LAST GLACIAL MAXIMUM

Pacific push into the Atlantic

Deep, carbon-rich Pacific waters intruded into the South Atlantic some 38 to 28 thousand years ago. This deep Pacific expansion could have represented a considerable sink of atmospheric CO_2, one that helped initiate the Last Glacial Maximum.

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Vast ice sheets began to expand some 33,000 years ago, eventually covering much of North America, Northern Europe and Asia, in a period known as the Last Glacial Maximum. At this time, global climate was generally colder and drier than today, while sea levels were at least 100 metres lower. The causes of the Last Glacial Maximum are intimately tied to complex interactions between the oceanic and atmospheric systems. For example, atmospheric carbon dioxide — a powerful greenhouse gas — can be sequestered for long periods in the deep ocean as a function of the overturning, or ventilation, of these immense deep waters. Thus, greater storage of carbon in the abyss can reduce greenhouse insulation and drive climate to cooler states. Writing in *Nature Geoscience*, Yu and colleagues[1] use proxy records that track the identity and carbon characteristics of water masses to hypothesize that glacial Pacific deep water expanded into the Southern Atlantic prior to the onset of glaciation, acting as an important factor in the initiation of the Last Glacial Maximum.

Ocean circulation is considered a fundamental driver of global change over time (Fig. 1). Determination of deep ocean circulation, in particular, is critical to an accurate accounting of global fluxes of carbon, heat and oxygen. The establishment of conclusive ancient circulation patterns, however, remains a challenge for palaeoceanographers. For instance, one of the long-standing ideas in palaeoceanography has been that there are two Atlantic deep-water sources, one each from the northern and southern high latitudes, which alternately exchange influence in the deep Atlantic over climate cycles. This is epitomized by the suggestion of a millennial-scale 'seesaw'[2]. While probably an oversimplification of the history of Atlantic circulation, it has generally been assumed that deep Atlantic water masses come from Atlantic sources.

Yu and colleagues challenge this long-held view that the majority of Atlantic deep waters were sourced from areas of deep-water formation within the Atlantic. Combining carbon and neodymium isotope data, they find a cluster of Last Glacial Maximum samples in the southern Atlantic Ocean that suggest water mass characteristics incompatible with coeval Atlantic source waters. That is, conservative mixing of the previously accepted glacial Atlantic source waters — Glacial North Atlantic Deep Water and Glacial Antarctic Bottom Water — fails to account for a considerable volume of the mid-depth southern Atlantic. Rather, Glacial Pacific Deep Water appears to provide a better fit for these data. Moreover, by compiling foraminiferal B/Ca data, a proxy for dissolved inorganic carbon, Yu et al. illustrate that this anomalous South Atlantic water mass was relatively enriched in dissolved inorganic carbon, which is consistent with a Glacial Pacific Deep Water source. As is the case today, deep glacial waters of the Pacific tended to have greater accumulations of carbon and thus ultimately represent a larger sink-term for atmospheric carbon.

Fig. 1 | Deep ocean circulation. Yu and colleagues[1] suggest that Pacific deep waters intruded into the Atlantic and helped trigger the Last Glacial Maximum via sequestration of atmospheric carbon dioxide. Moving beyond the traditionally held view of two Atlantic sources for deep waters at this time will require new understanding of the roles other ocean systems have played — and will play — in dramatic climate shifts. Credit: Dmytro Tolokonov / agefotostock / Alamy Stock Photo

Through multi-proxy reconstructions and several assumptions, Yu and colleagues conclude that Glacial Pacific Deep Water made substantial contributions to the composition of this South Atlantic intermediate water mass. If true, this implies that there was greater sequestration of atmospheric carbon, which would have certainly impacted global climate. Ultimately, they suggest that the Atlantic-only template for deep ocean circulation in the Last Glacial Maximum may be confounded by a third non-Atlantic component. This challenges the idea of a simple exchange and adds degrees of freedom and complexity to the question of ocean circulation over time.

However, the logic is not unquestionable. For example, the conclusions of Yu and colleagues depend on proxies faithfully recording past ocean conditions, a challenge shared by all palaeoceanographers. However, even with accurate proxy records, the interpretation of these data as tracers of water mass — and thus circulation — is in some ways uncertain. Circulation tracers based on carbon cycling, including carbon isotopes and B/Ca, can be influenced by processes dissociated from deep circulation and are thus inherently ambiguous[3,4]. To help with this issue, the authors have used biologically inert neodymium isotopes as a pseudo-conservative proxy of circulation[5], but interpretations of these data are not without concern[6].

Despite these uncertainties, the suggestion that there were more than two deep-water sources in the Atlantic during the Last Glacial Maximum and that one was from outside of the Atlantic will prompt questions in the community. Moving beyond a two-endmember concept for the Atlantic circulation is intriguing, as it forces issues of zonal and oblique circulation into what is often conceptualized as a simple north–south exchange. Moreover, rejecting an Atlantic-only assumption may draw the spotlight away from water-mass subduction in the Atlantic, and inspire us to look at potential influences from the Pacific or Arctic. This opens up numerous research avenues because much more is currently known about circulation changes in the Atlantic than its bigger, more voluminous counterpart the Pacific. At twice the size and with far greater potential as a store of heat and carbon, the Pacific's role in climate change may have been critically underrepresented so far. Of course, that then leaves us wondering what happens in the Pacific during climate cycles.

Yu et al. suggest that there were more than two sources of deep water in the Atlantic during the Last Glacial Maximum and speculate that the Pacific may hold the key to deep-ocean carbon sequestration that led to the Last Glacial Maximum. In chasing down the agents of climate change, perhaps the greatest advances will now be found by looking outside of the Atlantic. ❐

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Competing interests

The author declares no competing interests.