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Article abstract

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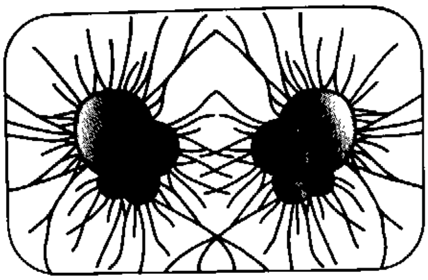
Articles



Late Glacial-Postglacial Foraminiferal Boundary in Sediments of Eastern Canada, Denmark and Norway

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Summary
Sediments in cores collected from the Scotian and Labrador shelves contain a faunal discontinuity where older benthic foraminiferal assemblages dominated by *Elphidium excavatum* f. *clavata* change to more diverse present day continental shelf assemblages. A similar change is found in Late Quaternary borings in Denmark (Jutland) and in the Oslofjord area of Norway. The ^{14}C age of the faunal break varies from 10,000 years B.P. in the European sediments to 13,000 years B.P. on the Scotian Shelf and 15,000 years B.P. on the Labrador Shelf.

The present day oceanographic setting along the coasts of Norway, Denmark and eastern Canada was established when the glacial ice retreated inland. The dominance of *E. excavatum* f. *clavata* in the older sediments is related to diluted and cold coastal waters during the time when continental ice was ablating on the inner shelf. The disappearance of *E. excavatum* f. *clavata* therefore can be used to estimate the Late Glacial-Postglacial boundary in the Canadian and Scandinavian North Atlantic continental shelf sediments. This paper reviews the evidence of the faunal break to alert geologists in its possible use.

Introduction
Many sediment cores collected from Scotian and Labrador Shelves (Fig. 1) contain a foraminiferal discontinuity, where an indigenous shelf assemblage at the top of the core changes to an inshore assemblage dominated by *Elphidium excavatum* forma *clavata* towards the bottom, e.g., King (1969), Vilks and Rashid (1976), Schnitker (1976), Vilks and Mudie (1978), and Vilks (1980). Foraminiferal faunas dominated by *E. excavatum* f. *clavata* are also found in older Quaternary sediments along the east coast of the North Atlantic, e.g., Feyling-Hansen (1972b), Knudsen (1971).

Because the change does not reverse itself over the time interval of the last 20,000 years B.P., the discontinuity appears to be a useful stratigraphic marker, provided there is a proper understanding of its cause. This paper suggests a reason for the abundance of *E. excavatum* f. *clavata* in the older sediments through a comparison of some environmental aspects of glacial versus

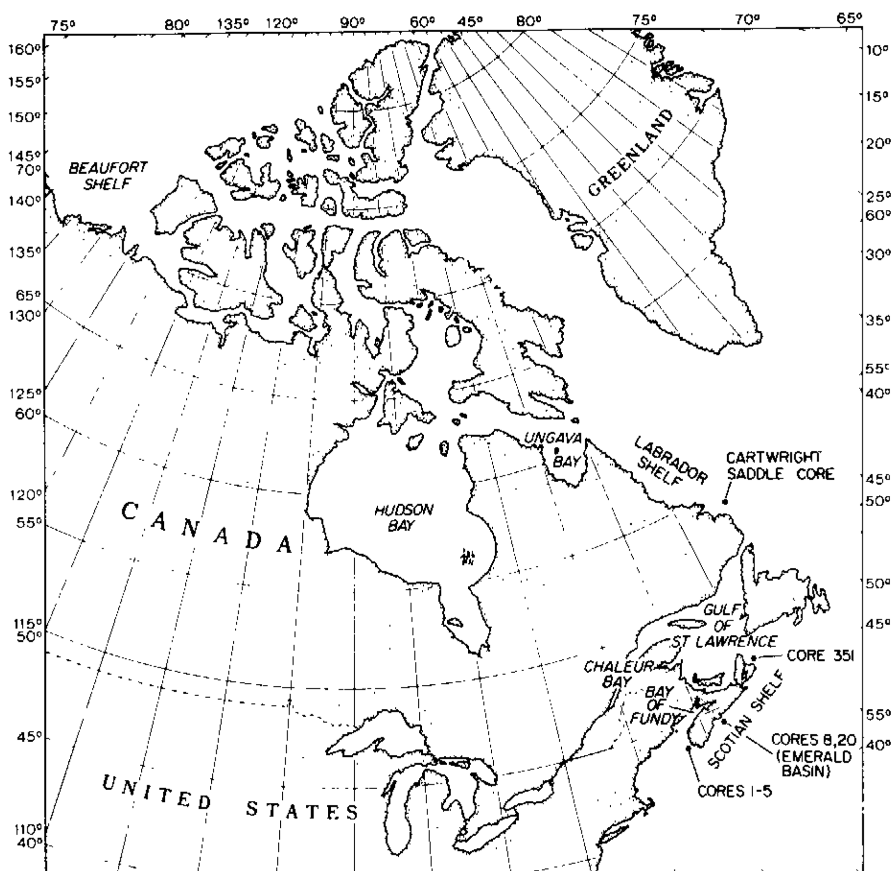

Figure 1 *Sample sites on Labrador and Scotian Shelves.*

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post glacial oceanography and how the change in water mass properties could influence the distribution of *E. excavatum*. Species of foraminifera, ^{14}C dates, and sampling methods have been discussed by Feyling-Hansen (1964), Vilks and Rashid (1976), Schnitker (1976), King (1980), Mudie (1980), Vilks (1980) and L.H. King, G. Fader, and H. Josenhans, Atlantic Geoscience Centre (pers. commun., 1980).

Circulation of Surface Water in the North Atlantic

During an interglacial period such as the present, major current systems in the North Atlantic are the Gulf Stream, the North Atlantic Current, the Labrador Current and the Nova Scotia Current (Fig. 2). The North Atlantic Current carries the relatively warm waters of the Gulf Stream to the coasts of Europe and finally into the Arctic Basin (Sverdrup *et al.*, 1942) resulting in a net transfer of heat into the high latitudes of the northern hemisphere. Conversely, the currents along the west coast of the Atlantic flow to the south and carry cold waters to lower latitudes. The Labrador Current contains waters that have their origins in Hudson Bay, the Arctic Archipelago, Davis Strait and in the North Atlantic via the West Greenland current (Dunbar, 1951). Because of the addition from Hudson Bay and the Arctic Archipelago, the inner shelf component of the Labrador Current is slightly diluted, in addition to being very cold.

The southeastward flowing Nova Scotia Current contains some water from the Labrador Current and additions from the Gulf of St. Lawrence. Along the outer margin of the Scotian Shelf, it is possible to recognize slope water that is Atlantic water diluted by approximately 20 per cent of coastal water (Hachey, 1961).

During a glacial period a major change in the circulation pattern involves a reduction of heat transfer to the north (Fig. 3) (Johnson and McClure, 1976). Most of the eastward flowing Gulf Stream water is returned to the south along the African coast. In the North Atlantic the surface water is restricted to the south of a presumed polar front in a semi-isolated subpolar gyre. Thus, during a glacial period, the shelf waters of eastern Canada and Europe are under more or less similar arctic conditions.

The Last Glacial Maxima and Deglaciation

The extent of the last glacial ice on the Canadian continental shelves is difficult to determine and most proclaimed limits are conjectural (Fig. 3) (Prest, 1969; Flint, 1971; Prest and Grant, 1969). King *et al.* (1972) described end moraines on the

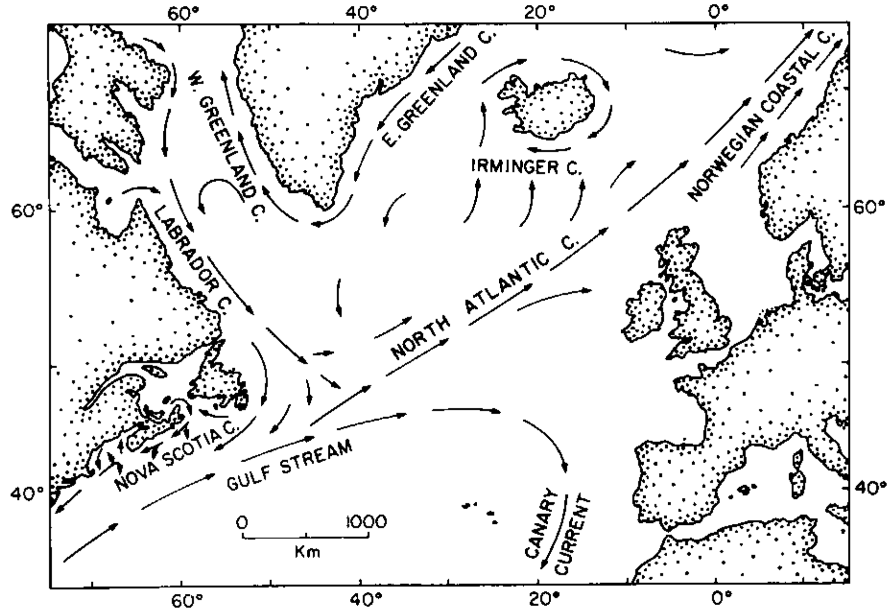

Figure 2 *Major surface currents in the North Atlantic (after Sutcliffe* et al., *1975, and Sverdrup* et al., *1942).*

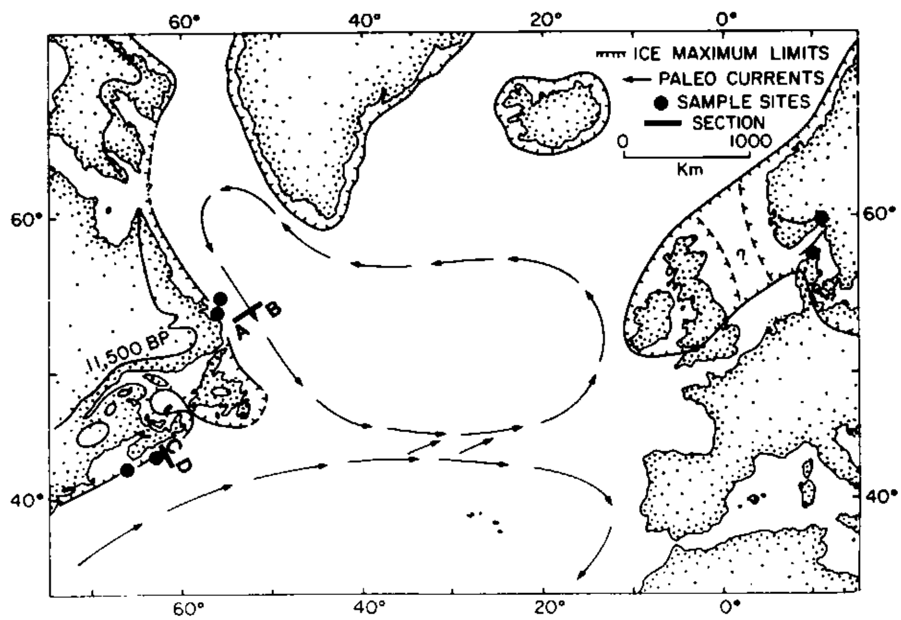

Figure 3 *Presumed surface currents in North Atlantic during a glacial maximum (Johnson and McLure, 1976). Ice limits after Flint (1971) and Prest (1969). A-B and C-D indicate location and extent of temperature and salinity profiles shown in Figures 11-14. Solid line in Labrador and Baffin Island indicates 11,500 year B.P. ice limit.*

Scotian Shelf which may delineate the Late Wisconsinan maximum. According to these reports, the Laurentide ice sheet covered at least the inner shelf both off Labrador and Nova Scotia. The concept of an extensive Late Wisconsinan margin on the continental shelf has been challenged, e.g., Grant (1977), and Ives (1978), by postulating the possibility of coastal nunataks and ice-free shelf waters (Vilks and Mudie, 1978).

During the Weichselian maximum a small part of Denmark was not glaciated, although in Norway and Sweden the ice extended over the continental shelf (Flint, 1971). There the Scandinavian and the British ice sheets may have joined to cover most of the North Sea, the Norwegian inner Shelf and the northwestern offshore areas of England (Fig. 3).

The chronology of glacial retreat over North America and Scandinavia is much better known than the ice limits in the sea. In North America the ice margin had retreated well inland by the year 11,500 years B.P. (Prest, 1969) (Fig. 3). On the basis of evidence to date we can be certain that by 10,000 years B.P. Nova Scotia was free of glacial ice, and only in Ungava Bay of northern Labrador the continental ice margin may have still been in contact with the open sea.

The Scandinavian glacial retreat took place towards the northeast and Denmark was free of continental ice by 11,500 years B.P. (Fig. 4). In Sweden and Norway the 11,500 years B.P. isochrone was still relatively close to the marine environment, but at 10,000 years B.P. the continental ice may have been in contact with the sea only in the Oslofjord area (Andersen, 1960).

The above evidence suggests that up to 10,000 years B.P. the extent of the glacial retreat along the coast of Labrador was comparable to the retreat in the Oslofjord area in Norway and that the timing of the retreat in Nova Scotia was comparable to that observed in Denmark. Thus, as far as the influence of glacial ice on the environment of the inner continental shelves is concerned, there was very little difference between the two sides of the Atlantic up to the post glacial time.

At the onset of deglaciation, the character of the offshore waters may have changed in a different fashion in the eastern and western North Atlantic. The polar front may have migrated towards the north along the European coast earlier and faster than in the western North Atlantic off Canada. During the return to the present circulation pattern that began shortly after 18,000 years B.P. (Ruddiman and McIntyre, 1973), the entrance of warm water in the Norwegian Sea

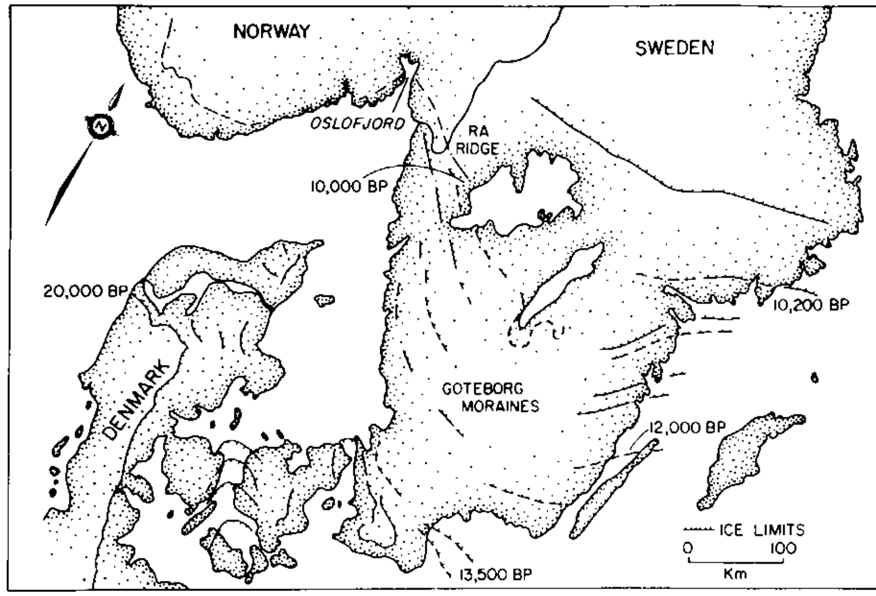

Figure 4 *The chronology of glacial retreat in Denmark and southern Sweden. (Andersen, 1960).*

brought about interglacial conditions in the offshore waters, while the continental shelf off Norway was still within the late glacial environment.

Late Glacial-Postglacial Foraminifera

The similarity in nearshore oceanographic conditions on both sides of the Atlantic during the Late Glacial times is reflected by similarity in the distribution of foraminifera. The Late Glacial deposits are characteristically dominated by *Elphidium excavatum* forma *clavata* and *Cassidulina crassa.*

The distribution of *E. excavatum* f. *clavata* in recent sediments is difficult to determine, because of the complex synonomy and the possibility of misidentification. In most reports it has been referred to as *Elphidium clavatum* (Kundsen, 1971) or *E. incertum* (Leslie, 1965). With Feyling-Hansen's (1972a) and Miller's (1979) concept of this species, *E. excavatum* f. *clavata* dominates foraminifera in arctic and cold-temperate waters.

In present day North American waters the species may represent over 20 per cent of the total population in areas that are characterized by winter ice and by surface waters having reduced salinities (Leslie, 1965; Schafer and Cole, 1978; Vilks *et al.*, 1979) (Table I). In the Beaufort Sea and Hudson Bay the water is less than 0° C below the seasonal layer, which is diluted as a result of extensive runoff. Chaleur Bay (Fig. 1) contains a cold water below the diluted seasonal layer that is typical of the Gulf of St. Lawrence. In the Bay of Fundy, tidal and seasonal variability imposes fluctuations in salinity and temperature with slightly less saline waters and warmer temperatures in summer and below freezing temperatures and higher salinities in winter.

On the Labrador Shelf the surface sediments are almost barren of *E. excavatum* f. *clavata* and contain species that are typical of continental shelves off Labrador and Nova Scotia today (Vilks, 1980). The subsurface sediments in five cores taken in the Cartwright Basin, Labrador Shelf, show at various levels increasing relative percents of *E. excavatum* f. *clavata* associated with a concurrent increase of *Cassidulina crassa.* Thus, there is evidence of a greater nearshore influence or of shallower water depths when these older sediments were deposited. The increase in water depths to present day is indicated by the gradual change to a modern shelf assemblage in the younger sediments (Vilks, 1980).

In the Oslofjord area of Norway, on shore borings of Late Quaternary sediments contain foraminifera that show a faunal break comparable to that of Labrador Shelf sediments (Fig. 5). Towards the top of the Norwegian section shelf species such as *Bulimina marginata* and eventually *Eggerella scabra* take over with occasional occurrences of *Milliammina fusca. E. scabra* and *M. fusca* are nearshore shallow water to estuarine species and reflect the shallowing of the waters due to postglacial isostatic rebound. The whole assemblage is dominated by arenaceous species indicating

Table I *Typical salinities and temperatures of waters* E. excavatum *f.* clavata *commonly occur.*

Area		T°C	Sal. ‰
Continental Shelf of southeastern Beaufort Sea	Surface (summer)	5.4	16.0
	Bottom	-1.5	32.5
Hudson Bay	Surface (summer)	4.0 - 9.0	23 - 32
	Bottom	1.0 - 1.5	32 - 33
Chaleur Bay	Surface (summer)	9 - 13	26
	Bottom	1 - 2	30 - 32
Bay of Fundy	Mixed (summer)	12 - 15	29 - 32
	Winter	1.0 - -1.0	30 - 32

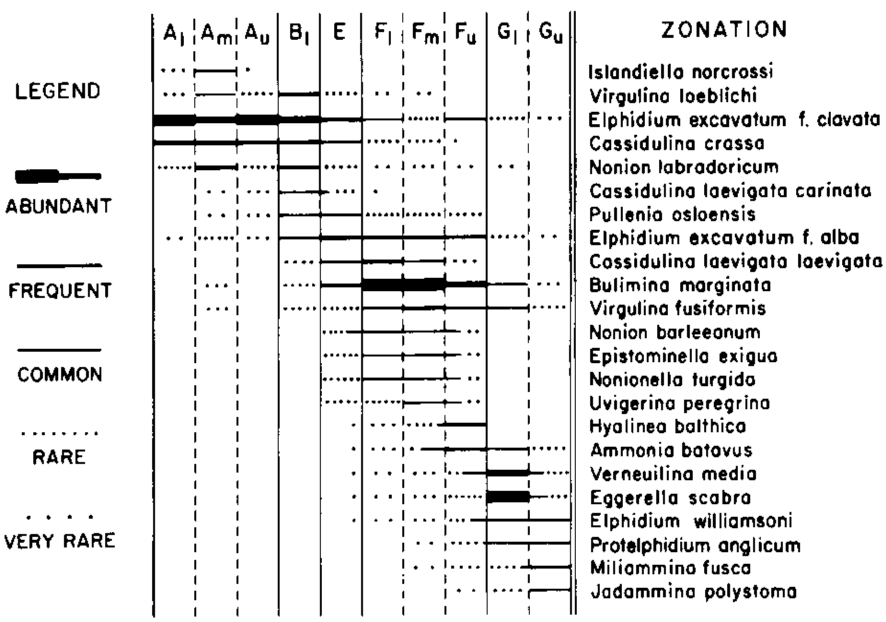

Figure 5 *Foraminifera zonation in the southern art of Oslofjord area (after Feyling-Hansen, 1964).*

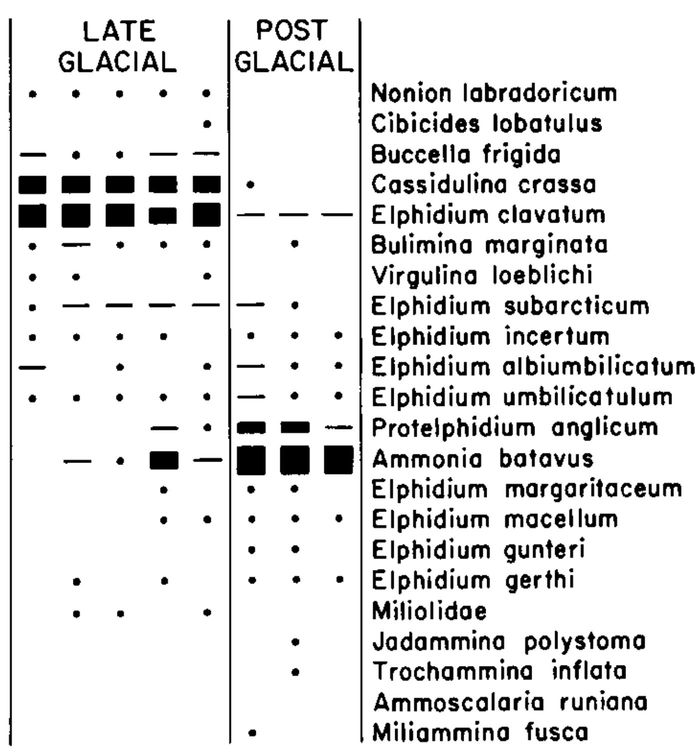

Figure 6 *Percentage distribution of foraminifera at Lokken, Denmark (after Knudsen, 1971).*

the increasingly restricted conditions of the Oslofjord area.

Classic Late Glacial-Postglacial microfossil sequences were obtained at Lokken, Denmark, from a series of borings (Knudsen, 1971) (Fig. 6). Here also the Late Glacial deposits are dominated by *Elphidium excavatum* f. *clavata* (*Elphidium clavatum* Fig. 6) and *Cassidulina crassa*. These are overlain by nonmarine beds barren of foraminifera. Following a transgression, the postglacial marine sediments at Lokken are dominated by *Ammonia batavus*, which is a nearshore warm water species indicating the shallowing conditions due to the postglacial isostatic rebound of the area.

Age of Boundary

The prominence of the faunal change suggests that it may represent a major environmental change on the continental shelf. The two Labrador Shelf cores that were dated indicate that the change occurred at about 15,000 ^{14}C years B.P. (Fig. 7). The reduction of *E. excavatum* f. *clavata* at this time coincides with increased numbers of the planktonic foraminifera *Neogloboquadrina pachyderma* and with the occurrence of sandier sediments. The increased presence of the planktonic foraminifera suggest increased offshore influence.

An assemblage change was also recorded in a number of cores collected on the Scotian Shelf (Fig. 8). Cores 1-5 were collected by L.H. King and G. Fader of the Atlantic Geoscience Centre to investigate geotechnical characteristics of sediments that lie below the LaHave clay (Holocene) according to high resolution seismic profiles. The sediments did not yield ^{14}C dates younger than 17,000 years B.P. and contain relatively large amounts of *E. excavatum* f. *clavata* (see Table II for exact dates and core intervals). The old dates and the faunal content thus indicate that very little post glacial sediment has been deposited at these localities (see Fig. 1).

Core 8 (Fig. 8) was taken from Emerald Basin and contains a distinct surface layer where *E. excavatum* f. *clavata* is entirely lacking. Below this surface layer is an intermediate zone underlain by sediment where *E. excavatum* f. *clavata* is found making up close to 100 per cent of total foraminifera. The sharp break in the foraminiferal profile suggests two phases of sedimentation separated by a time hiatus at the break. The sediment rich in *E. excavatum* f. *clavata* was apparently deposited about 15,290 years B.P., the intermediate zone about 7,770 years B.P., and the surface layer about 7,180 ^{14}C years B.P. The nonlinear relationship of dates with core intervals suggests sporadic sedimentation, i.e., the sediment rates have not been constant.

^{14}C dates obtained from four Scotian Shelf cores (2-5) and core 351 from the Laurentian Channel were correlated with core intervals and a linear relationship was found to be highly significant (Table II, Fig. 9). Core 351 was also taken by L.H. King and G. Fader from an area where pre-Holocene sediments are found close to the surface of the sea floor according to the seismic evidence. The close relationship between core intervals and dates makes extrapolation beyond the range of recorded ages reasonably reliable. Thus, the age of sediment in cores 2-5 can be estimated and according to Figure 9, the ^{14}C age at 2 m level is about 15,000 years B.P. and at the surface 12,000 years B.P. Surface to two metres is the range of sediment depths where the *E. excavatum* f. *clavata* is found in these cores.

One core from Emerald Basin, collected by Dalhousie University (Core 20), which is almost barren of *E. excavatum* f. *clavata* gave dates not older than 12,000 years B.P. (Mudie, 1980) (Table II), but the 15,290 years B.P. date of Core #8 also from Emerald Basin is well within the *E. excavatum* f. *clavata* zone. Because of the nonlinear relationship between the two Emerald Basin core intervals and ^{14}C dates, the extrapolated age of the *E. excavatum* f. *clavata* boundary would be highly questionable. Schnitker (1976) dated an increase in *E. excavatum* f. *clavata* at 13,000 years B.P. in a core taken from the Gulf of Maine, which is within

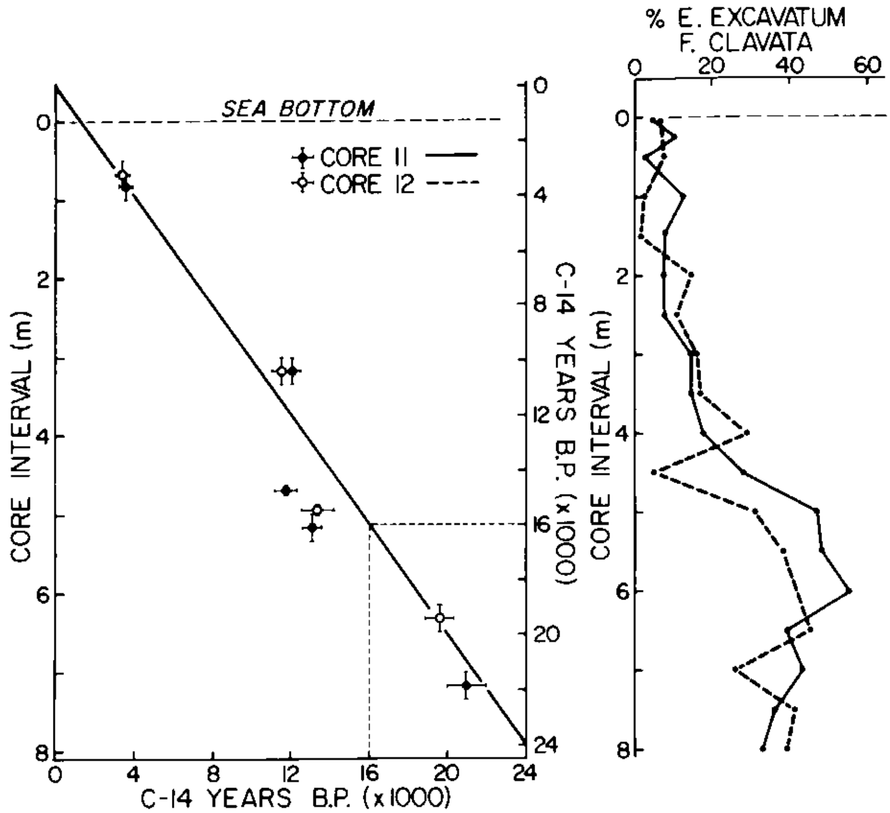

Figure 7 *Relationship between core intervals and ^{14}C years in Cartwright Saddle cores (Fig. 3). The vertical ^{14}C axis is used to estimate age of any interval of the cores showing the relative percents of* E. excavatus *f.* clavata.

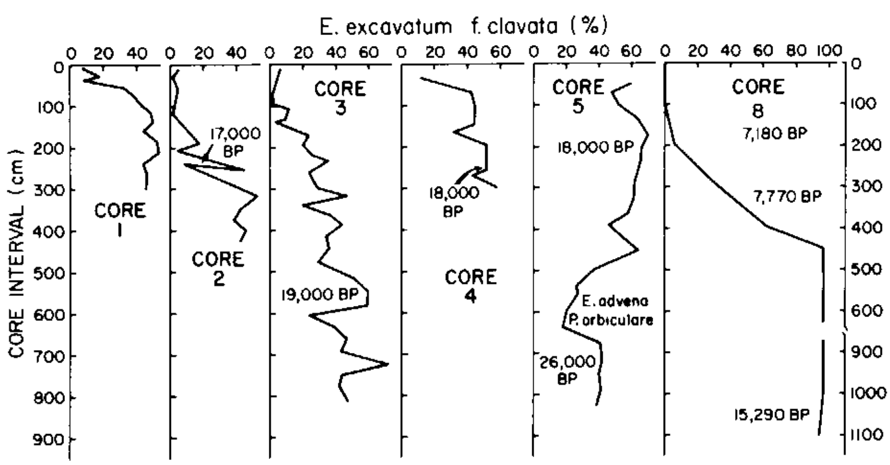

Figure 8 *^{14}C dates and distribution of* E. excavatus *f.* clavata *in Scotian shelf cores.*

Table II ^{14}C *dates from Emerald Basin and Scotian Shelf (core locations Fig. 3)*

Core	Interval (cm)	Age	Laboratory No.
2	224-249	17,000 ±900	GSC 2709
3	550-575	>19,000	GSC 2711
4	275-300	18,000 ±990	GSC 2755
5	207-232	>18,000	GSC 2270
5	735-760	26,600 ±1600	GSC 2715
351	90-125	16,170 ±520	GX-6695
351	230-265	17,245 ±450	GX-6696
351	620-655	27,150 +2260 -1770	GX-6697
351	880-915	30,260 +2500 -1900	GX-6698
8	150-192	7,180 ±120	I-8857
8	350-392	7,770 ±130	I-8855
8	1050-1092	15,290 ±280	I-8858
20	200-225	10,100 ±300	RL-1110
20	400-425	11,500 ±300	RL-1111
20	675-695	12,100 ±360	RL-1112

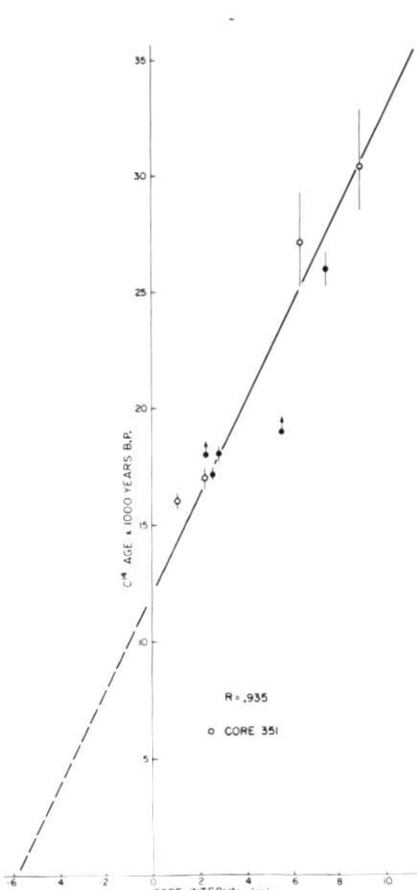

Figure 9 *Relationship between* ^{14}C *ages and Scotian shelf core intervals.*

the range of dates for the faunal discontinuity estimated from the Scotian Shelf core data.

Marine deposits in Denmark and Norway have been correlated using molluscan and pollen stratigraphy (Fig. 10) (Feyling-Hansen, 1964, 1972b; Knudsen, 1971). In the northern Denmark (Jutland) the Late Glacial and Postglacial seas covered the area in a series of transgressions and regressions. The Late Glacial marine beds are overlain by nonmarine deposits that are dated between 12,000 and 8,000 years B.P. thus spanning the Pleistocene-Holocene boundary. The postglacial *Littorina* seas lasted between 8,000 and 2,500 years B.P. when the present shoreline was established. In the Oslofjord area of Norway, the break between the assemblages rich in *E. excavatum* f. *clavata* and subsequently deposited *Bulimina marginata* assemblages occurs somewhere in the upper part of Zone A and lower part of Zone B. Thus the Late Glacial-Postglacial boundary here may be about 10,000 years B.P.

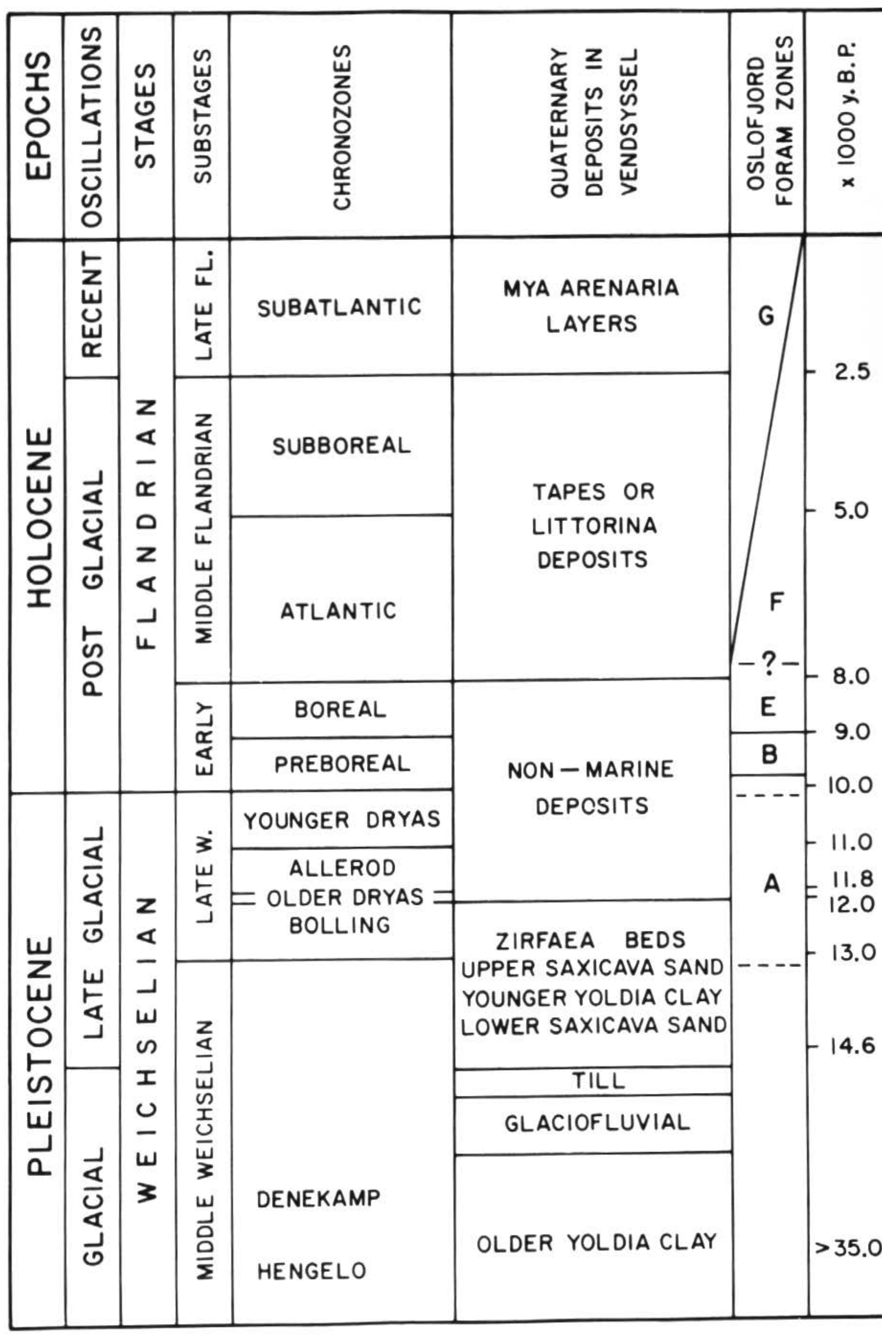

Figure 10 *Foraminiferal zonation correlated with molluscan and pollen stratigraphy in Denmark and Norway.*

The Paleoceanographic Model

The present average salinity and temperature distribution profiles across the southeastern Labrador Shelf illustrate the various components of the Labrador Current (Figs. 11 and 12) (Andersen, 1968). Closer to the coast are the relatively cold and less saline inner shelf waters that originated from local runoff, Hudson Bay and from the Arctic Archipelago. Along the bottom of the basins and the continental slope, there is the warmer and more saline offshore Labrador Current water with a large component from the North Atlantic Ocean. Typical to the Labrador Current is the core of very cold water with average temperatures less than -1° C. Warm seasonal water is present in a very thin layer on the surface. A generally similar distribution of water temperatures are present across the Scotian Shelf in the Emerald Basin area with the colder Nova Scotia Current waters inshore and the warmer slope waters offshore and along the bottom of the deeper basins (Fig. 13) (Hachey, 1953).

During Late Glacial times the presence of melting glaciers maintained a more extensive zone of relatively cold and slightly diluted waters on the continental shelves. The coastal waters that were formed during this time kept the warm offshore water away from the nearshore Danish and Norwegian coasts and also minimized the effect of offshore Labrador Current on the Labrador and Scotian Shelves, thus explaining the similarity of Late Glacial faunas on the both sides of the Atlantic. Along the Labrador coast the coastal waters were sufficiently extensive to maintain nearshore conditions far offshore out to depths of 500 metres (Fig. 14).

The higher relative percents of *E. excavatum* f. *clavata* found in subsurface sediments may thus reflect oceanographic conditions originating from extensive melting of continental ice in the marine environment. The North Atlantic sub polar-gyre that may have existed during the glacial periods (Johnson and McLure, 1975) would have helped to maintain the presence of the very cold and diluted waters along the continental margin off Labrador as suggested in Figure 14. The reduction of *E. excavatum* f. *clavata* abundance in conjunction with the appearance of the diverse present day species assemblages towards the surface of the cores thus coincided with the retreat of ice margins inland and the establishing of present day circulation patterns in the North Atlantic.

The discontinuity in faunal characteristics provides a method for the recognition of a change in the marine paleoenvironment on the Canadian and Scandinavian continental shelves. The change is associated with the retreat of glacial ice inland from the coastline and is sufficiently widespread to be useful as an ecostatigraphic horizon. This marker could help to establish the age of late Quaternary marine deposits and the time of formation of major features on the sea floor, such as iceberg scours.

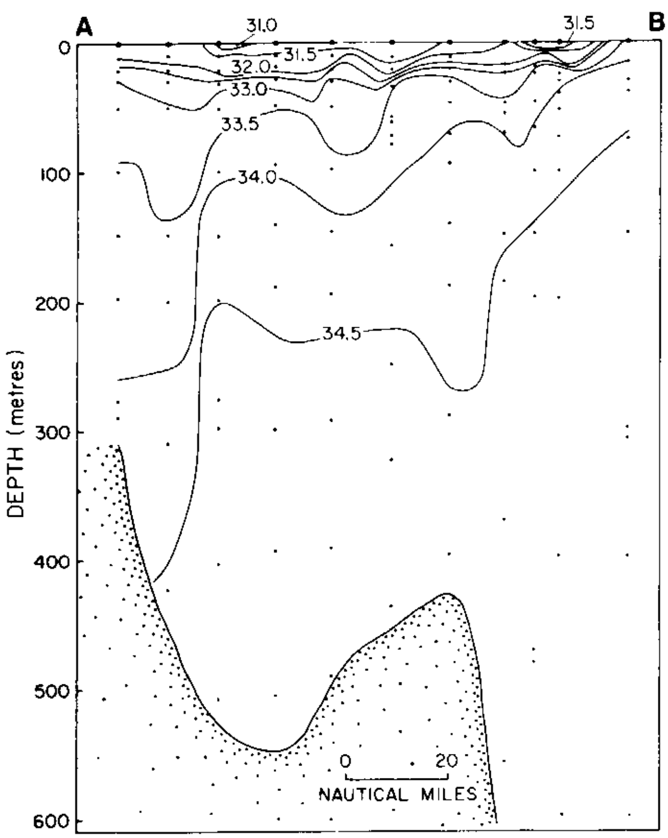

Figure 11 *Salinity profile across southeastern Labrador shelf (see Fig. 2 for location) July, 1968 (after Andersen, 1968).*

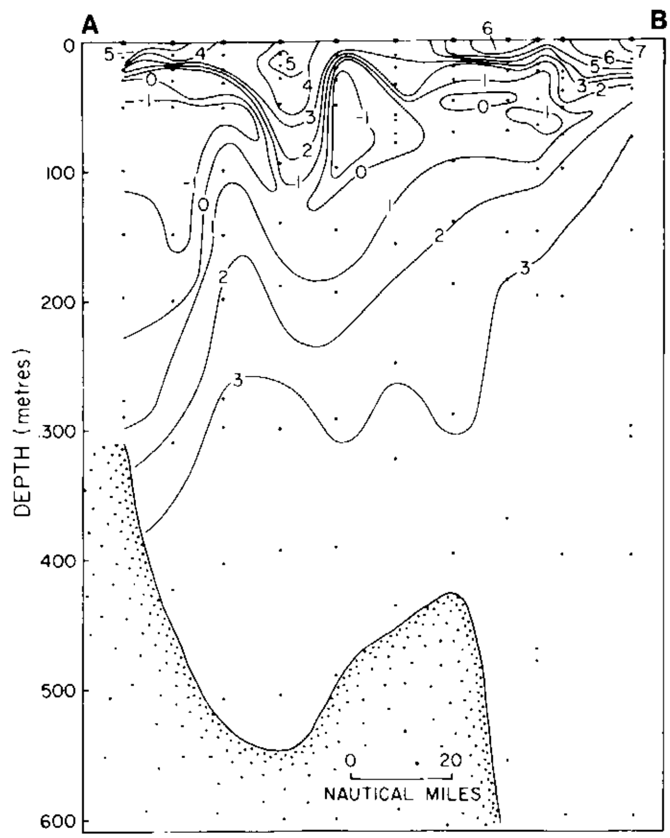

Figure 12 *Temperature profile across southeastern Labrador shelf (see Fig. 2 for location) July, 1968 (after Andersen, 1968).*

Acknowledgements

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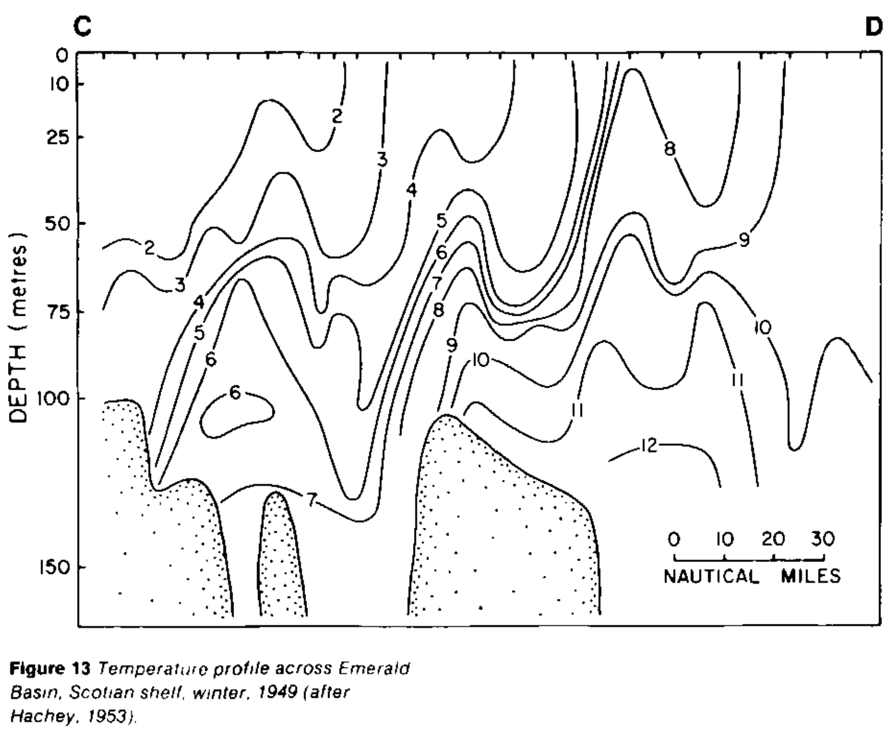

Figure 13 *Temperature profile across Emerald Basin, Scotian shelf, winter, 1949 (after Hachey, 1953).*

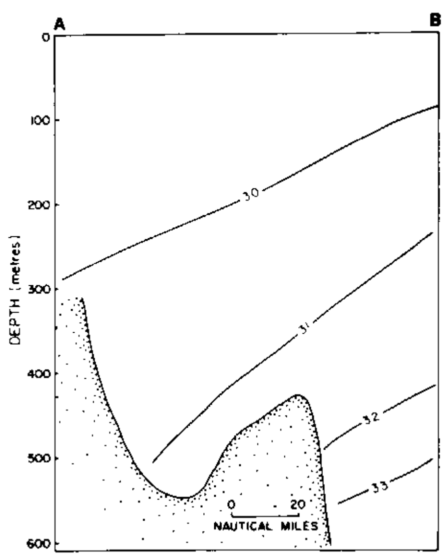

Figure 14 *Presumed salinity profile across southeastern Labrador shelf during Late Glacial times*