The history of Greenland's ice

Global sea levels would rise by several metres if the Greenland Ice Sheet melted completely. Two studies have examined its past behaviour in an effort to evaluate its vulnerability in a warming world — and have come to seemingly conflicting conclusions. Two geochemists and a glaciologist discuss the issues. SEE LETTERS P.252 & P.256

THE PAPERS IN BRIEF

- Knowledge of the ancient history of ice sheets is needed to inform predictions of their future response to climate change.
- On page 252, Schaefer *et al.*[1] present measurements of beryllium-10 (^{10}Be) and aluminium-26 (^{26}Al) from bedrock beneath the Greenland Ice Sheet.
- From their data, they propose that Greenland has undergone one or more episodes of deglaciation during the past 1.1 million years.
- On page 256, Bierman *et al.*[2] present ^{10}Be and ^{26}Al data from marine sediment cores collected off the coast of Greenland.
- They conclude that the East Greenland Ice Sheet remained present during the Pleistocene (the epoch that lasted from 2.6 million to 11,700 years ago), but grew and shrank dynamically in response to climate.

Cosmic signature

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It is difficult to find evidence for past waxing and waning of the Greenland Ice Sheet (GrIS), because the glacial debris that can provide a record of ice-sheet dynamics (Fig. 1) is erased each time glaciers advance after a period of deglaciation. Schaefer *et al.* and Bierman *et al.* now report the presence of two rare nuclides (^{10}Be and ^{26}Al) in Greenland's geological archives. These 'cosmogenic' nuclides are produced by the interaction between atoms in minerals and high-energy cosmic neutrons that probably originated in supernovae, and they provide much-needed evidence about the GrIS's ancient past.

A key characteristic of these isotopes is that they are produced in detectable quantities in only the first few metres below Earth's surface. If they become buried below hundreds of metres of ice, their concentrations decrease through radioactive decay. The half-lives of ^{10}Be and ^{26}Al are 1.4 million and 0.7 million years, respectively, so the presence of these nuclides in bedrock under ice sheets is direct evidence that one or several ice-free episodes occurred in the recent past (less than 5 million years ago).

Bierman *et al.* report variations in ^{10}Be and ^{26}Al from marine sediments deposited near the eastern margin of today's GrIS over the past 7.5 million years. The low ^{10}Be concentrations suggest that the sedimentary material originates from locations that were efficiently shielded from cosmic rays. The authors therefore conclude that large ice caps probably existed continuously across East Greenland — the source of the sedimentary material — during the past 7.5 million years. They also observe an additional long-term decrease in ^{10}Be and ^{26}Al concentrations during this period, which indicates a gradual increase in the volume of the GrIS.

In parallel, Schaefer *et al.* analysed bedrock samples recovered from beneath several kilometres of ice in the centre of the present-day GrIS. These rocks cannot have been transported to their current position from elsewhere. The presence of ^{10}Be and ^{26}Al in these samples is therefore direct evidence for past deglaciation episodes at this location.

Schaefer and colleagues used the observed concentrations and ratios of ^{10}Be and ^{26}Al in a numerical model to explore plausible glaciation–deglaciation scenarios. They firmly conclude that the sampled bedrock must have been ice-free for at least one episode of about 280,000 years during the past 1.1 million years. Other glaciation–deglaciation scenarios are more plausible, however, such as several shorter disappearances (several thousand years) of the GrIS during the warmest interglacial periods of the Pleistocene[3].

The deglaciation proposed by Schaefer

NICK COBBING/GREENPEACE

Figure 1 | Ice-sheet dynamics. These icebergs calved from the Helheim Glacier, an outlet glacier at the periphery of the Greenland Ice Sheet. Such glaciers are responding rapidly to climate change.

et al. seems at odds with Bierman and colleagues' conclusions. But small ice caps might have persisted on the East Greenland highlands during such deglaciated episodes, and could be the origin of the ^{10}Be-poor material observed in Bierman and co-workers' marine sediments. Indeed, modelling experiments[4] estimate that ice caps 1,000 metres thick might persist on the south-eastern Greenland highlands in the future even if 95% of the GrIS disappears (Fig. 2).

Could the GrIS undergo similar deglaciations in the future? Average global warming of just 2 °C compared with preindustrial temperatures could be enough to melt more than 75% of the GrIS[3]. If this high sensitivity to warming is confirmed, then the current worst-case scenarios[5] for future sea-level rise associated with anthropogenic global warming will need to be revised.

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