reveal the extent to which the evolution of behaviour is targeted to particular nodes in neural circuits. ■

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PALAEOCLIMATE

Ancient ice sheet had a growth spurt

An analysis of ancient coral from the Great Barrier Reef reveals that global sea level fell rapidly at the end of the last glacial period. The findings suggest that ice sheets are more dynamic than was previously thought. SEE LETTER P.603

PIPPA WHITEHOUSE

The episode known as the Last Glacial Maximum extended from 26,500 to 19,000 years ago, and is often thought of as a prolonged time during which glaciation was continuously at its greatest extent[1]. But on page 603, Yokoyama *et al.*[2] report an analysis of relict coral reefs that suggests that the already extensive ice sheets underwent a final burst of rapid growth about 22,000 years ago, at a rate sufficient to lower global mean sea level by an astounding 17 metres in only 500 years — about ten times faster than the current rate of sea-level rise. This seems to have been followed almost immediately by ice-sheet retreat. Understanding the trigger for this previously undocumented growth is crucial to understanding the sensitivity of ice sheets to external drivers and internal feedbacks.

Previous studies have tended to focus on the magnitude of sea-level decline during the Last Glacial Maximum (LGM), rather than the timing of it, with the general consensus being that sea level was about 125–135 m lower than it is today[3,4]. Geological records that shed light on the detailed timing of sea-level change during this period are notoriously difficult to obtain, not least because they are often located about 100 m underwater. To address this problem, Yokoyama *et al.* analysed a 'staircase' of relict coral reefs that once formed part of the Great Barrier Reef at the edge of the Australian continent — analysis of the recovered corals indicates the sea level at the time they were alive, whereas the reef age was determined using radiometric dating techniques.

One issue with such studies is that modern corals live at a range of depths, creating considerable uncertainty about the depths that can be inferred from fossilized samples[5]. However, by piecing together information from adjacent reefs at different depths, Yokoyama *et al.* built up a composite picture of the timing and magnitude of LGM sea-level decline off the coast of Australia. Their approach is clever and simple: they reason that a hiatus in coral growth caused by sea-level fall at one site must coincide with the development of a second, nearby reef farther offshore, as water depths became shallow enough to support growth at the deeper site (Fig. 1). Moreover, samples recovered from the second site indicate that the sea-level minimum (the lowstand) was short-lived, and that sea level soon began to rise again.

To identify the ice sheets responsible for the dramatic sea-level fall, Yokoyama *et al.* turned to a technique known as glacial isostatic adjustment (GIA) modelling, which can predict how ice-sheet change translates into sea-level change[6]. Although increases in ice mass directly equate to decreases in ocean mass, the resulting pattern of sea-level change is not straightforward. This is because the land beneath ice sheets subsides as mantle material is displaced by the weight of the accumulating ice, and rebounds when the ice melts; an equivalent process takes place across ocean basins in response to increases or decreases in ocean mass. The changes in the shape of the solid Earth alter the shape of the planet's gravity field. And because the gravity field defines the

NATURE

50 Years Ago

Compensation of £3,200 has so far been paid by the Ministry of Technology for the damage caused by the four sonic boom tests carried out over London last summer with Lightning aircraft. The other seven tests over other parts of Britain cost just over £700 in compensation … With one exception, all the claims involved damage to property. The exception was a claim made by a woman from Hornchurch who suffered a partial loss of hearing … and accepted £150 settlement. Even before the tests, the British Government seems to have recognized that aircraft should not be allowed to fly at supersonic speeds over densely populated areas … It seems inevitable that all supersonic flight over land will be prohibited, at least until a great deal more information on the effect of sonic booms has been collected.
From *Nature* 27 July 1968

100 Years Ago

An article on coal-saving … appears in *Engineering* for July 12. The author … gives average figures for 250 typical steam-boiler plants, covering … 1910 to the present time. It is estimated that 58,500,000 tons of coal per annum are used in this country for steam-raising purposes … exclusive of 15,000,000 tons used in railways. The 250 plants had a total of 1000 boilers, principally of the Lancashire type. With hand-firing the average net working efficiency is 57.8 per cent., as against mechanical firing with an average net working efficiency of 61.4 per cent. … The author estimates that there are 45,000 to 60,000 steam boilers at work in Great Britain, calculated in terms of averaged-sized Lancashire boilers, and considers that all the steam produced in the country to-day could be obtained much more economically with 25 per cent. fewer boilers.
From *Nature* 25 July 1918

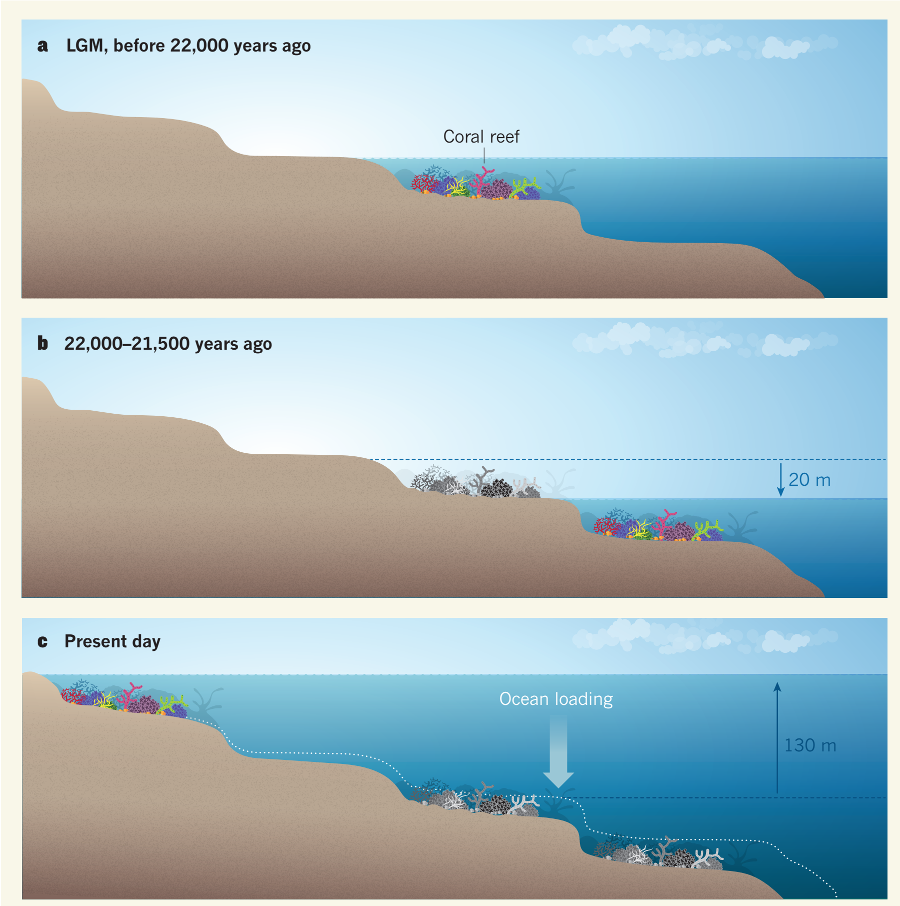

Figure 1 | Rapid changes of sea level recorded by coral reefs. Yokoyama *et al.*[2] studied fossil corals at the Great Barrier Reef to work out how sea level changed during the Last Glacial Maximum (LGM; 26,500 to 19,000 years ago[1]). **a**, Before 22,000 years ago, sea level was about 110 metres below the present level and the reef was confined to a region close to the edge of the continental shelf. **b**, Between 22,000 and 21,500 years ago, a sea-level drop of approximately 20 m altered the position at which coral could grow. The original reef died as it became exposed to air, and a new reef began to grow farther offshore. **c**, The sea surface then rose to present-day levels as ice sheets (not shown) melted. As the ocean flooded the continental shelf, the extra load of water caused the land to tilt (dotted line indicates original position of the continental shelf).

shape of the sea surface, the resulting pattern of sea-level change reflects mass redistribution throughout the Earth system, as well as the net change in ocean mass.

Using a priori assumptions about ice-sheet changes during the last glacial cycle, GIA models can predict the global pattern of sea-level change over time. In places such as Australia, which are far from major ice sheets, sea-level change will be close to the global mean — but even so, a correction must still be applied to account for the tilting of the continental shelf that occurs as it is flooded during post-glacial sea-level rise[7]. By testing different ice-sheet scenarios in a GIA model, and drawing on evidence from other locations that record the sea-level lowstand, Yokoyama *et al.* tentatively propose that growth of the North American ice sheet was the main cause of the rapid sea-level drop at the end of the LGM.

Techniques for reconstructing ice-sheet changes from sea-level observations rely on the fact that sea-level change is not uniform across the planet, but depends on proximity to the changing ice sheets. However, the distribution of currently available sea-level records is insufficient to allow us to determine the precise pattern of ice-sheet change during the LGM, making it difficult to pinpoint the cause of the sudden ice expansion and the reason for its brevity. Additional insight could be gained by studying sites at which sea-level change will be sensitive to changes in nearby ice sheets.

But the interpretation of such 'intermediate field' records would be complex. Most GIA models assume that Earth's properties do not vary from place to place, but analyses of the speed at which seismic waves travel show that this is an over-simplification (see ref. 8, for example). Future sea-level-based inferences of ice-sheet change should use GIA models that incorporate 3D structural variation in their representation of the solid Earth.

Direct evidence of past ice-sheet growth, rather than indirect evidence from ancient shorelines, would also provide crucial insight into the cause of the final LGM sea-level drop reported by Yokoyama and colleagues. Such evidence is, however, extremely difficult to piece together, because growing ice sheets tend to erase evidence of their past extent from the landscape.

Unlike ice-sheet retreat, the mechanisms responsible for rapid ice-sheet growth have received relatively little attention. It is tempting to equate cold periods in Earth's history to an increase in snowfall, but the opposite is actually true, because cold air holds less moisture than warmer air[9]. Yokoyama *et al.* suggest that an increase in the amount of solar radiation received by the Southern Hemisphere might have increased Antarctic snowfall towards the end of the LGM, but increased snowfall is not documented in ice-core records for this period (see ref. 10, for example).

An alternative explanation of Yokoyama and colleagues' findings is that cold ocean temperatures might have led to the expansion and thickening of floating ice adjacent to marine-terminating portions of the major ice sheets. Such buttressing ice shelves have a key role in reducing the flux of ice into the ocean[11], and their presence can promote ice-sheet growth. But reconstructing the extent of ice shelves to investigate this idea will be challenging. Moreover, there is much uncertainty about how ocean temperature changed during the LGM.

Rather than increasing in thickness, did one or more of the ice sheets increase in extent towards the end of the LGM? Lower sea levels and exposed continental shelves would have made it easier for ice sheets to advance offshore at that time, but growing ice sheets depress the land beneath, counteracting the effect of the lower sea level and potentially leading to ice-sheet instability. Could these feedbacks between ice dynamics, the underlying Earth and the adjacent ocean explain the short-lived nature of the final LGM sea-level lowstand, or did external climate factors bring it to an abrupt end? Whatever the explanation, it seems the LGM was more dynamic than previously thought. ■

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