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Pore Fluid Constraints on Chemistry and Temperature of the Glacial Ocean

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Since the 1950's, oxygen isotopic measurements of marine carbonates have been used to reconstruct past ocean temperatures. Such studies have been plagued by a fundamental ambiguity in the oxygen isotope paleothermometry technique: the oxygen isotopic composition of marine carbonate reflects both the temperature and the isotopic composition of the water in which it forms. Cooling during glacial episodes increases the mass-dependent fractionation of oxygen isotopes between water and calcite, resulting in higher $\delta^{18}O$ values of carbonate microfossils. The growth of large ice sheets on continents enriches seawater in ^{18}O, also resulting in higher $\delta^{18}O$ values for carbonate microfossils. Determining how much each of these components contributes to the total change in $\delta^{18}O$ of foraminifera is an important step toward understanding Pleistocene climate change.

One approach to circumventing this ambiguity is to use the chemical and isotopic composition of pore fluids in deep sea sediments to reconstruct the composition of seawater in the past. Initial studies from the tropical and north Atlantic showed a much smaller change in the isotopic composition of seawater (ice volume effect) and a larger change in deep ocean temperature than previous estimates. We present new results on oxygen isotopes in pore fluids from additional sites in the Atlantic and Pacific oceans. At these new sites, we use high precision measurements of chloride in pore fluid to estimate the salinity of deep water in the glacial ocean. We also supplement the oxygen isotope measurements with high precision hydrogen/deuterium measurements. The changes in oxygen isotopic composition and salinity caused by glaciation and deglaciation represent a periodic boundary condition for the sediment-pore fluid system, leaving a profile of $\delta^{18}O$ or chloride versus depth in the pore fluid that is a record (albeit degraded) of the history of the overlying seawater. This approach is exactly analogous to that used to reconstruct past surface temperatures from borehole temperature measurements in ice cores. The deuterium content of pore fluid, like oxygen isotopes, will record the change in seawater composition due to continental ice sheets as deuterium will not be affected by chemical reactions in the sediments over the time scale of glacial cycles. Deuterium measurements are an excellent test of the oxygen isotope data because the forcing function (change in seawater) for δD will be 8 times that for $\delta^{18}O$, falling on the meteoric water line, and the diffusivity will be exactly the same as for $\delta^{18}O$ (self-diffusion of water). However, the peak from the LGM will be affected by a slightly different boundary condition at the base as basalt alteration dos not affect δD nearly as much as $\delta^{18}O$. In addition, the deuterium data are an excellent check on problems with contamination of samples or fractionation due to evaporation.

The data from all sites in the Atlantic and Pacific confirm the earlier findings that the deep ocean temperature approached the freezing point of seawater during the LGM. The change in $\delta^{18}O$ of seawater is slightly larger in the Pacific than in the Atlantic due to the switch in water masses in the Atlantic. During the LGM, the data are consistent with a single source of deep water for most of the world's ocean basins, similar to suggestions from carbon isotopes, cadmium, and other chemical tracers. An interesting new result is that thermocline water (~450 m water depth) in the south Pacific shows a slightly larger change in isotopic composition than deeper water. This result opens up the possibility that such data may be used to reconstruct vertical temperature and salinity profiles through the glacial ocean.