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Pre-Wisconsin stratigraphy and paleoclimates off Atlantic Canada, and its bearing on glaciation in Québec

Stratigraphie et paléoclimats pré-wisconsiniens du Canada atlantique

Implications sur les glaciations du Québec

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Résumé de l'article

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PRE-WISCONSIN STRATIGRAPHY AND PALEOCLIMATES OFF ATLANTIC CANADA, AND ITS BEARING ON GLACIATION IN QUÉBEC

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ABSTRACT Cores from tops of seamounts close to the continental shelf west of the Grand Banks contain sequences of alternating clays (representing glacials) and foram nanno ooze (deposited in warmer periods), back to the Pliocene. Although sedimentation in the cores is controlled primarily by glacial conditions on the Grand Banks and Laurentian Channel, glacial history further inland can be inferred. The Wisconsin sequence shows two cool interstadials and one rather warmer one, correlable with the Plum Point, Port Talbot and St. Pierre Interstadials. Clay sedimentation during Wisconsin glacial stages was minor, suggesting glaciers did not extend to the shelf edge. In the late Illinoian, there was a major influx of red sediments, indicating significant erosion of the Gulf of St. Lawrence and Laurentian Channel. Glaciation was more extensive than during the Wisconsin. Two Illinoian interstadials, with temperatures between those of the Plum Point and St. Pierre interstadials are recognised. Early Illinoian glaciation was the most severe yet recognised in the cores. Sedimentation appears to have been controlled by the advance of a Newfoundland — Labrador — E. Québec ice sheet across the Grand Banks.

RÉSUMÉ *Stratigraphie et paléoclimats pré-wisconsiniens du Canada atlantique: implications sur les glaciations du Québec.* Des carottes prises au sommet de monts sous-marins près du plateau continental, à l'ouest des Grands Bancs, contiennent des séries d'argiles (représentant les périodes glaciaires) et des couches de vases à Foraminifères (représentant les périodes plus chaudes) qui remontent jusqu'au Pliocène. Bien que la sédimentation ait été contrôlée principalement par les conditions existant sur les Grands Bancs et dans le chenal laurentien, on peut tirer quelques conclusions sur l'histoire glaciaire de l'arrière-pays. La série wisconsinienne indique deux interstades relativement froids et un autre plus chaud, qu'on peut mettre en corrélation avec les interstades de Plum Point, de Port Talbot et de St-Pierre. La sédimentation des argiles n'était pas très importante pendant ces épisodes, ce qui laisse supposer que les glaciers n'ont pas atteint la limite du plateau continental. Le tardi-Illinoien est caractérisé par un dépôt important de sédiments rouges, ce qui indique l'érosion du golfe du St-Laurent et du chenal laurentien. Les glaciers étaient plus étendus que pendant le Wisconsinien. Deux interstades illinoiens, marqués par des températures intermédiaires entre celles des interstades de Plum Point et de St-Pierre, ont été identifiés. La glaciation de l'Illinoien inférieur fut la plus sévère, d'après l'observation des carottes. Il semble que la sédimentation ait été contrôlée par l'avancée d'une calotte de glace en provenance de l'ensemble Terre-Neuve-Labrador-Québec, à travers les Grands Bancs.

РЕЗЮМЕ ДО-ВИСКОНСИНСКАЯ СТРАТИГРАФИЯ И ПАЛЕОКЛИМАТ К ВОСТОКУ ОТ ПРИ-АТЛАНТИЧЕСКИХ ПРОВИНЦИЙ КАНАДЫ И ИХ ВЛИЯНИЕ НА ОЛЕДЕНЕНИЕ ПРОВИНЦИИ КВЕБЕК. Керны взятые с вершин поднятий морского дна вблизи от континентального шельфа к западу от Ньюфаундлендской банки, содержат последовательности чередующихся слоев глин (представляющих ледниковые периоды) и ил типа «Форам нанно» (отложенный в более теплые периоды). Полученные отложения берут свое начало в Плиоценской эре. Хотя речь идет об отложениях в районе Ньюфаундлендской Банки и в проливе Св. Лаврентия времен ледникового периода, сходное положение наблюдалось и внутри страны. Висконсинское оледенение содержит два холодных межстадиала и один весьма теплый, который можно сравнить с Плам Пойнтским, Порт Тальботским и Св. Петровскими межстаеиалами. Глинистые отложения в различные периоды Висконсинского оледенения были весьма незначительными. Это, видимо, указывает на то, что ледники не достигли края континентального шельфа. Однако, в поздний период Иллинойского оледенения наблюдались крупные отложения красной глины, что показывает на значительную эрозию в заливе Св. Лаврентия и проливе Св. Лаврентия. Иллинойское оледенение было более значительным, чем Висконсинское. Два иллинойских межстадиала, с температурами колеблющимися между таковыми Плам Пойнтского и Св. Петровского межстадиалов, были установлены. Согласно анализу кернов, раннее иллинойское оледенение было наиболее крупным из всех. Отложения же видимо, контролировались распространением ледяного покрова с Ньюфаундленда, Лабрадора и восточного Квебека на Ньюфаундлендскую Банку.

INTRODUCTION

A linear seamount chain lies south west of the Grand Banks, 70-100 km from the shelf break. Water depth on top of the seamounts is around 3 km, and they are about 1 km above the regional sea floor. The seamounts are out of the reach of turbidity currents, and have accumulated only thin Pleistocene sediment sequences. Muds derived from the adjacent continent accumulated during glacial periods; foram-nanno ooze during interglacials.

Piston cores have been examined from the tops of five of the seamounts (Fig. 1). Two of these have been described in detail in a thesis by ALAM (1976). A preliminary interpretation of a third was published by PIPER (1975a): we present a fuller interpretation here. Work on the other two cores is in progress. The general setting of the Grand Banks continental margin is described by PIPER (1975b).

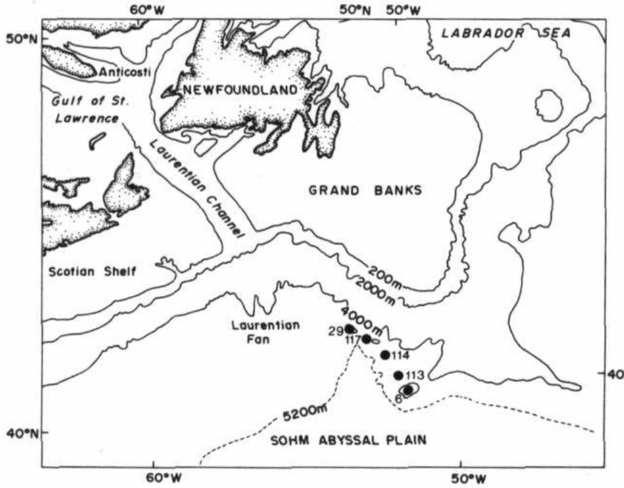

FIGURE 1. General map of area around the Grand Banks, showing location of cores studied.

Carte de la région des Grands Bancs et localisation des forages étudiés.

RESULTS

A. LITHOLOGY

The lithological sequence in the five cores examined is summarised in Figure 2. There are three principal lithologies. *Foram-nanno ooze* contains variable amounts of terrigenous material, includes ice-rafted pebbles, and has carbonate contents generally between 50% and 75%. Carbonate content is generally highest near the middle of beds, and decreases upwards and downwards. *Red mud* is grayish red (10R4/2) to pale brown (5YR5/2) in colour. It consists of about 70% clay and 30% silt. The sand fraction is generally less than 1% and consists mostly of foraminifera. The red mud is mostly structureless, but locally contains fine silt laminae. *Grey mud* is brownish gray (5YR4/1) to olive gray (5Y4/1) in colour: it is otherwise rather similar to the red mud. In places, there is a lithology transitional between the grey mud and the foram-nanno ooze.

These lithologies occur in a distinctive sequence, which allows a lithologic correlation between cores. Correlable lithologic units are identified by letters in Figure 2: units A, C, E, G and I are the principal foram-nanno ooze horizons; units B, F and H are mostly gray mud; and unit D and part of H are dominantly red mud.

B. CHRONOSTRATIGRAPHY

All the cores except core 6 (the southernmost core) fall entirely within the Brunhes normal magnetic epoch. In core 6, the Brunhes rests disconformably on Pliocene sediments. Five carbon-14 dates have been obtained on bulk foram-nanno ooze samples, and are summarised in Fig. 2.

Several biostratigraphic markers have been recognised. *Globorotalia menardii flexuosa* is present in the lower part of the cores, but disappears above unit C. This extinction level is generally accepted as marking the Sangamon interglacial (*i.e.* following termination II of BROECKER and van DONK, 1970, dated at around 127,000 BP). This interpretation is confirmed by the restriction of the coccolith *Emiliania huxleyi* to unit C and above: the base of the E. huxleyi zone is dated at around 150,000 BP (GEITZENAUER, 1972). Discoasters first occur below the disconformity in core 6; this corresponds to the disappearance of *Globorotalia truncatulinoides* and indicates a Pliocene age.

The chronostratigraphy of the upper part of the cores is well established; below unit C, extrapolations can be made on the basis of sedimentation rates. It is hoped that coccolith zonation will refine the stratigraphy of the lower parts of the cores. Unit G is probably around 200,000 to 300,000 BP and unit I 400,000 to 600,000 BP

C. PALEOTEMPERATURE ANALYSIS

A variety of foraminiferal indicators of water mass temperature have been used to document the surface water paleotemperatures of cores 29, 117 and 6. These include the coiling direction of *Globigerina pachyderma,* the relative abundance of the *Globorotalia menardii* complex, *Globorotalia truncatulinoides* and other major planktonic foraminifera, and the porosity of tests of *G. pachyderma* and *G. bulloides.* The results are summarised in Figure 2 and 3. The warmest intervals correspond to the lithogies with the highest calcium carbonate contents, notably the foram-nanno ooze units. Comparing with the tops of the cores, which represent present day conditions, units C, G and I have

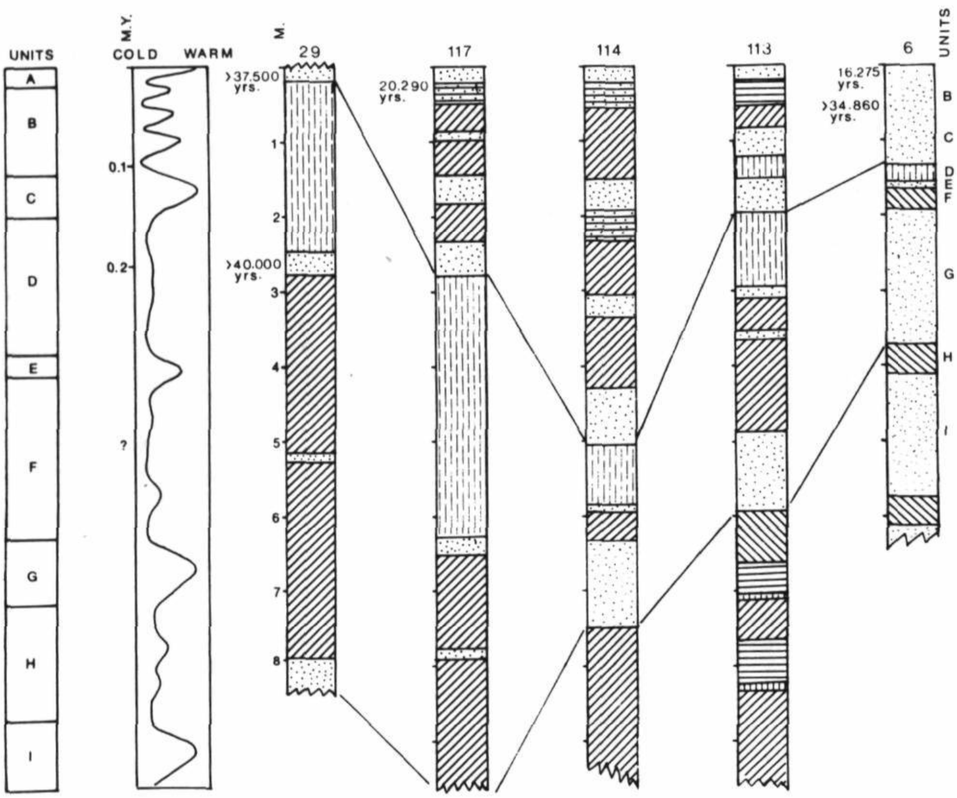

FIGURE 2. General stratigraphic correlation and paleoclimatic interpretation of cores studied. Cold-warm curve based on foraminiferan analysis. Ages are radiocarbon dates. Lithologies: stipple-oram nanno ooze; vertical dashed lines — red mud; oblique lines — grey mud; horizontal lines with stipple — muddy foram nanno ooze.

Corrélations stratigraphiques et interprétation paléoclimatique des forages étudiés: courbe des tendances réchauffement — refroidissement à partir des assemblages de Foraminifères. Chronologie ¹⁴C. Lithologie: boues à Foraminifères (pointillés); argile rouge (verticales); argile grise (obliques); boues argileuses à Foraminifères (horizontales et pointillés).

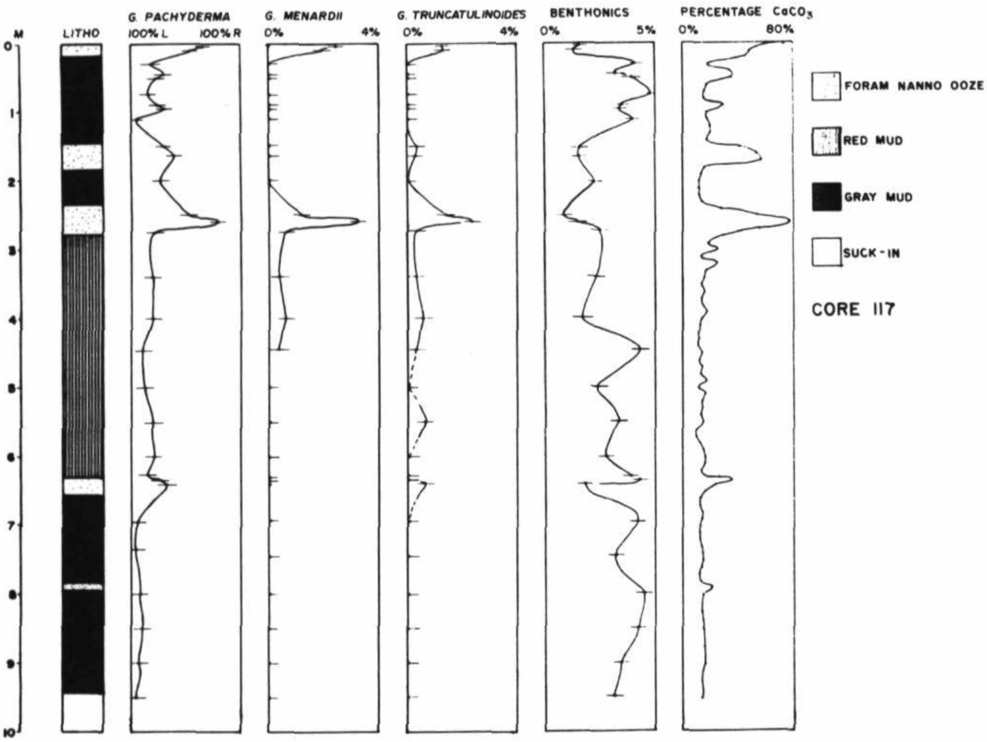

FIGURE 3. Details of paleoclimatic indicators for core 117 (units A-F).

Détail des indicateurs paléoclimatique du forage 117 (unités A-F).

paleotemperatures similar to, or warmer than, those at present. Thinner foram-nanno ooze horizons, with rather low calcium carbonate contents, such as those in unit B, or in the middle of unit F, represent conditions cooler than the present. The red and grey muds represent cold conditions. The very low abundances of planktonic foraminifera in these muds is principally due to low productivity, since the abundance of benthonic foraminifera is roughly constant throughout any one core.

D. PROVENANCE OF DETRITAL SEDIMENT

X-ray diffraction analysis shows that the clay fraction of red muds consists of about 60% illite, 15% chlorite, 15% kaolinite and 10% montmorillonite. The grey muds have higher chlorite and lower kaolinite, averaging 65% illite, 20% chlorite, 5% kaolinite and 10% montmorillonite. The grey muds also have more quartz, feldspar and amphibole than the red muds, both in the $< 2\mu$ fraction (x-ray diffraction) and the 10-30μ fraction (petrographic microscope). The red mud is richer in silt sized hematite, ilmenite and rutile. Following the interpretations of PIPER and SLATT (1977) of the provenance of glacial till and surficial sediments of Atlantic Canada from their $< 2\mu$ mineralogy, we suggest that the red muds are derived from a source similar to that of the red muds of the Laurentian Channel (CONOLLY *et al.*, 1967), Laurentian Fan, and red tills of Nova Scotia — namely Carboniferous and Triassic redbeds of the Maritime Provinces and Gulf of St. Lawrence. The grey muds are similar to tills derived from Newfoundland, and reworked tills on the Grand Banks.

The sand fraction of the muds has been studied in detail in cores 29 and 117. The absence of pebbles and coarse sand suggests the sands were transported not by ice rafting, but in suspension from the shelf break of the Grand Banks. This is confirmed by the presence of glauconite and fine molluscan shell fragments, bored by sponges, in the sand fraction. These lithologies are common on the Grand Banks (Slatt, pers. comm., 1976), but absent in demonstrable ice-rafted sediment. The ratio of rounded to angular quartz grains shows a progressive increase from unit F upwards. Surface textures of quartz grains are dominantly glacial in unit F, but in unit D and especially unit B, grains showing beach reworking are common. There is also a corresponding decrease in abundance and increase in the amount of alteration of feldspar from unit F upwards.

THE STRATIGRAPHIC SEQUENCE

Units A and B correspond to the Holocene and Wisconsinian. There is considerable information available on the extent of glaciation, position of sea level, and sedimentation in nearby areas for these times, which permit a detailed interpretation of these units.

Unit B consists of four cold mud units, separated by three warmer muddy foram-nanno ooze units (B2, B4 and B6). Carbon-14 dating indicates that the youngest warmer unit, B2, is around 20,000 BP. Unit B6 is substantially warmer than B2 or B4, but cooler than the Sangamon (C). It has an extrapolated age of around 75,000 BP This correlates well with the Ontario — Québec terrestrial stratigraphy, where the St. Pierre Interstadial (at around 65,000 BP) was substantially warmer, with deglaciation of the St. Lawrence Lowlands, than the Port Talbot and Plum Point interstadials (corresponding to B4 and B2).

Unit B1, which appears to correspond to the late Wisconsin glaciation, is represented by a reddish muddy foram-nanno ooze. The carbonate content is higher and the foraminiferal paleoclimate indicators slightly warmer than those in glacial units B3, B5 and B7. The clay fraction has a typical red clay mineralogy. During the late Wisconsin, red clay was supplied to the Laurentian Fan down the Laurentian Channel, and red lithologies were ice-rafted westwards along the Scotian Slope (PIPER, 1975b). Sea level was lowered by about 115 m, thus exposing much of the Grand Banks, especially the area near our cores.

Units B3, B5 and B7 consist of grey mud. Their sand fraction suggests an origin from resuspension of sediment on the Grand Banks.

Ice rafted coarse sand and granules are almost restricted to the foram-nanno ooze interstadials and interglacials. Their petrology indicates a Labrador Sea source.

Unit D, corresponding to the latest Illinoian of the terrestrial chronology, is a thick red mud, with very rare thin mottled horizons of foram-nanno ooze. It contains twenty to thirty times as much red mud as unit B1. Foraminifera indicate surface water temperatures similar to those during B1. The sand fraction indicates some resuspension from the Grand Banks.

Unit E has an extrapolated age of about 200,000 BP; it represents an interstadial similar to the St. Pierre in temperature. Unit F is a thick sequence of grey mud, with a thin interstadial foram-nanno ooze in the middle. Paleotemperature indicators, especially in the upper part, are substantially colder than in unit D.

Unit H has not yet been examined in detail. Preliminary work suggests several glacial advances comparable to those of the Wisconsin.

A MODEL OF SEDIMENTATION

Several variables control the supply of sediment and the types of microfossils accumulating on the seamounts.

1. *Sea level.* During the late Wisconsin glaciation sea level was lowered by about 115 m (KING, 1976); less extensive glaciations would have lowered sea level less, while a maximum lowering of 150 m is possible during the most severe Illinoian glaciation. Lowering of more than 90 m results in most of the Grand Banks being exposed, and the development of a coastline at the shelf edge. Rip currents in submarine canyon heads would transport littoral sands into deep water as turbidity currents.

A lesser lowering of sea level would not give a shelf-edge coastline, but would result in a large area of very shallow water, susceptible to wave reworking, over much of the Grand Banks.

2. *Continental Ice extent.* Two main ice sheets have a direct influence on the seamounts — the local Newfoundland ice-caps (PREST and GRANT, 1969) and the ice sheet moving down the Laurentian Channel, probably in part Laurentide ice.

A restricted Newfoundland ice sheet, not crossing the Avalon Channel, would supply outwash sediment and icebergs to the Avalon Channel, but this sediment would not cross an emergent Grand Banks but would be advected westwards by the Labrador Current. If ice extended across the Avalon Channel, outwash streams would flow across the Grand Banks.

The extent and temperature of the Laurentian Channel ice will affect its role in supplying sediment. The water depth in the Laurentian Channel suggests an ice sheet would terminate as a calving ice shelf. If cold, this would supply little sediment to the Laurentian Channel area; but if rapidly ablating, a surface plume of cold fresh muddy water might be produced.

3. *The role of the Labrador Current.* If the Grand Banks is emergent and the Avalon Channel blocked by ice, the Labrador Current cannot cross into the area west of the Grand Banks. Furthermore, an emergent Grand Banks area means there is no source for cold shelf water to develop in the winter. Two possible effects are that ice-bergs or muddy freshwater from the Laurentian Channel will advect westwards less rapidly; and Gulf Stream eddies will more easily penetrate the region west of the Grand Banks. Furthermore, icebergs from the Labrador Sea will not reach the area.

With the Grand Banks partially or completely submerged, and the Avalon Channel open, some of the Labrador Current will cross the Grand Banks, advecting sediment westwards.

4. *Surface water conditions.* Temperature and salinity conditions in surface waters are particularly hard to predict. They are related to the position of sea level and the rate of supply of glacial meltwater. During glacial periods, probably both temperature and salinity are reduced, although the greatest reduction may not correspond to the most extensive glaciation.

These variables can be combined to develop a predictive model for Pleistocene sedimentation on the seamounts (Fig. 4). Only for the late Wisconsin do we have independent data on some of the controlling variables.

1. *Late Wisconsin* (Fig. 4a). In the late Wisconsin, sea level was lowered by 115 m, thus exposing much of the Grand Banks. The extent of ice in the Laurentian Channel is disputed, but GRANT (1976) believes it was not extensive. KING (1975) and STOW (1975) describe evidence of iceberg transport of sediment in the Laurentian Channel. The extent of Newfoundland ice is also uncertain, GRANT (1976) believing it reached little further than the present coastline, while Slatt (*in* PIPER and SLATT, 1977) believes it filled the Avalon Channel.

On the seamounts we find a reddish muddy foram-nanno ooze. There appears to have been substantial sediment supply from the Laurentian Channel. If the Avalon Channel was not actually blocked by ice, the sea level lowering was sufficient to block the Labrador current. Resedimented sand grains appear reworked, suggest no directly supply of outwash sand to the Grand Banks.

2. *Earlier Wisconsin* (Fig. 4b). In the earlier Wisconsin, prior to 20,000 BP, the available evidence (BLOOM *et al.* 1974) suggests eustatic sea level was not lowered during glacial advances as much as during the late Wisconsin glaciation. This would have resulted in less of the Grand Banks being emergent. In consequence, the Labrador Current would play a greater role, and storm resuspension of sediments on the Grand Banks would be more important. Both would tend to favour supply of grey mud from the Grand Banks rather than red mud from the Laurentian Channel. In addition, the southward penetration of cold Labrador Sea water, and the generation of cold shelf water on the Grand Banks would result in cooler planktonic foraminiferal indicators compared with the late Wisconsin. The lack of fresh glacial sand grains suggests Newfoundland ice did not cross the Avalon Channel.

3. *Late Illinoian* (unit D: Fig. 4). Clay mineralogy and pebble petrology suggest that sedimentation at this time was dominated by discharge of sediment from the Laurentian Channel. Glacial melt water, rich in suspended sediments and sometimes with icebergs, covered a large part of the continental margin off Atlantic Canada. The Avalon Channel was probably closed because otherwise this «red plume» would have been diverted towards the southwest by the Labrador Current. Newfoundland ice probably extended across the channel, since the clay mineralogy suggests some supply from Newfoundland, and the silt and sand fraction appears fresh.

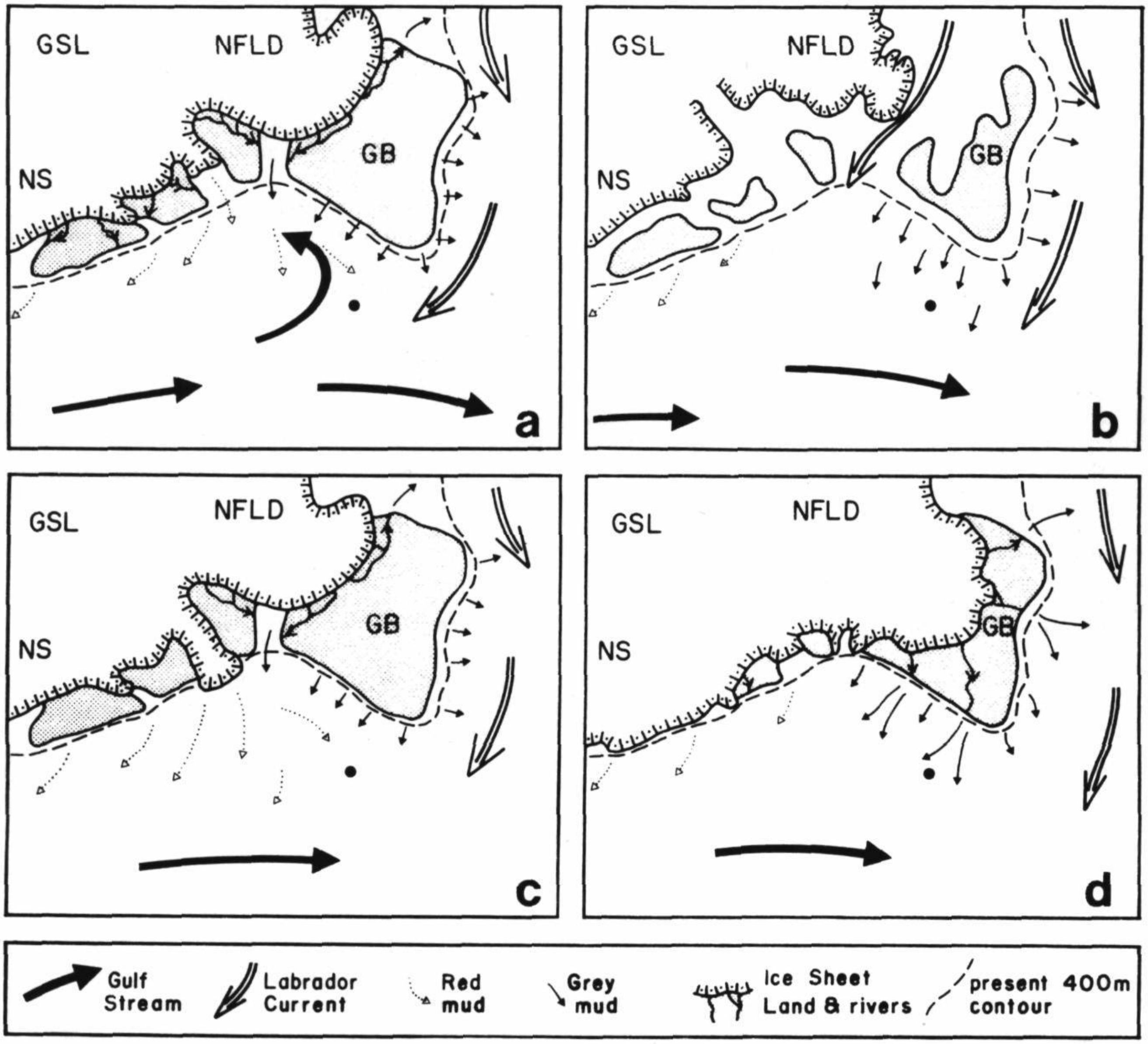

FIGURE 4. Speculative late Quaternary paleogeography of south-eastern Canada: a) late Wisconsin glacial; b) early and mid Wisconsin glacials; c) late Illinoian glacial; d) mid Illinoian glacial. For fuller explanation, see text. GSL — Gulf of St. Lawrence, GB — Grand Banks.

Paléogéographie hypothétique du sud-est du Canada à la fin du Quaternaire: a) glaciation du Wisconsinien supérieur; b) glaciations du Wisconsinien inférieur et moyen; c) glaciation de l'Illinoien supérieur; d) glaciation de l'Illinoien moyen. Pour de plus amples explications, se reporter au texte. GSL = golfe du Saint-Laurent, GB = Grands Bancs.

4. *Earlier Illinoian* (unit F: Fig. 4d). The foraminiferal data suggests that during the deposition of the grey mud of unit F, surface water was exceptionally cold. Clay, silt and sand mineralogy indicate that sedimentation on the seamounts was controlled by the advance of an ice sheet from Newfoundland. Surface textures of the quartz grains, as well as the feldspar/quartz ratio and the ratio of angular/rounded quartz grains suggest that the source of the sediments was very close, and the sediments had undergone very little reworking before final deposition. This suggests that the ice sheet covered a substantial part of the Grand Banks and completely closed the Avalon Channel (Fig. 4d).

The much greater extent and intensity of the mid and late-Illinoian glaciations may indicate direct ice supply from the main Laurentide ice sheet, rather than supply from local Maritime ice-caps that characterised the Wisconsinian.

CONCLUSIONS

The Pleistocene record in the deep sea is superior to that on land in its continuity of deposition. The opportunities for establishing a reliable chronology in the mid and early Pleistocene are greater at sea. Only near the continental margin in glaciated regions is there much direct representation of terrestrial glacial events. In most areas, there is a great thickness of Pleistocene continental margin sediments: the seamounts we have sampled are exceptional in being out of the reach of turbidity currents.

We have semi-quantitative data on the temperatures prevailing in eastern Canada during interstadials and interglacials. Full interglacials, warmer than at present, and thus presumably representing complete deglaciation, occur in units C, G and I, dating from 125,000 ??250,000 and ??400,000 BP. Warm interstadials, comparable to the St. Pierre Interstade, and thus reflecting substantial deglaciation of eastern Canada, are represented by units B6, E, H2 and H4. Cool interstadials, comparable to the Plum Point Interstade, are found in units B2, B4 and F2.

For glacial periods, we have two types of information. Foraminifera indicate the surface water temperature; but this probably does not correspond in a simple manner to either temperatures on land, or temperatures in the open ocean. Petrologic analysis indicates the source of glacial sediment accumulating on the continental margin: but it does not indicate the route by which the sediment was transported. We can recognise four types of glacial conditions: (i) Unit B1, the late Wisconsinian, with cool surface temperatures and accumulation of red mud along with foram-nanno ooze; (ii) Units B3, B5 and B7, the mid and early Wisconsin, with cold surface temperatures, and accumulation of grey mud, perhaps largely reworked from the Grand Banks; (iii) Unit D, the latest Illinoian, with cool surface temperatures and the accumulation of large amounts of red mud. This represents a more severe glaciation than the Wisconsinian. This time was clearly a major period of erosion of the lowlands of Maritime Canada and the Gulf of St. Lawrence. During the late Wisconsin, some 300 km^3 of red mud were supplied to the Laurentian Fan and Scotian margin (STOW, 1975; PIPER, 1975b). The corresponding late Illinoian quantity would be around 7 500 km^3, suggesting major erosion of the Gulf of St. Lawrence at that time. (iv) Unit F, the mid-Illinoian, with very cold surface temperatures and the accumulation of thick grey muds, with fresh quartz and feldspar, with a source in Newfoundland.

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QUESTIONS AND COMMENTS

I. A. BROOKES:

1) «What is the meaning of the 37,500 BP date at the top of the climate diagram?»
2) «What is the depth of Avalon Channel and what would be the effect of sea level lowering on water transport through it?»

M. ALAM and D. J. W. PIPER:

1) «This applies to zone C and not to the top of the diagram.»

2) «Up to 300 m and therefore water can still flow through it at glacial maximum.»