OCEAN CIRCULATION

An unstable superconveyor

Wallace S. Broecker

THE glacial portion of the record kept in Greenland ice is riddled with large and abrupt shifts in oxygen isotope ratio and dust content. These climatic changes have been attributed to switches in the mode of operation of the Atlantic Ocean's thermohaline circulation[1]. Ocean dynamicists were quick to take up the challenge to simulate this phenomenon, and indeed have succeeded. Many of their models exhibit multiple states of operation. By releasing excess fresh water to the surface of their model's northern Atlantic, they can produce sudden switches in circulation from one mode to another, sometimes followed after a thousand years or so by an abrupt recovery to the initial state. This success has led to a general agreement that while it was surrounded by ice sheets the Atlantic Ocean's thermohaline circulation was vulnerable to meltwater-induced mode switches, and that these switches were responsible for the large temperature changes in the lands surrounding the northern Atlantic. By contrast, during the Holocene era, when large ice sheets were absent, the Atlantic's circulation was well behaved.

Then, with the publication last July[2] of an oxygen isotope record from the Summit site in Greenland, this simple concept of a noisy glacial Atlantic and a quiet interglacial Atlantic came under challenge. The oxygen isotope ratios and dust contents for the last interglacial period displayed abrupt shifts akin to those that characterize the glacial portion of the record. Once again, the dynamicists have risen to the challenge. On page 447 of this issue, Weaver and Hughes[3] present model results which suggest that the stronger hydrological cycle expected to accompany the warmer than Holocene climate of the last interglacial could have induced instabilities in the Atlantic's circulation.

Their simple two-basin model ocean exhibits three stable states. In all three, two Atlantic circulation cells are operative: a shallow conveyor driven by deep-water formation at its northern end, and a deep conveyor in the opposite sense driven by deep-water formation in the Southern Ocean. The states differ in the relative strengths of these circulation cells. The conveyor's water flux varies from 1.5 sverdrups in its weak mode to about 10 sverdrups in its median mode and about 25 sverdrups in its strong mode. As the heat transport to the atmosphere over the northern Atlantic varies in proportion to the conveyor's strength, Weaver and Hughes take these three modes to be analogues for the three temperature regimens that characterized the Greenland record during the last interglacial.

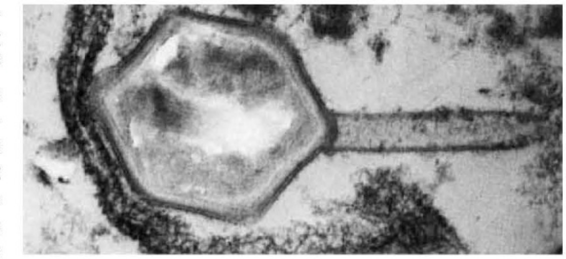
They also succeed in inducing cycles involving millennium-long intervals during which the strong conveyor mode is operative. These intervals terminate with sharp transitions to the weak mode followed immediately by a more gradual shift to a millennium-long stint in the medium mode. The cycle ends with an abrupt shift back to the strong conveyor. The authors drive this cycle by introducing large stochastic changes to the strength of the model's hydrological cycle (that is, in the freshwater flux to high latitudes).

But two questions haunt this exercise. The first has to do with the reliability of the Greenland ice-core record for the Eemian time (~115–135 kyr ago). Late last year, published comparisons of the records for the two Summit ice cores cast serious doubt on the existence of the Eemian temperature fluctuations. Although the records for the upper 90 per cent of these two 3-km-long cores (drilled 30 km apart) are identical down to the smallest details, the lowest 10 per cent are not[4,5]. They are so different that one or both must contain missing or repeated sections. Indeed, tilting, drag folding and thrusting of annual layers demonstrate that deformation has occurred in the lower several hundred metres of the ice column. Although the presence of ice with significantly higher $^{18}O/^{16}O$ ratios in both cores leaves no doubt that ice from a several-degree-warmer Eemian period is present, the dramatic shifts to cold separating these intervals of warmth could well be of tectonic origin; ice representing quite different climates may have been shuffled together by thrust faulting.

As were Weaver and Hughes, I was initially captivated by these abrupt Eemian shifts. But now, having studied the papers comparing the two records, having listened to and discussed the additional evidence presented at recent meetings in Berkeley and San Francisco, and having pondered why these large shifts in climate have never been recognized in the northern Atlantic marine or European pollen records, I find myself a Doubting Thomas. Only when matching records for the Eemian period have been obtained from a pair of Greenland ice cores will I be confident of the existence (or non-existence) of large and abrupt climate changes during times of interglaciation. But a decade is likely to pass before further such cores can be obtained and analysed.

The second question has to do with the suitability of the ocean models used to generate changes in the mode of thermohaline circulation. Anyone who has pondered their architecture is aware that the results depend heavily on the assumptions made with regard to the surface boundary conditions. The strengths of the conveyor and anticonveyor circulation cells that jockey for dominance in the models'

A particular mystery



THE nature of the object pictured here is not known. It comes from a vacuole of the phaeodarian radiolarian *Porospathis*, a marine protozoan. At first sight it looks like a virus. But if it is, it would be a Goliath of the sort, for its 'head' is well over 300 nm long, some five times that of well-characterized marine viruses. So what else could it be? At present its status remains a mystery, as indicated by its loose designation as a large virus-like particle (LVLP). Such particles were recognized only a few years ago, and the latest report on their distribution has been compiled by Marcia M. Gowing (*Mar. Ecol. Prog. Ser.* 101, 33–43; 1993). Gowing has looked in particular at their occurrence in phaeodarians — so-called because of their possession of a phaeodium, the collective name for the food and waste vacuoles which are unique to the group and which provide a record of their food intake. Not only did LVLPs crop up in samples taken in various areas and at various depths, but Gowing estimates that a single phaeodarian could carry a cargo of over 5,000 of them. She thinks the phaeodarians acquire the particles during feeding, pointing out that it is unlikely that they are infected as such (LVLPs were never found in the cytoplasm or nucleus). And on the question of alternative identities, she offers the possibilities that they might be stages in the life cycle of some organism or other, eukaryote organelles or gametes, spores, or hitherto undescribed microorganisms. Whatever they are, the oceans are shot through with them.

T.L.

1. Broecker, W. S. *Oceanography* **4**, 79–89 (1991).
2. Greenland Ice-core Project Members *Nature* **364**, 203–207 (1993).
3. Weaver, A. J. & Hughes, T. M. C. *Nature* **367**, 447–450 (1994).
4. Taylor, K. C. *et al.* *Nature* **366**, 549–552 (1993).
5. Grootes, P. M. *et al.* *Nature* **366**, 552–555 (1993).