

A PALEO PERSPECTIVE ON THE OCEAN'S ROLE IN THE CARBON CYCLE

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ABSTRACT

Recently developed proxies for the seawater carbonate ion concentration were used to reconstruct the vertical gradient in the carbonate ion concentration for times in the past corresponding to the glacial-interglacial cycles. The reconstructed changes leave little doubt that the ocean drove the large natural variations in atmospheric carbon dioxide that accompanied the glacial cycles, most likely through the combined influence of changes in the biological pump and deep ocean circulation. Below 1500 m the carbonate ion concentration changes little, evidence of the ocean's ability to buffer changes in carbon chemistry over thousands of years.

The concentration of carbon dioxide in the atmosphere has varied by over 30% over the past several hundred thousand years [Petit, *et al.*, 1997], and the ocean, containing roughly sixty times more carbon than the atmosphere, plays a key role in both the natural variations of the past and also the future change over long time scales. Carbon dioxide dissolves in seawater to form carbonic acid, carbonate and bicarbonate ions, and observations of past change in ocean carbonate ion concentration provide a means to understand the ocean's role in the carbon cycle in the past. The vertical profile in the carbonate ion concentration is inversely related to the vertical profile in total carbon dioxide (Fig. 1) and provides a useful surrogate for the total CO₂. The vertical gradient in both properties is related to the combined influence of the biological pump and the mixing that reduces the gradient. The vertical profile in the carbonate ion concentration was reconstructed using geochemical proxies found in marine sediments for times corresponding to the present, and for the Last Glacial Maximum (LGM) approximately 21,000 years ago (Fig. 2). The sea surface reconstruction is a low latitude mean based on the U/Ca, 11B, 13C, and shell weight methods, and the subsurface reconstructions are based on the modern analog technique [Anderson and Archer, 2002], Zn/Ca, shell weight, and foraminifer fragmentation proxies. A remarkable result is the agreement among different methods across geographically widespread locations. The carbonate ion concentration at the sea surface increased by 80 micromoles per kilogram at the LGM compared to the present, large enough to explain the decrease in atmospheric carbon dioxide observed in ice cores. Below 1500 m there was little change in the carbonate ion concentration, consistent with the hypothesis proposed by others that the deep ocean buffers changes in carbon chemistry over thousands of years [Broecker and Peng, 1987].

The results leave little doubt that changes in the ocean drove these large natural cycles in atmospheric carbon dioxide, most likely through changes in the biological pump and/or ocean circulation. The 3 degree C cooling of the sea surface indicated by other paleo proxies and its associated change in the equilibrium concentration of dissolved carbon dioxide contributed to the total 80 ppm decrease in atmospheric carbon dioxide at the LGM. Our results are significant in revealing natural cycles in the partitioning of carbon between the surface and deep ocean, and also in revealing how the slow physics of the ocean operates over thousands of years to influence the composition of the atmosphere.

REFERENCES

- Anderson, D. M. and Archer, D., (2002), Glacial-interglacial stability of ocean pH inferred from foraminifer dissolution rates. *Nature*, 416, 70-73.
- Broecker, W. S. and Peng, T.-H., (1987), The role of calcium carbonate compensation in the glacial-interglacial atmospheric CO₂ change, *Global Biogeochemical Cycles*, 1, 15-29 (1987).
- Petit, J. R. & et al., (1997), Four climate cycles in Vostok ice core. *Nature*, 387, 359-360.

FIGURES

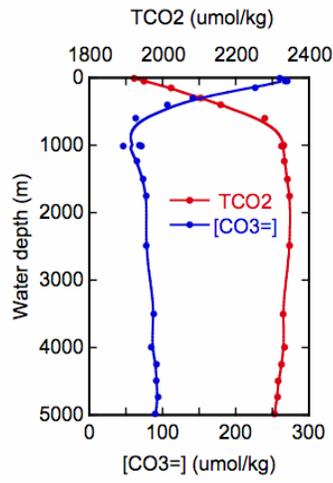


Fig. 1. Vertical profile of total carbon dioxide (TCO_2 , mmol.kg^{-1}) and carbonate ion concentration ($[\text{CO}_3^-]$, mmol.kg^{-1}) at WOCE station P15N in the tropical Pacific ($20^\circ 1' \text{N}$, $166^\circ 11.4 \text{W}$).

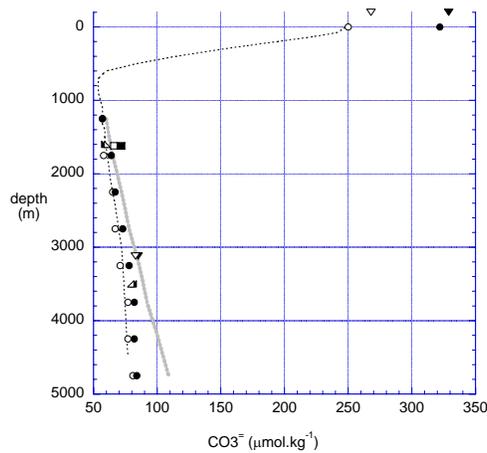


Fig. 2 Vertical profile of the carbonate ion concentration ($[\text{CO}_3^-]$, mmol.kg^{-1}) in the Pacific at 180°E , 20°N (dashed), saturation concentration with respect to calcite (gray), and the reconstructed concentration for modern (open symbols) and the Last Glacial Maximum (filled symbols). The sea surface concentration is the average for all cores and all proxies within 25° of the equator. Above the axis is the calculated concentration at the sea surface for an area-weighted average ocean in equilibrium with the pre-industrial (open triangle) and Last Glacial Maximum (filled triangle) atmosphere. Sea surface proxies are based on U/Ca, 11B, 13C, and foraminifer shell weights in marine sediments, and the subsurface are based on the modern analog technique (circle, left-facing triangles), the Zn/Ca (right-facing triangle), and fragment methods (downward triangles, squares).