

SHORT PAPER

High Resolution Isotope Study of the Latest Deglaciation Based on Bermuda Rise Cores

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A stable isotope and  $^{14}\text{C}$  investigation of carbonates from three late Quaternary cores with high rates of sedimentation from the northeastern Bermuda Rise has produced the highest resolution record of the glacial maximum to Holocene stable isotope change yet obtained from an open ocean location. The record includes a three-step "termination" and the first direct evidence of an early deglacial meltwater "spike" in the open sea. © 1984 University of Washington.

Sedimentation rate is the variable which chiefly limits stratigraphic resolution in deep-sea sequences. For stable isotope results this was clearly demonstrated in records published by Shackleton (1977). Those records show increasing detail in cores with increasing sedimentation rate. The plateau of the northeastern Bermuda Rise (~4500 m) stands about 1 km above the Sohm Abyssal Plain and is a region of very rapid sediment accumulation. High accumulation rates of hemipelagic lutite are believed to be maintained by lateral advection of distal, fine-grained components of turbidity flows derived from eastern Canadian sources by the deep western return flow of the Gulf Stream system (Laine and Hollister, 1981).

We assume that at the location of our cores (Table 1) foraminifera settle from the overlying water column without significant lateral transport. There is no evidence of turbidity currents. Only traces of sand are found in these cores, and that fraction is largely the shells of planktonic foraminifera. The remaining sediment is in the clay and silt fractions (Silva *et al.*, 1976).

McCave *et al.* (1982) found evidence of increased erosion and transport at the base and slope of the Bermuda Rise. On the uppermost undulating plateau, the location of core GPC-5, these workers found high turbidity and current velocities of <10 cm/sec, probably insufficient to transport foraminifera. We cannot rule out, however, brief pulses of stronger currents which might resuspend and transport foraminifera. Resuspension of foraminifera has been shown by Gardner *et al.* (1983) to be significant on the Nova Scotia Rise; however, the mean current speed at this location is 32 cm/sec.

Oxygen isotope results on the planktonic foraminifera *Globorotalia inflata* are presented in Figure 1. Carbon isotope results show very little variability and are not discussed here. *G. inflata* is a species typical of the western Atlantic transition zone between subtropical and subpolar waters, north of 30° (Bé and Tolderlund, 1971; Kipp, 1976), but its abundance in our small samples (10 cm<sup>3</sup>) was insufficient to analyze discrete size fractions. Several features in the oxygen isotope results appear correlat-

TABLE 1. CORES FROM THE BERMUDA RISE USED IN THIS STUDY

Cruise	Core	Depth (m)	Latitude	Longitude
KNR31	GPC-5	4583	33°41.2'N	57°36.9'W
EN23	LGC-07	4516	35°13.5'N	60°37.0'W
EN24	PC-06	4508	35°10.7'N	60°35.3'W

able among these cores. Each core has maximum  $\delta^{18}\text{O}$  values of about 2.2‰ (labeled as "glacial max." in Fig. 1). Minimum values of  $\sim 0.5\text{‰}$ , representing the upper part of the Holocene, are found at each core top, giving an average glacial-interglacial  $\delta^{18}\text{O}$  range of  $\sim 1.7\text{‰}$  (the maximum range is 2.0‰ at GPC-5). This range is consistent with those of many other locations and is inferred to be largely due to decreased continental ice volume from glacial to interglacial time. Similar oxygen isotope features occur within the change from glacial maximum to Holocene at each core. Immediately following the glacial maximum at each core is an interval of low  $\delta^{18}\text{O}$ , la-

beled "a" in Figure 1. Following that section is a return to greater values at "b." Additional detail in GPC-5 is not clearly correlated with lower sedimentation rate cores PC-06 and LGC-07.

Earlier, Duplessy *et al.* (1981) found evidence of two steps in the most recent deglaciation from four cores in the northeast Atlantic. Radiocarbon stratigraphy revealed that the first step in deglaciation, Termination 1A, occurred between about 15,000 and 13,000 yr B.P., followed by Termination 1B between about 10,000 and 8,000 yr B.P. The oxygen isotopic changes at Terminations 1A and 1B are seen in both benthic and planktonic foraminifera, which led Duplessy *et al.* (1981) to conclude that they probably reflect the record of decreasing continental ice volume.

Figure 2 compares our  $\delta^{18}\text{O}$  results from core GPC-5 with core CH73139C of Duplessy *et al.* (1981). As the sedimentation rate at GPC-5 is about twice that of CH73139C, we have compressed the depth scale for GPC-5. It is seen that at GPC-5, Termination 1B, which marks the final  $\delta^{18}\text{O}$

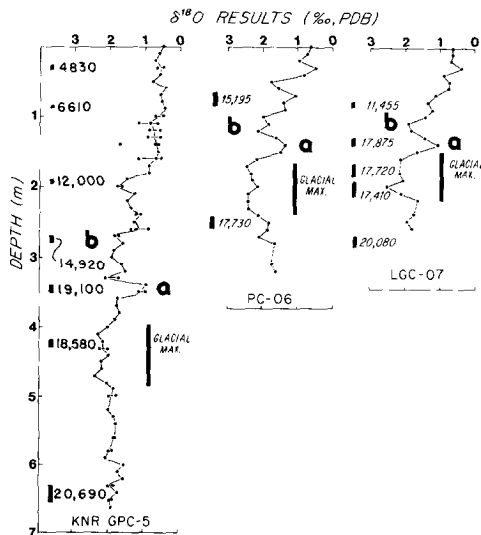


FIG. 1. Correlation of  $\delta^{18}\text{O}$  (‰, PDB) results (*G. inflata*) among Bermuda Rise cores. Glacial maximum and core-top values are the same in each core. Event depleted in  $^{18}\text{O}$  at "a," an inferred meltwater spike, and return to enriched values at "b" are also correlative among these cores.

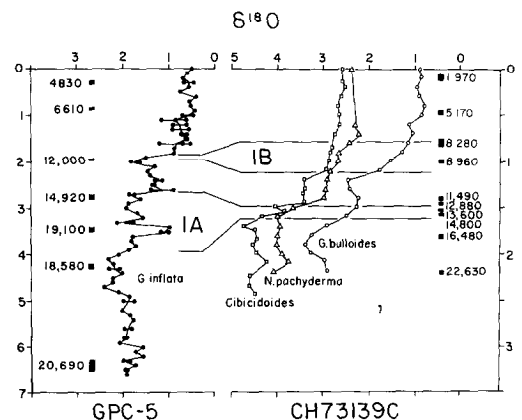


FIG. 2. Correlation of  $\delta^{18}\text{O}$  results between core GPC-5 (this study) and core CH73139C (Duplessy *et al.*, 1981). Termination 1B in GPC-5 occurs at 180 cm. Termination 1A occurs within a 1-m interval and is seen to include two steps. Minimum  $\delta^{18}\text{O}$  values at 350 cm probably reflect a pulse of  $^{18}\text{O}$ -depleted meltwater early in the deglaciation. The average difference in age of 3000 yr between the two records is due to the influence of detrital carbonate on the bulk sediment dates at GPC-5.

decrease to Holocene values, occurs at about 180 cm. In the Duplessy *et al.* data, Termination 1A occurs between glacial maximum values and the last  $\delta^{18}\text{O}$  maximum before Termination 1B, but the GPC-5 record reveals two steps in this interval. The most prominent feature within this interval is that labeled "a" in Figure 1, which may be evidence of glacial meltwater in the central North Atlantic. It is unlikely that a brief warming was the cause of this event, as it would represent as much as  $4^\circ\text{C}$ , which is contradictory to available evidence which shows a cooling early in the deglaciation (Ruddiman and McIntyre, 1981a).

Although Berger (1978) and Berger *et al.* (1977) have claimed oxygen isotope evidence for a global lid of low salinity during the latest deglaciation, Jones and Ruddiman (1982) have questioned their application of deconvolution techniques to stable isotope signals in sequences with low sedimentation rates. Nevertheless, many workers have shown oxygen isotope evidence for surface waters of low salinity during deglaciation in cores from nearshore marine environments (see Jones and Ruddiman (1982) for a review). Such intervals of low  $\delta^{18}\text{O}$  have previously been attributed to local changes in precipitation and runoff patterns, as well as influx of  $^{18}\text{O}$ -depleted meltwater from glaciers, but are now thought not to represent a *global* lid of low salinity (Jones and Ruddiman, 1982). Ruddiman and McIntyre (1981a, b) and Jones and Ruddiman (1982) acknowledge that the northern North Atlantic may have been affected by meltwater as far south as  $35^\circ$  or  $40^\circ\text{N}$ , which may have decreased or prevented carbonate productivity. Evidence for this comes from many cores that are marked by ice-rafted detritus and by low  $\text{CaCO}_3$  abundance, and contain either no carbonate microfossils or very few which are thought to result from reworking (Ruddiman and McIntyre, 1981b).

If the meltwater-productivity hypothesis of Ruddiman and McIntyre (1981b) is correct, then there should be a low salinity in-

fluence at some lower latitude with limited biogenic carbonate production. This is evident from their study of cores from the southern margin of the subpolar gyre ( $40^\circ$ – $45^\circ\text{N}$ ) where there apparently was phytoplankton productivity with insignificant zooplankton productivity. By extension of this reasoning, there must be some latitude farther south at which zooplankton were able to survive. Judging from the North Atlantic mixing line of Craig and Gordon (1965), our data suggest that salinity of surface waters overlying the Bermuda Rise ( $33^\circ$  to  $35^\circ\text{N}$ ) was reduced by about 1‰ early in the latest deglaciation.

Absolute timing of events in the Bermuda Rise deglaciation record is uncertain, as most  $^{14}\text{C}$  results are based on analysis of bulk sediment. Radiocarbon analyses from cores PC-06 and LGC-07 were performed at a commercial laboratory and those from GPC-5 were performed at Woods Hole using gas proportional counting techniques. Our GPC-5 results are approximately 5000 yr older than results published previously by Silva *et al.* (1976), which also were performed on bulk sediment from GPC-5. The reason for this difference has not been determined; however, available evidence supports the WHOI results.<sup>1</sup> Figure 2 shows that events in the GPC-5 record appear some 3000  $^{14}\text{C}$  yr older than similar events in core CH73139C, which were  $^{14}\text{C}$  dated after removal of detrital carbonate from the  $>44\text{-}\mu\text{m}$  fraction (Duplessy *et al.*, 1981). We suspect that the age difference between these two records is due to the influence of detrital carbonate in GPC-5. As a test of this hypothesis, we resampled the interval at 25–31 cm and compared dates on the fine ( $<63\text{-}\mu\text{m}$ ) and coarse ( $>63\text{-}\mu\text{m}$ ) fractions. Radiocarbon analyses revealed a coarse fraction age of  $1890 \pm 140$  yr B.P., and a fine fraction age of  $5680 \pm 210$  yr B.P. As we suspected, the fine fraction was older than the bulk sediment analysis ( $4830 \pm 60$  yr B.P.) which confirms the presence of detrital carbonate in the fine fraction. In addition, the anomalously old age at 340–350

cm (20,  $380 \pm 300$  yr B.P.) in GPC-5 probably reflects an intense pulse of detrital sedimentation associated with the meltwater influence at the same level.

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