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North Pacific Deep Water Formation During the Last Glacial Maximum?

Steven L. Goldstein (steveg@ldeo.columbia.edu), **Sidney R. Hemming** (sidney@ldeo.columbia.edu), **Alexander M. Piotrowski** (arcturus@ldeo.columbia.edu) & **Malka Machlus** (machlus@ldeo.columbia.edu)

Lamont-Doherty Earth Observatory, Rt. 9W, Palisades, NY, 10964, USA

Thermohaline circulation in the oceans is a primary means of transporting heat around the Earth. In the present-day, substantial deep water formation is only known to be occurring in the North Atlantic and in the Weddell Sea. The system has been likened to a great "conveyor" in which North Atlantic Deep Water (NADW) flows southward to the Circum-Antarctic. From there deep Circumpolar water flows to the Indian and Pacific, where it upwells diffusively and returns to the North Atlantic as intermediate and surface water. NADW formation is driven by high salt content resulting from evaporation in low and middle latitudes. The basic instability of a salt-driven system led Broecker and Denton (1989) to suggest that NADW weakened or shut down during cold climate intervals, triggering or enhancing dramatic global climate changes. It has also been suggested that glacial-interglacial reorganizations in thermohaline circulation involved deep-water formation in regions different from today. For example, higher variability of benthic foraminiferal $\delta^{13}C$ during the Last Glacial Maximum (LGM) led Curry et al. (1988) to suggest that deep water may have formed in the Pacific. This suggestion has found some support (e.g. Lynch-Steiglitz and Fairbanks, 1994), but the evidence from paleoceanographic tracers is still scarce and contradictory. The mode of thermohaline circulation is a primary climate parameter that must be constrained in order to understand changes in the global system. Here we present evidence for a shut-down of NADW export to the Southern Ocean and formation of deep water formation in the North Pacific during the LGM.

We are using Nd isotope ratios in the dispersed Fe-Mn component of deep sea cores as a paleoceanographic tracer. Nd isotope ratios are distinct in seawater of different ocean basins, with the most extreme values in the North Atlantic (ε_{Nd} <-13) and North Pacific (ε_{Nd} to ~0), and intermediate values in the Circum-Antarctic and Indian Oceans. They are not measurably fractionated by biological processes and temperature, and variations in seawater can be directly related to water masses in depth profiles. A survey of Nd isotope ratios in the Fe-Mn component of core-tops shows that they are the same as the local bottom seawater (LDEO data), demonstrating that the Nd faithfully records the deep water signal.

Our recent study of two southeast Atlantic cores from 40ºS and 43ºS (Rutberg et al., 2000) shows that the deep water was even more Pacific-like during the LGM (ε_{Nd} =-6.5 and -4.5, respectively) than present-day Circumpolar Deep Water (ε_{Nd} =-8.5). The Nd isotope ratio of the southerly core is the same as equatorial and southern Pacific seawater, which suggested to us that NADW export to the Southern Ocean may have shut down.

We have now further extended our LGM coverage to the Circum-Antarctic. In the South Atlantic, results to date show a systematic gradient southward, increasing to ε_{Nd} =-2 within the Antarctic Circumpolar Current (ACC). Such high values are only seen in the present-day North Pacific. Unless there was a significant source of Nd to the ACC that is not present today, the data suggest that in the LGM the ACC may have been dominated by export from the North Pacific. Two additional samples, from the Drake Passage and the west Pacific sector, also have LGM values of ε_{Nd} =-2, but Sr isotope ratios of 0.7084 and 0.7080, respectively, are lower than seawater. Although the Sr makes us hesitant to rely on these results, we note that there is evidence from Fe-Mn crusts that Nd can retain its marine signal even when the Sr is modified [Burton, 1997]. We mention these two results because they are intriguingly consistent with the Atlantic sector data. LGM values of ε_{Nd} =-4.5 in both a well-dated Fe-Mn crust from the central Pacific (Abouchami et al., 1997), and in a core from the East Pacific Rise (LDEO data), are the same as present-day equatorial and southern Pacific water. This may indicate that the North Pacific Deep Water followed a discreet southward flowpath in the western Pacific.

A Pacific-based "conveyor" operating during cold climate intervals has important implications for climate models and the overall understanding of climate system dynamics. We are actively extending our sampling coverage.

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