and x-ray diffraction techniques. In addition, bulk sand fraction mineralogy has been examined by x-ray diffraction in cores BP-103 (Fig. 4) and 77-034-051 (Fig. 5).

1. SAND AND GRAVEL FRACTION

Statistically representative gravel samples are not available. Crystalline rock fragments predominate in unit A and at some other levels; in some samples, notably in unit B, sedimentary rock fragments make up 5 to 35% of the gravel fraction: lithologies include carbonates and red sandstones.

The light mineral fraction of the sands shows variations similar to that shown by bulk mineralogy by x-ray diffraction, with almost equal abundances of quartz, feldspar and carbonate (calcite and dolomite subequal). The persistence of dolomite indicates that at least some of the carbonate is detrital, not biogenic. Heavy mineral assemblages do not vary significantly through the section: opaques, pyroxene, garnet and amphibole predominate, along with glauconite. Very small numbers of tourmaline, zircon and apatite grains are found in brownish lithologies and in unit B, and garnet is also more abundant in these samples. The principal source of heavy minerals thus appears to be from crystalline rocks (indicated by pyroxene and amphibole in particular), augmented in the brownish lithologies by a polycyclic sedimentary source represented by glauconite, tourmaline, zircon, apatite and garnet.

It is difficult to evaluate the relative importance of ice rafting compared with reworking of local till or bedrock. The gravel fraction appears ice-rafted, at least when associated with predominantly fine grained muds, but in areas of irregular topography and thin surficial sediment cover, some contribution from storm wave erosion of till cannot be ruled out (*c.f.* FILLON, 1976). The lack of gravel and coarse sand below unit B on the deeper parts of the continental slope (Fig. 3) suggests storm wave erosion is important in the lower part of the shelf cores as a source of coarse sediment.

2. CLAY FRACTION

Clay mineral abundances have been quantified in the same way as by PIPER and SLATT (1977). Unit A contains about 70% illite, with sub-ordinate chlorite and rare montmorillonite and kaolinite. PIPER and SLATT (1977) interpreted similar assemblages as derived from tills eroded from pre-Mesozoic strata. Unit B and other olive grey lithologies typically have 50-70% illite, 10-15% montmorillonite, up to 10% kaolinite and 20-30% chlorite. Brown lithologies have less illite (40-50%) and correspondingly higher proportions of other minerals. PIPER and SLATT (1977) interpreted such assemblages as derived from reworking of tills from Mesozoic or Cenozoic strata, or directly from bedrock of that age.

3. VOLCANIC ASH

Shards of volcanic ash are a minor component of many north-west Atlantic cores. AKSU (1977) found shards concentrated in the coarse silt fraction of cores from Baffin Bay. The coarse silt fraction of cores BP-103 and 107 was systematically examined for ash. Ash was extremely rare (Fig. 4), but concentrations of 3 or more grains per 10 gm were found in adjacent samples at two levels — in the middle of unit C (both cores), and in unit F (not penetrated in 107).

The ash is so diluted that no great reliance can be placed on its use as a stratigraphic marker. However, its presence in the cores is probably related to two widespread ash layers recognized in the north-west Atlantic (RUDDIMAN and GLOVER, 1972, 1975) dated approximately at 9300 BP and 63,000 BP, or to two additional ash layers found in the North-west Atlantic mid-ocean canyon, dated at (?) 17,000 BP and about 23,000 BP (CHOUGH, 1978). Both re-sedimentation and bioturbation can redistribute ash through the stratigraphic column.

ENVIRONMENTAL CONDITIONS RECORDED IN CORE BP-103

The environmental conditions that may have influenced late Quaternary sedimentation in the North-east Newfoundland shelf cores can vary in a complex manner. Surface water temperature and circulation affects both microfossils and the supply of ice-rafted debris. Sea level changes influence benthonic foraminifera and sedimentation, including reworking of older deposits. Proximity of Newfoundland glacial ice may influence freshwater discharge and sedimentation. A tentative interpretation of core BP-103 is presented.

1. *Unit A1, 0-3 cm.* This represents modern conditions, dominated by the Labrador Current. There is fairly high diatom productivity but low production of calcareous

microbiota, and the few planktonic foraminifera found are the "very cold" assemblage, exclusively left coiling *Globogerina pachyderma* (= *Neoglobobulimina pachyderma*). The continental slope cores, where planktonic foraminifera are abundant, confirm this interpretation for the shelf. The pollen is derived predominantly from the boreal forest of Newfoundland. Ice rafted gravel is rare; in contrast, it is common in the continental slope cores, suggesting that most bergs are transported and melt off the edge of the shelf.

2. *Unit A2, 3-5 cm.* This is similar to A1, but has a greater amount of gravel sized material, presumably ice rafted. Planktonic foraminifera are more abundant and species other than left coiling *G. pachyderma* appear, indicating warmer water.

3. *Unit B, 5-14 cm.* This unit shows a continuation of the trend seen in unit A2. Planktonic foraminifera ("cold" assemblage) are relatively abundant and indicate warmer water than at present; a few coccoliths occur. The spiniferitid dinocysts also suggest water temperatures warmer than at present. Pollen indicates open boreal woodland interspersed with tundra, and larger numbers of redeposited palynomorphs probably indicate shallower water conditions. The continental slope core 052 confirms the interpretation of the planktonic foraminifera. Abundant ice-rafted carbonate is also found in the slope cores (Fig. 5, core 051). In general, this unit indicates warmer water conditions than at present, but probably cooler conditions on land, and a somewhat lower sea level.

4. *Unit C1, 14-20 cm.* Total foraminiferal abundance and the percentage of planktonic foraminifera is decreased, but the assemblage is still "cold", coccoliths are present and diatoms are abundant (the diatom assemblage from here down is colder than in units A and B). Pollen suggests a sparsely vegetated shrub-tundra upland. Detrital carbonate is much less abundant than in unit B. Sand and gravel, presumably ice-rafted, are found only in the most seaward slope core (051, Fig. 3), suggesting an eastward movement of the Labrador current, or the zone of melting.

5. *Unit C2, 22-32 cm.* Planktonic foraminifera are rare but probably "cold" while benthonic foraminifera and diatoms are quite abundant, with nearshore pennate diatoms particularly common. Reworked pollen becomes abundant; well preserved pollen indicates herb tundra, and dinocysts suggest a strong fresh water influence. Thus there appears to be a marked decrease in supply of surface open oceanic water, and perhaps the development of a broadly estuarine type of circulation. This could result from a substantial lowering of sea level. The absence of sand and gravel in the slope cores suggests coarse sediment on the shelf is probably reworked rather than ice-rafted.

6. *Unit C3, 32-57 cm.* This shows rather variable conditions, with total foraminiferal abundance and percentage of planktonic foraminifera comparable with the present day. The planktonic assemblage is "cold" at some levels, "very cold" at others. However, *C. excavatum clavatum* dominates the benthonic foraminiferal assemblage, the sediment is reddish brown in colour, and pollen from this unit in BP-106 suggests tundra, with abundant reworked pollen.

7. *Unit C4, 57-60 cm.* The extreme base of unit C is distinctly olive grey in colour. It is similar to the overlying part of unit C, except that there is a peak in both total foraminiferal abundance and the proportion of planktonic foraminifera (which are of a "cold" assemblage). No palynomorph sample has been examined.

8. *Unit D, 60-78 cm.* This unit has low numbers of benthonic foraminifera, low diatom and dinocyst concentrations, and a low proportion of "very cold" planktonic foraminifera. The sediment is reddish brown, and there is considerable gravel sized material. Although the calcareous biogenic assemblages are not greatly different from those at core tops, the sediment is very different from unit A1, pollen indicates the proximity of tundra conditions, and the dinocysts suggest the continued influence of Gulf Stream water.

9. *Unit E1, 78-90 cm.* This is rather similar to unit B, with high presumably ice-rafted carbonate (including dolomite) and abundant foraminifera, including a high percentage of "cold" planktonics. However, no coccoliths were seen, planktonic foraminifera are less common than in B and C. *exclavatum clavatum* makes up > 90% of the benthonic foraminifera. The well preserved pollen has a mixed aspect, including southern boreal forest and herb tundra elements. Dinocysts suggest cool, relatively low salinity water.

10. *Unit E2, 90-100 cm.* The foraminiferal assemblages and abundant diatoms are very similar to the top of unit C (14-20 cm) except for the dominance of *C. excavatum clavatum*.

11. *Unit F, 100-112 cm.* This unit closely resembles D, except that foraminifera are even less abundant. Pollen indicates a cold tundra-dominated terrestrial environment, but warmer water spiniferitid dinocysts are again found.

12. *Unit G1, 112-120 cm.* This is similar to unit B, with abundant detrital carbonate and with planktonic foraminiferal abundances higher than in E. The pollen is similar to B, while the dinocyst assemblage is cold.

13. *Unit G2, 120-126 cm.* This is similar to the top of unit C (14-20 cm), with very high diatom abundances, some ice-rafted sediment and moderate foraminiferal abundances. In core BP-105, this unit almost entirely lacks sand and gravel, suggesting that the coarse sediment is locally eroded rather than ice rafted.

AGE

Unit A1 represents modern conditions. Marine microfossils in unit A2 show substantial warming and it might correspond to the early Holocene time when the Labrador Current was not developed, prior to about 6000 BP (FILLON, 1976), or it may simply correspond to the climatic optimum (hypsihermal) interval, ca. 4000-6500 BP, in S. E. Canada. CARTER *et al.* (1979) obtained a ^{14}C date of 4135 ± 230 yr. BP from the middle of unit A on the north-east Newfoundland slope.

Unit B records an interval of carbonate-rich sediment deposition. Carbonate-rich ice-rafted sediment is widespread at the end of the late Wisconsinan in Baffin Bay (AKSU, 1977; AKSU and PIPER, 1979). CHOUGH (1978) found two phases of carbonate-rich turbidite sedimentation in the Northwest Atlantic mid-ocean channel; the younger one terminated about 7100 BP and began perhaps 11,000 BP, while the older one began ca 23,000 BP. We tentatively correlate the carbonate-rich unit B with the period of rapid deglaciation of Foxe Basin, or Devon and Ellesmere Island, 7000-8000 BP. The low inclination magnetic event in unit B of BP-103 (Fig. 4) and unit A2 of BP-107 may thus correspond to the Laschamps event at 7000-9000 BP (NOEL and TARLING, 1975).

The increase in number of shards in unit C2 overlying a sequence of core with no detectable ash may be due to fortuitous reworking, but probably corresponds with the 9300 BP ash layer of RUDDIMAN and GLOVER (1973). Alternatively, it might correspond to either of the ca. 17,000 or 23,000 BP ash layers of CHOUGH (1978). However, the presence of ash all the way to the base of core BP-103 suggests it does not penetrate below the 65,000 BP layer of RUDDIMAN and GLOVER (1975), hence we favour the youngest date for unit C2.

Units C through G appear to have accumulated under cool conditions with lowered sea level. They contain no datable material, and their age remains speculative. They do not clearly record an interglacial interval. With a high sedimentation rate, they could be entirely late Wisconsinan. However, the substantial variations in microfossil type and abundance, and in sediment type, suggests a succession of stadials and interstadials, implying that unit G lies in the mid- or even early-Wisconsinan. In particular, a number of indicators (foraminifera, dinocysts, pollen) point to a warming episode (? interstadial) in unit E. The pre-late Wisconsinan stratigraphy of Newfoundland is virtually unknown (TUCKER, 1976; GRANT, 1977), but comparison with Nova Scotia (PREST, 1977) and the Magdalen Islands (PREST *et al.*, 1976) suggests E could possibly correlate with the interstadial giving ^{14}C dates of 32,000-35,000 BP. Such an interpretation is consistent with a fairly uniform overall rate of sedimentation, rather more rapid in unit B, and rather slower in unit A (line A in Fig. 6).

Alternatively, the ice-rafted carbonate in unit E may correspond to the carbonate event that began 23,000 BP (CHOUGH, 1978). This would imply a marked decrease in sedimentation rate in unit A, and is shown as line B in Figure 6. This interpretation is supported by the pollen data, which do not indicate maximum glacial conditions in the upper part of unit C, hence suggesting a date younger than 18,000 BP. If so, unit D would correlate with a late Wisconsinan maximum 18,000-22,000 BP.

Conditions during the deposition of unit H in core 77-014-1 were much more extreme and rapid sedimenta-

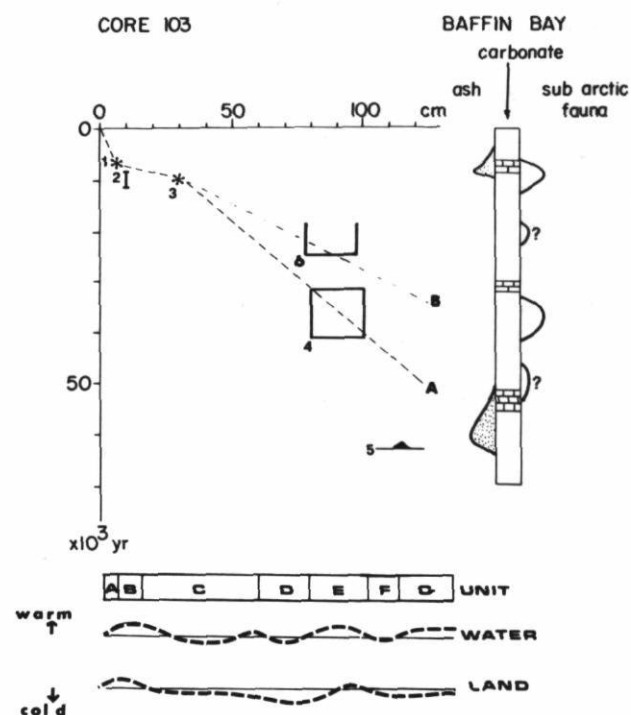


FIGURE 6. Summary of inferred land and water temperatures, and rate of sedimentation in core BP-103, compared with generalised succession in Baffin Bay. A and B are two alternative interpretations. Datable events: 1) termination of carbonate rich turbidites in NAMOC; 2) Laschamps event; 3) 9300 BP ash horizon; 4) mid-Wisconsinan interstadial in Nova Scotia; 5) 63,000 BP, ash horizon (not penetrated); 6) beginning of lower carbonate horizon of CHOUGH (1978). Fuller explanation in text.

Sommaire des reconstitutions des températures de l'eau et de la terre ainsi que des taux de sédimentation de la carotte BP-103, comparées à la succession généralisée des événements de la mer de Baffin. A et B représentent une alternative. 1) Fin des turbidites riches en carbonates dans NAMOC; 2) événement de Laschamps; 3) horizon des cendres de 9300 BP; 4) interstades du Wisconsinien moyen en Nouvelle-Écosse; 5) horizon des cendres de 63 000 BP (aucune pénétration); 6) début de l'horizon carbonatée de CHOUGH (1978). Explications supplémentaires dans le texte.

tion of kaolinite muds occurred. The palynomorphs and benthonic foraminifera suggest proximity of extensive glacial ice and much shallower water. It seems that this must date from either early Wisconsinan or more probably an Illinoian ice advance across much of the continental shelf.

DISCUSSION

The cores studied reveal a complex environmental history probably from the mid-Wisconsinan to the present, with some evidence in core 77-014-1 of even earlier conditions. Any detailed interpretation is hindered by the uncertainties of dating the lower parts of the cores, the lack of data on contemporary marine microfossil distribution in this region, and the complexity of the pollen record because of reworking. It will require many more cores to unravel the detailed geologic record in this area: of ten cores that we examined, only two had a continuous probably mid-Wisconsinan record.

The late Holocene sedimentation conditions are unique in the cores; at no other time does there appear to be so little evidence of reworking of continental shelf strata. This probably indicates that the present water depth is greater than at any other time represented in the cores. The abundance of kaolinite, glauconite, and the presence of reworked pollen throughout the rest of the cores suggests substantial sea-floor reworking of Cretaceous, Cenozoic (including earlier Quaternary) strata, either directly, or in till, presumably by storm waves, since there is no evidence of close proximity of glacial ice above the H unit. A combination of "eustatic" sea level lowering and a peripheral bulge marginal to a Newfoundland ice cap that extended approximately to the present coastline (GRANT, 1977) could have reduced water depth by 50 to 150 meters.

Despite the problems of reworking, the Quaternary pollen assemblages imply a post-glacial terrestrial vegetation history that is internally consistent and also compatible with other data in the core; hence, some remarkable coincidences are required if the pollen spectra are to be interpreted as entirely reworked. Most of the core sequences correspond to tundra conditions prevailing in adjacent land areas, with regional boreal forest clearly indicated in the uppermost part of the core. The boreal and temperate forest elements in the lower part of core BP-103 provide less clear evidence for interstadial forest development in this region and may represent long-distance transport from the south or the reworking of Sangamon interglacial deposits.

Seawater temperatures, estimated from planktonic foraminifera and dinocyst assemblages, do not correspond precisely to inferred terrestrial temperature

conditions. Three or possibly four periods of rather warmer water (units B, E and G and possibly C4) are characterized by sub-arctic ("cold") planktonic foraminifera, tundra pollen assemblages, and considerable abundance of ice-rafted carbonate. B probably represents the early Holocene. E and G are probably mid-Wisconsinan interstades and might be broadly correlated with the periods of sub-arctic water penetration into Baffin Bay recognised by AKSU and PIPER (1979) (Fig. 6), which apparently triggered melting of ice shelves or glaciers around Baffin Island with abundant carbonate detritus. The peaks in carbonate abundance in units B, E and G (Fig. 3) can perhaps be correlated with carbonate-rich horizons in Baffin Bay (Fig. 6).

The age indicators (Fig. 6) suggest that sedimentation was unusually rapid during unit B (even on interpretation A). This is supported by the evidence of slumping in cores 106 and 014-1. Much of this sediment appears to have been ice-rafted debris. The generation of slumps on slopes of less than 1 in 400 on the continental shelf suggest that where unit B accumulated on steeper continental slopes, there would have been much slumping and turbidity current generation. It is not clear whether ice-rafted debris was entirely derived from the north, or whether any was supplied from Wisconsinan ice sheets in Newfoundland. The ice-rafted clasts of sedimentary lithologies, including red sandstones, could be derived either from the Arctic Islands (AKSU, 1977) or from glacial erosion of the Newfoundland Shelf (since similar ice-rafted lithologies are found in Baffin Bay, a Newfoundland source is not essential). It is also not clear whether much of the gravel in units C through G is ice-rafted: it may well be reworked by storm waves off till hummocks into the sediment basins.

The lower part of unit H is quite distinct, with a very low biogenic content, and much better sorting than other units. It clearly indicates quite different sedimentation conditions. Clay mineralogy suggests a source in kaolinitic Cretaceous sediments and pre-Quaternary palynomorphs indicate a Cretaceous-Tertiary marine sediment source. Sedimentologically the unit is similar to pro-glacial clays (PIPER and IULIUCCHI, 1977), the pollen suggests much more extreme conditions than in units A through G, and the foraminifera suggest proximity of ice. Slatt (pers. comm.) obtained a core of reddish till on the central N.E. Newfoundland shelf. These lithological and palaeontological data point to an extensive (?) Illinoian ice advance that glacially eroded Cretaceous and Cenozoic shelf strata, probably comparable with the late Illinoian advance that supplied red sediment to the Fogo Seamounts (ALAM and PIPER, 1977).

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