

NEWS & VIEWS

CLIMATE CHANGE

The Arctic tells its story

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The Arctic is one of the sensitive pressure points for Earth's climate. A new sediment core reveals much more about the region's role in a long-term transition from 'greenhouse' to 'icehouse' conditions.

Just as a white T-shirt keeps us cooler on a hot sunny day, a blanket of reflective snow and sea ice over the polar regions reduces the amount of sunlight the Earth absorbs. Ice and snow cover grows in response to cooling temperatures, and so amplifies climate change. But the Arctic and the Antarctic were not always frozen and barren. Over the past 55 million years or so, the Earth has experienced a major cooling, from a greenhouse climate to the current icehouse climate. The results of a remarkable scientific project in the Arctic¹, as reported in three papers in this issue^{2–4}, provide a detailed picture of the Arctic's role in the long-term cooling, and its response during oscillations of the preceding greenhouse climates.

Despite the effect that the Arctic has on global climate — both through its icy reflection of the Sun's gaze and its efficient embrace of warm, salty currents from lower latitudes — its role in the climate transition has been a puzzle because no long geological record had been recovered from the central Arctic. Our understanding of Arctic climate evolution came from studies of cores and outcrops thousands of kilometres away. An astute strategy combining icebreakers and drilling rigs (Fig. 1) has finally succeeded in getting the story from the horse's mouth. The Arctic coring expedition recovered a remarkable climate record spanning the past 55 million years from the central Arctic, and the inferences drawn from that record are described in the new papers^{2–4}.

Declining atmospheric CO₂ has long been envisaged as a culprit for the past 55 million years of cooling climates, and the consequent transition from an ice-free world to one with large ice sheets on Greenland and a frozen Arctic, as well as with a deep-frozen Antarctica. Indeed, reconstructions of past atmospheric CO₂ concentrations, based on isotopic markers from marine algae⁵, show a dramatic drop in atmospheric CO₂ between about 45 million and 25 million years ago that corresponds quite well to the onset of major global cooling (Fig. 2a,b, overleaf). However, although the onset of glaciation and sea ice in Antarctica about 43 million years ago matched the onset of global cooling and CO₂ decline, the Arctic



Figure 1 | Core contributions. Three ships, seen here on location, that worked together on the Arctic coring expedition: the icebreaker/drillship *Vidar Viking*, and the ice-breakers *Oden* and *Sovetskiy Soyuz*.

seemed to march to a different drummer. Arctic cooling, with concomitant growth of ice sheets and sea ice, seemed to hold off for tens of millions of years, until about 2–3 million years ago when pebbles carried by icebergs first appeared in North Atlantic sediments.

To explain the long delay between Antarctic and Arctic glaciation, palaeoclimatologists suggested that Antarctic ice sheets started to grow not because of global climate factors such as CO₂, but in response to regional changes in the Southern Hemisphere. When the continents of South America and Australia drifted away from Antarctica, warm currents could no longer follow the coastline and make it all the way to Antarctica. Yet recent models suggested that cutting off currents alone would not have cooled Antarctica enough to start ice-sheet build-up⁶.

The puzzle is solved nicely with the new record reported by Moran *et al.*² (page 601), which shows that Arctic ice developed much earlier than previously believed. Pebbles

carried to the middle of the Arctic basin by icebergs appear by 45 million years ago, about the same time as around Antarctica (Fig. 2c). Abundant sand and iceberg-delivered pebbles confirm that sea ice and icebergs were widespread in the Arctic by 14 million years ago. This earlier onset of Arctic glaciation, synchronous with glaciation in Antarctica, supports the idea that changes in atmospheric CO₂ were the major driver in initiating glaciation in both hemispheres.

Although Moran and colleagues' paper² reveals a closer link between atmospheric CO₂ and the greenhouse-icehouse transition, results from older sediments in the Arctic core expose some surprising gaps in our understanding of the workings of climate in a greenhouse world. Sluijs *et al.*³ (page 610) report that 55 million years ago Arctic summertime surface-ocean temperatures were as high as 18 °C. Such temperatures are comparable to those of the modern summer ocean on the French coast at Brittany (where hardy

souls even go swimming). Most importantly, climate models for 55 million years ago don't come close to simulating such warm waters, even when reflective ice sheets are left out and atmospheric CO₂ levels are pumped up to 2,000 parts per million — nearly ten times the levels before the Industrial Revolution. Clearly, CO₂ is not the only driver of the extreme polar warmth. Something is missing from the models' climate simulation. The authors propose that that 'something' is another greenhouse agent, clouds of frozen water vapour in the lower stratosphere of polar regions. Like greenhouse gases in the atmosphere, these ice crystals trap part of the energy that Earth emits back to space, keeping Earth's surface warmer in polar regions.

Sluijs *et al.*³ also provide intriguing results for a dramatic burst of intense warming — the Palaeocene–Eocene Thermal Maximum — that occurred 55 million years ago. This 'Palaeocene supergreenhouse' is believed to have been caused by a massive release of carbon to the oceans and atmosphere, either from methane present in deep-sea sediments or as organic carbon vaporized by volcanism during the opening of the North Atlantic Ocean. In either case, the extra CO₂ in the atmosphere increased the greenhouse effect and warmed tropical temperatures by 4–5 °C (ref. 7). Sluijs *et al.* show that Arctic temperatures also soared, rising from 18 °C to 23 °C (Fig. 2c). Models are again unable to get the absolute temperatures right for the Arctic warming, but they do agree with the amount of Arctic warming caused by the CO₂ increase.

Unlike the situation observed over recent swings into and out of ice ages, where temperatures in the Arctic change by at least twice as much as those in the tropics, the warming in the Arctic during the Palaeocene supergreenhouse is about the same as that observed in tropical and subtropical regions. In this respect, paradoxically, this result confirms one aspect of our understanding of icehouse climates — that sea ice and ice sheets are responsible for the larger temperature swings in the polar regions, and in ice-free greenhouse climates the poles respond to climate changes just like everywhere else. This result reaffirms that, although the rate of CO₂ change and warming during the Palaeocene supergreenhouse may be similar to that expected in the coming centuries, in one respect future warming will be different — it will be strongly amplified at high latitudes by the reduction in snow and sea ice cover.

Finally, Brinkhuis *et al.*⁴ (page 606) provide a glimpse at the early operation of another crucial climate feedback in the Arctic, the relationship between heat transport and salinity. Today, warm salty currents feed into the Arctic. There, by releasing their heat, these waters become dense enough to sink into the deep ocean as North Atlantic Deepwater. Fluctuations in the intensity of these currents and deepwater formation participated in causing or amplifying the most abrupt climate

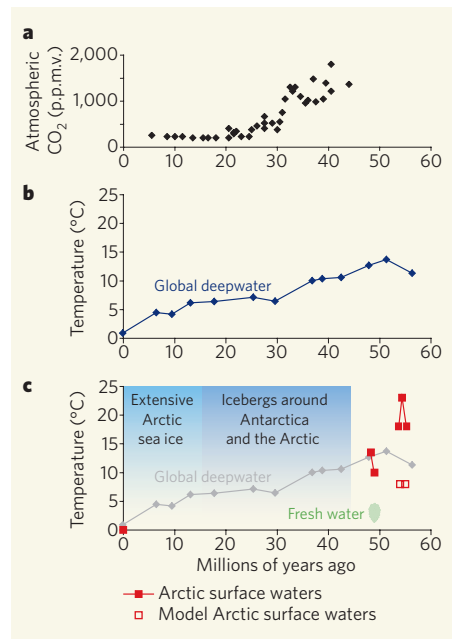


Figure 2 | Evolution of global and Arctic climate over the past 55 million years. **a, b,** Declining concentrations of atmospheric CO₂ (parts per million by volume; ref. 5) coincide with cooling inferred from deepwater temperatures⁸. **c,** Summary of the new results^{2–4}. The development of ice in the Arctic² occurred earlier than previously thought, and was synchronous with Antarctic glaciation. Fifty-five million years ago, during the Palaeocene–Eocene Thermal Maximum, summer temperatures of surface waters in the Arctic 'spiked' with a 5 °C rise. Temperatures before and during this event exceeded modelled temperatures by at least 10 °C (ref. 3). Finally, 49 million years ago, in a brief span of about 1 million years, the Arctic experienced an interval of unusually fresh surface waters⁴. This interval was truncated by influx of warm and salty currents originating in lower latitudes, which caused a rise in sea surface temperatures.

changes of the past tens of thousands of years.

Brinkhuis *et al.* identify an 800,000-year interval of time, 49 million years ago, when it seems that the Arctic may have been almost completely cut off from the inflow of warm and salty currents originating in lower latitudes. Without salty currents flowing in, the local excess of precipitation over evaporation created a freshwater environment (Fig. 2c) characterized by communities of aquatic ferns, *Azolla*, which today grow naturally only in waters with less than 0.2% salt. During this unique interval, pulses of freshwater even overflowed from the Arctic and carried remains of the ferns into the surrounding ocean basins.

The reign of the freshwater ferns in the Arctic ended abruptly 48.3 million years ago when waters became salty again. Significantly, Brinkhuis *et al.* show that the rise in salinity of the Arctic corresponded with a small but important rise in the temperature of Arctic waters — indicative of the entrance of warm and salty ocean currents from lower latitudes. As the younger sediments of the Arctic core release their secrets, we should find out

how the transport of warm ocean currents continued to evolve in the subsequent tens of millions of years, and how such changes relate to the falls in global temperatures over the past 20 million years.

Taken together, these papers²⁻⁴ resolve some enigmas about the climatic evolution of the Arctic. But we still need to sort out why the intensity of glaciation stepped up around 14 million years ago and increased further around 3 million years ago, because neither step was tied to decreases in atmospheric CO₂. Also, given that the modelled effect of CO₂ is not sufficient to explain the Palaeocene super-greenhouse, and some other (possibly greenhouse) agent is required, then the demise of this other factor may also have affected the growth of ice sheets and the global cooling.

In all this, there's a particular challenge for those involved in climate modelling. If they can incorporate the processes causing the hot poles in the past, we will have even greater confidence in their predictions for the future. ■

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