PALAEOCEANOGRAPHY

The briny deep

Modern deep waters form in the Nordic seas when high-salinity surface waters cool and sink. An analysis of Arctic Ocean sediments suggests that throughout the past fifteen million years, brines created during sea-ice formation controlled the sinking of water.

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The retreat of sea ice in the Arctic this summer far exceeded expectations[1], and the rate of meltback appears to be accelerating as the ice-free ocean absorbs more solar irradiance than the ice, creating a positive feedback to warming. Despite the critical role of the Arctic in recent climate change, we have very little information about the links between this ocean/ice world and changing temperatures in the geologic past. It is particularly unclear how changing sea-ice volumes affected the formation and circulation of water masses formed in the Arctic. On page 68 of this issue, Brian Haley and co-authors[2] analyse the neodymium isotopic composition of ocean sediments to reconstruct the history of Arctic intermediate water circulation. They show that brines produced during Arctic sea-ice formation controlled the formation and characteristics of intermediate water masses over the last 15 million years.

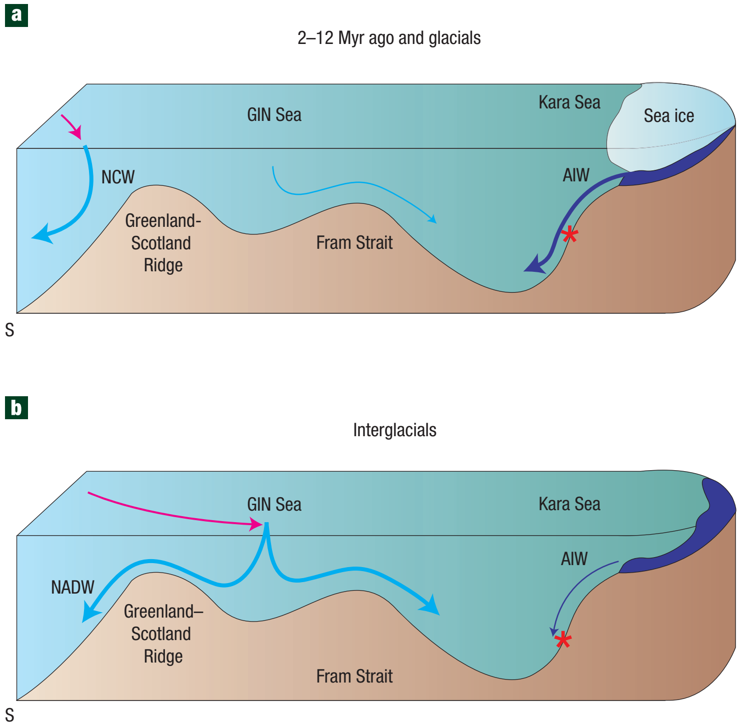

Figure 1 Changing circulation patterns in the Arctic Ocean. **a**, Between 12 and 2 million years ago and during glacial periods since then, Arctic Intermediate Water (AIW) was mainly produced in the Kara Sea, bathing the core site (red star) in water with a relatively radiogenic neodymium signature (purple arrows). Ventilation in the North Atlantic Ocean occurred south of the Greenland-Iceland-Norwegian (GIN) seas, forming non-radiogenic Northern Component Water (NCW, blue arrows). Deep-water formation in the GIN seas was greatly reduced. **b**, During interglacial periods that occurred over the last 2 million years, deep-water formation occurred mainly in the Greenland-Iceland-Norwegian seas, producing non-radiogenic North Atlantic Deep Water (NADW) that flows into both the Atlantic and Arctic Ocean basins. Antarctic Intermediate Water production is reduced, and non-radiogenic North Atlantic Deep Water dominates the core location.

Much of our understanding of past climate conditions comes from deep-sea sediments that record a relatively continuous record of climate through time and often include biologically derived material that can be used for dating and studies of environmental conditions. The ice-covered Arctic Ocean represents a formidable drilling challenge (see the Backstory on page 76). Nevertheless, in 2006 the Integrated Ocean Drilling Program recovered a >400 m composite of sediment cores from the Lomonosov Ridge spanning ~55 Myr (ref. 3). Unfortunately the material in the upper 200 m (~the past 16 Myr) largely comprises mineral, rather than biogenic, sediments, which precludes the use of most proven and widespread analytical techniques such as investigation of oxygen and carbon isotopes of biological carbonates. But iron–manganese coatings that form on sediments accumulating on the sea floor contain measurable quantities of neodymium. Nd isotopes extracted from these coatings are one of the few tracers of past ocean circulation. The isotopic signature of a water mass is imparted from weathering of continental material in the region where the water mass sinks below the surface. Radiogenic Nd isotope values reflect a contribution from relatively young volcanic material, whereas non-radiogenic values are a consequence of inputs from old continental crust. The water mass carries its distinctive signature as it circulates through the oceans.

Deep waters in the Southern Hemisphere form as the brines produced during sea-ice formation increase the density of cold surface water. In contrast, modern North Atlantic deep water, which has distinctly non-radiogenic Nd isotope values, forms as the relatively warm and salty surface waters from the North Atlantic current cool and sink in the Greenland–Iceland–Norwegian Sea. However, the Nd extracted from the Lomonosov Ridge sediments was surprisingly radiogenic. Haley and co-authors suggest that intermediate water formed in the Kara Sea bathed the site as the coatings were deposited (Fig. 1). Owing to input of weathering products from the Putorana Basalts in Siberia, surface water in the Kara Sea region had a radiogenic Nd-isotope value. This signature was subsequently carried to intermediate depths as a brine generated during sea-ice formation. Pacific waters are another potential source of such radiogenic Nd isotopes, but the connection between the Atlantic and Pacific oceans through the Bering Strait was closed until ~5.5 Myr ago (ref. 4).

The scenario Haley and co-authors propose would have required an open Fram Strait to allow inflow of seawater into the Arctic, and the development of sea ice in the Kara Sea at a time for which there is conflicting evidence regarding the existence of substantial ice in the Northern Hemisphere[3]. Finally, the inflow of North Atlantic intermediate waters over the Greenland–Scotland Ridge must have been limited between 12 and 2 Myr ago, requiring ventilation of North Atlantic deep waters at a location south of the Greenland–Iceland–Norwegian seas. A similar ventilation scenario has been proposed for Pleistocene glacial intervals due to sea-ice coverage in the Greenland–Iceland–Norwegian Sea[5], and is supported by more-radiogenic Nd isotope values in the Arctic during cold periods over the past 400,000 years[2] (Fig. 1). This correlation confirms the idea that more-radiogenic Nd values are not related to Pacific inflow because the sea level was significantly lower during glacial periods, which severely limited flow from the Pacific into the Arctic Ocean through the Bering Strait.

Although independent analyses of the same Arctic cores support the development of Arctic sea ice as early as 16 Myr ago[3], the cause of the required shift of North Atlantic ventilation to a more southerly location between 12 to 2 Myr ago — when the Greenland–Iceland–Norwegian seas were presumably largely ice-free — remains unclear.

The limited data for inferring past conditions in the Arctic Ocean mean that the interpretations are relatively unconstrained. However, Haley and colleagues present an interesting idea that other scientists can evaluate and challenge. An important implication of their work is that brine rejection during sea-ice formation may have been the dominant process in making surface waters dense enough to sink to deep and intermediate water depths during the past ~15 Myr in both the Northern and Southern Hemispheres. In that case, modern deep-water formation patterns in the North Atlantic Ocean would represent an anomaly rather than the norm[6].

The potentially widespread occurrence of brines in the North Atlantic Ocean has important implications for paleoceanographic studies based on the oxygen isotopes of material derived from these waters. Much of what we have learned about conditions and processes occurring in this region comes from this proxy. Yet interpretations of oxygen isotopes are highly dependent on estimates of seawater salinity[7], which may have been very different in a system dominated by brine.

Finally, brine formation in the Arctic Ocean throughout the past 15 Myr implies the presence of persistent sea ice, and therefore suggests that the Arctic may have played a critical role in the cooling of the Northern Hemisphere through the ice-albedo feedback, in a reverse of the climate response that we are observing today.

References

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TECTONICS

Arabia's slow dance with India

India and Arabia collide with Eurasia at slightly different velocities. Detailed mapping of the Arabian Sea suggests that this motion started between 3 and 8 million years ago, possibly with a transfer of an Arabian plate wedge to the Indian plate.

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Deep beneath the Arabian Sea, the 1,100-km-long Owen fracture zone marks the boundary between the Indian and Arabian tectonic plates (Fig. 1). Both plates are colliding with the southern edge of Eurasia but the Arabian plate is generally considered to be moving northeastward slightly faster than the Indian plate, and it is this difference in motion that is accommodated by the Owen fracture zone. The rate of differential motion along this fracture zone has long been known as one of the slowest among major plate boundaries, but until recently this area has not been surveyed with modern geophysical equipment, leaving important gaps in our understanding of plate tectonics in this region. On page 54 of this issue, Fournier and co-authors[1] describe a detailed survey of the southern end of the Owen fracture zone near the Aden–Owen–Carlsberg triple junction, including direct evidence for the direction and velocity of movement along the Owen fracture zone. The evidence suggests that a significant wedge of the Arabian plate was scavenged by the Indian plate some time between ~10 Myr ago and today.

The principal challenge in studying the Owen fracture zone is that, until now,