Palaeoceanography

Evidence of a freshwater Arctic Ocean

Sharon Hoffmann

A geochemical study of sediments suggests that, during recent glacial periods, the Arctic Ocean was completely isolated from the world ocean, with fresh water filling the basin for thousands of years. **See p.97**

The Arctic region is undergoing rapid climatic and environmental change[1], so knowledge of its past variability is crucial for understanding modern trends and predicting future ones. Ancient climate conditions and ocean behaviour are often reconstructed by analysing marine sediments. But Arctic sediments can be difficult to interpret, and much is still unknown about how the Arctic Ocean changed during specific glacial and interglacial periods over the past few million years[2,3]. On page 97, Geibert *et al.*[4] report analyses of an isotope of the element thorium in sea-floor sediments, which suggest that the Arctic Ocean swung between being filled with salt water and fresh water during periods of the two most recent glacials.

The authors base their argument on records of thorium-230, produced from the decay of dissolved uranium that is naturally present in seawater. Thorium is highly insoluble and sticks to solid particles such as dust grains or biological material, which sink to the sea floor and become buried in sediments[5]. Thorium that derives from the water column in this way is known as excess thorium-230 ($^{230}\text{Th}_{\text{ex}}$). It is typically present in sediments deposited during the past 450,000 years and is often measured to determine sediment-deposition rates[5,6]. Geibert and colleagues' innovation is instead to use these measurements to reconstruct how much $^{230}\text{Th}_{\text{ex}}$ was produced in the Arctic Ocean over time, and thereby to determine how the salinity has changed.

The authors examined sediment cores from across the Arctic and Nordic seas, and found that $^{230}\text{Th}_{\text{ex}}$ is absent in several layers of sediment deposited during the past 200,000 years. The cores suggest that no ^{230}Th was produced in the water above the study sites between about 150,000 and 131,000 years ago (during the next-to-last glacial), 70,000 and 62,000 years ago (during early parts of the last glacial) and perhaps even as recently as about 15,000 years ago (at the end of the last glacial).

Thorium-230 produced in seawater is removed so rapidly by sinking particles that its net horizontal transport across the ocean is typically low[5], even in the particle-poor Arctic. The intervals of absent $^{230}\text{Th}_{\text{ex}}$ in the sediment cores therefore imply that the uranium concentration was low to non-existent in the water above the study sites when those sediments were deposited. This, in turn, implies that the entire water column was essentially fresh down to the sea floor – there were no dissolved salts of any type.

Thick ice shelves covered regions of the Arctic during previous glacials[7]. Geibert *et al.* posit that such ice shelves could have extended into the Nordic seas, possibly grounding on the Greenland–Scotland Ridge – the tall underwater feature that separates the Nordic seas from the rest of the Atlantic basin (Fig. 1). The ice shelves might, in effect, have dammed the Arctic and Nordic seas, isolating them from salty inflows from the Atlantic. The low sea levels at that time blocked the exchange of water with the Pacific Ocean through the Bering Strait. Fresh water from melting land ice and precipitation could therefore have entered and eventually filled the isolated northern basins.

An advantage of Geibert and co-workers' $^{230}\text{Th}_{\text{ex}}$ method is that, unlike many other techniques used in palaeoceanography, no biologically produced material is needed for the analysis. It can therefore be used to probe environments that would have had low to no biological productivity, such as a freshwater Arctic Ocean beneath ice shelves. Indeed, microfossils in the $^{230}\text{Th}_{\text{ex}}$-free sediment layers are absent or extremely rare, or are derived from older deposits rather than being contemporaneous with the $^{230}\text{Th}_{\text{ex}}$ minima.

This new interpretation of $^{230}\text{Th}_{\text{ex}}$ might also provide an intriguing means of reconciling contrasting results previously obtained from different methods of estimating past sea levels. The relative abundances of oxygen isotopes in global seawater are recorded in microfossils, and, in part, reflect the sequestration

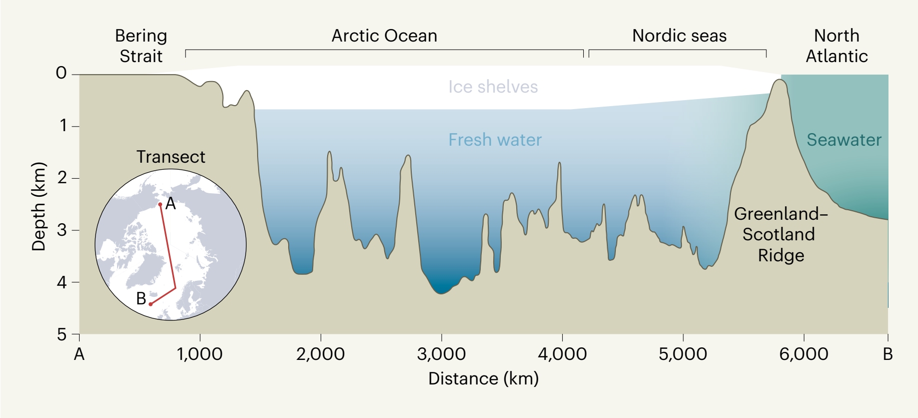

Figure 1 | Isolation of a freshwater Arctic Ocean during glacial periods. By analysing marine sediments, Geibert *et al.*[4] infer that the Arctic Ocean was filled with fresh water during periods of the two most recent glacials. They propose that thick ice shelves covering the region extended into the Nordic seas, and grounded on the undersea Greenland–Scotland Ridge, as shown in this transect. This would effectively have dammed the Arctic Ocean and Nordic seas, isolating them from salty inflows from the Atlantic Ocean. The low sea levels at that time would also have blocked exchange of water with the Pacific Ocean through the Bering Strait. Fresh water from melting land ice and precipitation could therefore have entered and eventually filled the isolated basins beneath the ice shelves. (Adapted from Extended Data Fig. 5 of ref. 4.)

of evaporated ocean water into ice sheets or other freshwater reservoirs, which can affect sea level. For certain times during recent ice ages, sea-level records obtained from isotopic analyses of microfossils are inconsistent with records derived from corals[8]. Geibert *et al.* suggest that these inconsistencies could be explained by the proposed storage of large volumes of fresh water in the Arctic Ocean.

Various complications in the analysis will no doubt raise questions. Arctic sediments are notoriously hard to date owing to the lack of microfossils, and because sedimentation rates varied[2,3]. It is therefore uncertain whether the $^{230}\text{Th}_{\text{ex}}$-deficient intervals in the cores were produced at exactly the same times at all sites across the ocean basins. Moreover, the authors had to correct their data to account for ^{230}Th that was produced from uranium decay in sediment grains, rather than in the water column[5], and this contributed to the uncertainty in measured $^{230}\text{Th}_{\text{ex}}$. These corrections become proportionally more important for older sediments because $^{230}\text{Th}_{\text{ex}}$ itself decays away; thorium decay also limits the time span over which the method can be used to investigate Arctic salinity. Finally, no freshwater fauna have been identified in the sediments concerned, so direct evidence of freshwater intrusion into deep Arctic basins remains to be found.

However, the various absences – of $^{230}\text{Th}_{\text{ex}}$, of microfossils and biological productivity, and of elements such as sulfur, which partly derive from salinity in marine sediments[9] – suggest exciting avenues for future research. Computational modelling of Arctic Ocean circulation and ice-sheet behaviour will be needed to determine realistic estimates of the circulation and freshwater run-off from land that could produce a basin filled with fresh water. Further geochemical and fossil analyses might help to support or challenge the assertion that the Arctic Ocean could have been fresh. Geibert and colleagues' innovative use of ^{230}Th might spur a re-evaluation of what is possible in the Arctic Ocean, and of how dramatically this region can change.

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Coronavirus

An estimation of undetected COVID cases

Jeffrey Shaman

Most SARS-CoV-2 infections are undocumented. French health-care records and modelling were used to assess the rate of documentation of COVID-19 cases. The findings highlight the need for improved identification of infections. **See p.134**

The ongoing COVID-19 pandemic has stretched health-care systems, disrupted economies and frayed the fabric of societies around the globe. Nation states have responded differently to the crisis, and only a few countries have managed to achieve continued control of coronavirus transmission. On page 134, Pullano *et al.*[1] report their study of SARS-COV-2 infections in France during late spring and early summer of 2020. Their analysis came after the peak of the first wave of COVID-19 cases there, but before the increase again in the autumn, which led to a higher second wave of cases. The results offer some important lessons.

Three key characteristics of the SARS-CoV-2 coronavirus have made it particularly challenging and disruptive. First, it is a newly emerged virus to which most people have little or no pre-existing immunity. Second, most infections are not documented by health-care systems; many individuals with these undocumented infections have no or only mild symptoms and can unknowingly spread the virus[2]. Moreover, the individuals with infections that are eventually documented typically become contagious before symptoms appear[2,3]. As a result, most of the viral transmission within and between communities is driven by a combination of pre-symptomatic individuals who will later develop symptoms, those who never develop symptoms (asymptomatic individuals) and those with mild symptoms who do not seek medical attention. Third, despite the preponderance of undocumented infections, the total number of global infections (documented and undocumented) is so high – with hundreds of millions infected so far – that the relatively small fraction of infections that result in severe outcomes or death[4] already numbers in the millions.

To understand and control the pandemic, it is crucial to estimate how widespread the disease is within communities. One means of determining infection prevalence is provided by a measurement called the ascertainment rate – the fraction of all infections that are documented in the health-care system as confirmed cases. A higher ascertainment rate signifies a greater capacity to identify infections and thus possibly control the onward spread of the virus through the isolation of infected individuals, along with other interventions. Pullano and colleagues present two independently generated estimates of new COVID-19 symptomatic cases in France during a seven-week period from mid-May to June (generating both these estimates using data and inference approaches), to quantify the ascertainment rate for symptomatic infections. They find a substantial discrepancy between their estimate of the number of detected symptomatic cases and of the total number of detected and undetected symptomatic cases (Fig. 1), revealing a low ascertainment rate. The findings suggest that the overall testing and control system in place was inadequate to contain the virus successfully in this country of around 65 million people.

Pullano and colleagues derived their first estimate of confirmed symptomatic cases of COVID-19 from a nationwide database, which was designed to track and record SARS-CoV-2 test results. This database was launched in May 2020, at the end of the spring lockdown in France. The information it contains includes routine virological testing and symptom reports for: health-care personnel; elderly individuals in nursing homes; residents of long-term care facilities; and patients hospitalized for any reason, as well as data on the tracing and testing of contacts of confirmed COVID-19 cases. In addition to these surveillance measures, any individual who showed COVID-19 symptoms could obtain diagnostic testing if referred by their doctor. By accounting for asymptomatic and pre-symptomatic cases, as well as for delays from symptom onset to testing, Pullano *et al.* obtained an estimate of the number of people with confirmed COVID-19 in whom symptoms developed during the seven-week study period.

For their second estimate, Pullano and colleagues used a mathematical model, hospitalization records and a maximum-likelihood