

regions but absent in others, vary in thickness and reach heights of up to 100 km above the boundary. Using geodynamic modelling, the authors infer that the ridges are composed of material that is 1.5–2% more dense than the surrounding mantle rocks and contains approximately 4–5 volume % iron-rich ferroprecipitate<sup>11</sup>. The model results imply that the lowermost mantle beneath western North America is chemically very heterogeneous.

The detected structure is thicker and shows smaller seismic velocity reductions and density increases than the ULVZs<sup>8</sup>. Indeed, the structure appears to represent a previously undocumented class of chemical heterogeneity that may be linked to remnants of large-scale melting events early in Earth's history or material flux across the core–mantle boundary<sup>2</sup>. Resolution of these 3D structures is currently limited by the use of 1D and 2D modelling techniques. However, improvements in the theory and efficiency

of 3D wave-propagation techniques could provide further insight into the precise nature of this complicated lowermost mantle structure in the future.

Sun *et al.*<sup>2</sup> identify small-scale ridges of iron-rich material at the core–mantle boundary beneath North America. Identification of these structures was made possible, mostly, because of the rapid growth of seismic station numbers globally. The USArray is a prime example of a dense network of identical high-quality seismic stations that provide open data access through professional data centres. Other similarly dense station networks exist; sadly, the advantages of such networks are sometimes not realised as a result of limitations in data access. Further high-resolution and necessarily multidisciplinary studies have the potential to provide new understanding of how the interior of our planet works. □

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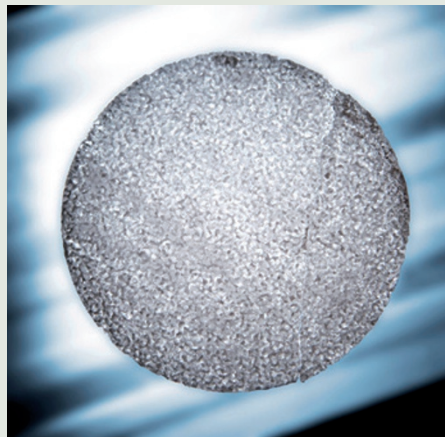
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## CRYOSPHERE

# Interglacial ice sheet survival

The continent of Greenland lies buried beneath an ice sheet that is 3,000 m thick at its greatest vertical extent. At the base of this vast sheet there is ice formed from snow that fell more than 120,000 years ago, during the last interglacial period. The chemistry of the ice — and of the air trapped within it — can be used to reconstruct climate conditions at the time of formation. But unlike the neatly layered ice near the top of the ice sheet, the oldest Greenland ice — from the last interglacial period — is often highly deformed where the ice melted or slipped over uneven bedrock. Folding, overturning and discontinuities at the base of the ice sheet have so far precluded any meaningful analysis of the climate of the last interglacial period, also known as the Eemian.

For the north Greenland Eemian ice drilling project (NEEM), a location on flat bedrock was carefully chosen in the hope of finally retrieving an ice core with intact interglacial ice. However, initial results revealed that this ice, too, was folded and discontinuous. Nevertheless, Dorthe Dahl-Jensen and her NEEM colleagues were able to unravel these records with the help of oxygen isotopes, an analysis of ice crystal structures and radar data. They present a temperature and ice-melt record that reaches back 128,000 years, to the peak



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of Eemian warmth (*Nature* <http://dx.doi.org/10.1038/nature11789>; 2013).

Dahl-Jensen and colleagues found a number of unexpected features. Between 127,000 and 118,300 years ago, mean annual temperatures were about 5 °C warmer than those of the last millennium. At their peak, 126,000 years ago, temperatures were as much as 8 °C warmer than during the last millennium. Surface melting throughout this interval was extensive. However, the team estimates that the ice thickness at their drill site declined by only about 400 m between 128,000 and 120,000 years ago, although the uncertainties in this value are considerable.

The last interglacial period saw sea levels about 4–8 m higher than present and global mean annual temperatures several degrees warmer than pre-industrial values. Many numerical simulations of the Greenland ice sheet during this warm period show a great deal of melting, including at the location of the NEEM ice core. The relatively small change in elevation as reconstructed by Dahl-Jensen and colleagues is consistent with only a few models. These models also suggest that the runoff of Greenland meltwater into the oceans raised sea level by only about 2 m, no more than half of the total observed sea level rise.

The thermal expansion of the warming oceans and melting of smaller alpine glaciers could, of course, have contributed to the sea level rise. But it is hard to reconcile modern values of water storage in ice outside of the ice sheets with the remaining 2–6-m sea level rise. Instead, at least some of that water must have come from melting of Antarctic ice.

We had long believed that ice on Antarctica was stable. But growing evidence suggests that the ice sheet covering West Antarctica may be prone to collapse during periods of warmth. Our first look at the Eemian ice in Greenland seems to support this idea.

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