

$\delta^{13}\text{C}$ - PO_4 relationships in the glacial Atlantic

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Introduction

Recently there has been much discussion concerning the discordance between $\delta^{13}\text{C}$ and Cd/Ca ratios in benthic foraminifera during the last glacial episode (Boyle, 1992). It seems possible that the imperfect relationship between Cd and $\delta^{13}\text{C}$ may be related to temperature dependent fractionation of carbon isotopes between the atmosphere and ocean, which disrupts the correlation between $\delta^{13}\text{C}$ and nutrients. This explanation has been proposed to account for shifts in $\delta^{13}\text{C}$ and PO_4 between the Holocene and glacial (Broecker, 1993) which are strongly discordant with what should be expected from Redfield ratios, such as those observed in the Southern Ocean (Boyle, 1992). However, data from the low latitude basins of the Atlantic show that $\delta^{13}\text{C}$ and PO_4 are changing in Redfield proportions between the Holocene and glacial, despite the fact that Southern source deep waters (AABW) became the dominant watermass ventilating low latitude Atlantic basins during glacial times. Here we attempt to reconcile this paradox by showing how changes in the thermodynamic effect on air-sea CO_2 exchange in high latitude surface waters may have significantly effected the $\delta^{13}\text{C}$ - PO_4 mixing slope for deep waters in the Atlantic during glacial times.

Methods

$\delta^{13}\text{C}$ - PO_4 results for the low latitude Atlantic in this study are based upon Cd/Ca ratios and $\delta^{13}\text{C}$ measurements on *C. wuellerstorfi* from E. Atlantic BOFS cores off the N. W. African margin. Stable isotope measurements were performed using a VG Isogas SIRA II mass spectrometer with a VG Isocarb reaction line, with a precision of better than 0.1‰ for both $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. Cd/Ca ratios were determined using graphite furnace and flame atomic absorption spectrophotometry.

Results

Cd/Ca and $\delta^{13}\text{C}$ values confirm that deep waters

in the low latitude E. Atlantic became nutrient enriched during glacial times. Cores within the deepest part of the basin (~5000m) show the greatest increases in nutrient concentration during the glacial, while cores at shallower depths (2500m) show little change in nutrient content. Although this data is consistent with a decline in North Atlantic Deep Water (NADW) formation and an increase in the influence of Antarctic Bottom Water (AABW), it seems that the occurrence of Holocene-glacial nutrient shifts in Redfield proportions in low latitude Atlantic basins conflicts with data from the S. Ocean where PO_4 and $\delta^{13}\text{C}$ do not change in Redfield proportions.

Discussion

At present the PO_4 - $\delta^{13}\text{C}$ relationship for deep waters has a distinctly different mixing slope (0.6;

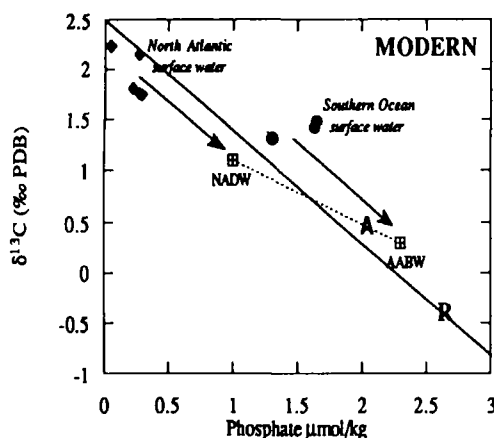


FIG. 1. Modern Atlantic: Line R represents the Redfield slope for warm nutrient depleted surface waters; line A represents the mixing slope for modern deep waters; solid triangles and circles represent N. Atlantic and S. Ocean surface water compositions respectively. Boxes represent end member compositions of NADW and AABW.

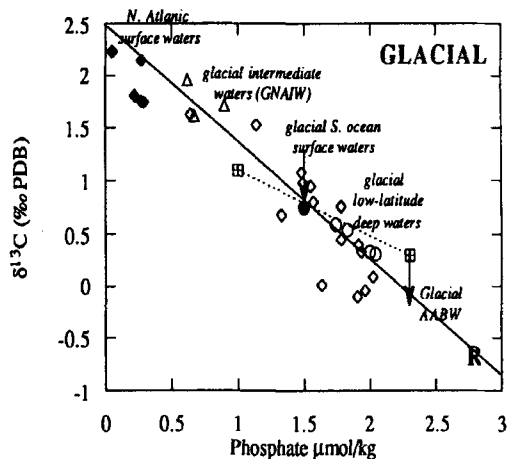


FIG. 2. Glacial Atlantic: Open symbols represent core data from Boyle (1992) (diamonds), Beveridge (circles) and Bertram (diamonds). Solid circle represents position of glacial S. Atlantic surface waters.

line A, figure 1) to that predicted by Redfield ratios (1.1; line R, figure 1). This is primarily due to the thermodynamic effect related to air-sea CO_2 exchange which appears to have little effect on N. Atlantic surface waters, but causes Antarctic surface waters to plot above the Redfield line by enriching their $\delta^{13}\text{C}$ values relative to PO_4 (figure 1). Because the composition of deep waters is related to the composition of surface waters by a nutrient regeneration slope which must parallel the Redfield line, then the thermodynamic effect results in the mixing slope for Atlantic deep waters being shallower than the Redfield line

(line A, figure 1). During the glacial, S. Ocean planktonic and benthic records show that while carbon isotope values decreased by at least -0.6‰ (after correction for the reservoir effect), Cd/Ca ratios and hence PO_4 values showed little change (Boyle, 1992). As a result, the composition of both surface and deep waters plot close to the Redfield line (figure 2), presumably due to significantly weakening the thermodynamic effect on S. Ocean surface waters during glacial times. In the N. Atlantic meanwhile, intermediate depth circulation (GNAIW) became enhanced at the expense of NADW formation. Because present day N. Atlantic surface waters lie close to the Redfield line, and planktonic $\delta^{13}\text{C}$ and Cd/Ca data suggests that the thermodynamic effect changed little for N. Atlantic surface waters during glacial times, then it is not surprising that the composition of GNAIW also plots close to the Redfield line. As a result, the mixing line for deep waters became steeper during glacial times, with both surface and deep waters throughout the Atlantic plotting close to the Redfield line (figure 2). This rotation of the mixing line for deep waters explains why low latitude Atlantic deep waters show Holocene-glacial nutrient changes in Redfield proportions despite non-Redfield nutrient changes in the Southern ocean. From this new mixing line it appears that during the last glacial AABW and northern source water mixed in proportions of 2:1 in the low latitude Atlantic, as opposed to 1:1 as previously thought.

References

- Boyle E. A. (1992) *Ann. Rev. of Earth and Planet. Sci. Let.*, **20**, 245–87.
 Broecker W. S. (1993) *Paleoceanography*, **8**, 137–9.