the Southern Ocean and equatorial Pacific, with higher $^{15}N/^{14}N$ associated with lower surface nitrate.

In a transect of cores from 40° to 55° S in the Indian sector of the Southern Ocean, Francois *et al.*[3] observed that the transition from high to low $^{15}N/^{14}N$ shifted closer to the South Pole during the last glacial maximum. Within the modern transition zone at a given site, $^{15}N/^{14}N$ was higher in glacial times, implying that nitrate utilization was higher there than today. But the range of values across the zone was similar to that of the present, implying that nitrate uptake at high latitudes remained as low as it is at present (at least at 55° S). Given micropalaeontological evidence that the Antarctic Circumpolar Front moved northwards during the most recent glacial maximum, it also seems that nutrient uptake was higher in the region between the modern and glacial positions of the circumpolar front. Overall, the nitrogen isotope data imply increased nitrate utilization in a band north of the present circumpolar front, but not south of this zone. This is the region of formation of Antarctic Intermediate Water, so this observation may account for reports of decreased nutrient concentrations in intermediate waters of the Northern Indian Ocean[9].

As Francois *et al.* admit, there are uncertainties in this interpretation: later changes will have overprinted the primary particle flux signal; the oceanic nitrogen isotope system is complex; and the nitrogen isotope signature of oceanic nitrate may vary over time. We may see new interpretations of their data as these effects are investigated in more detail. But their approach should certainly help to clarify the nutrient status of upwelling waters.

An entirely different approach to the problem is applied by Kumar *et al.* in this issue. They make use of the difference in 'stickiness' of the radioisotopes ^{231}Pa and ^{230}Th, which are generated uniformly throughout the ocean from the decay of dissolved ^{235}U and ^{238}U. Because ^{230}Th is highly 'particle-reactive', ^{230}Th generated in the ocean water column tends to attach itself to locally produced sinking particles which fall nearly vertically to the sea floor below. ^{231}Pa, on the other hand, is less particle-reactive, so that it can travel substantial distances through the ocean before becoming attached to a particle and falling to the sea floor. As a result, ^{231}Pa tends to migrate towards regions of highest particle flux, and the $^{231}Pa/^{230}Th$ ratio of the material falling to the sea floor reflects the productivity of the near-surface waters above the site.

Unlike all other tracers of past particle flux, this one is nearly immune to later modification; by the time they reach the sea floor, both elements are strongly attached to particles and do not move about in solution. Although the particles and their attached isotopes can be transported some distance from their orginal site of deposition, $^{231}Pa/^{230}Th$ is unaffected by this movement, so its value in the sediment reflects regionally averaged production. Both isotopes decrease through radioactive decay after deposition, but their initial ratio can be easily calculated for the past 200,000 years if the age of the sediment layer is known.

Kumar and co-workers traced the history of $^{231}Pa/^{230}Th$ in two cores covering the past 150,000 years in the Atlantic sector of the Antarctic seas. The core at 54° S showed decreased $^{231}Pa/^{230}Th$ (lower productivity) during glacial times, whereas the core at 48.7° S showed increased $^{231}Pa/^{230}Th$ (increased productivity). The geographical difference resembles that seen in silica sedimentation rates from cores in this region[10].

These two new approaches have the benefit of being directly related to productivity. From their results, as well as from earlier data on opal accumulation, it would appear that in glacial times there was a zone of higher productivity north of the present position of the Antarctic Circumpolar Front, and either a slight reduction or little change in productivity southwards. All of these indicators are inconsistent with a general increase of productivity in high southern-latitude waters during glaciation. Like the previous tracers (carbon isotopes and cadmium) they do not encourage the idea that the polar carbon system controls atmospheric CO_2, although (for the reasons noted above) they cannot rule it out. If the picture provided by these new tracers is confirmed, the details of how the control operates cannot be as simple as envisaged in the original models. □

Ed Boyle is in the Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA.

1. Neftel, A., Oeschger, H., Staffelbach, T. & Stauffer, B. *Nature* **331**, 609–611 (1988).
2. Barnola, J. M., Raynaud, D., Korotkevitch, Y. S. & Lorius, C. *Nature* **329**, 408–414 (1987).
3. Francois, R., Altabet, M. & Burckle, L. *Paleoceanography* **7**, 589–606 (1992).
4. Kumar, N., Gwiazda, R., Anderson, R. F. & Froelich, P. N. *Nature* **362**, 45–48 (1993).
5. Toggweiler, R. & Sarmiento, J. L. in *The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present* (eds Sundquist, E. & Broecker, W. S.) 163–184 (Am. Geophys. Un., 1985).
6. Ennever, F. & McElroy, M. in *The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present* (eds Sundquist, E. & Broecker, W. S.) 154–162 (Am. Geophys. Un., 1985).
7. Wenk, T. & Siegenthaler, U. in *Natural Variations in Carbon Dioxide and the Carbon Cycle: Archean to Present* (eds Sundquist, E. & Broecker, W. S.) 185–194 (Am. Geophys. Un., 1985).
8. Broecker, W. S. & Peng, T.-H. *Glob. biogeochem. Cycles* **3**, 215–240 (1989).
9. Kallel, N., Labeyrie, L. D., Juillet-Laclerc, A. & Duplessy, J. C. *Nature* **333**, 651–655 (1988).
10. Mortlock, R. A. *et al. Nature* **351**, 220–222 (1991).

DAEDALUS

Blue electrons

DAEDALUS has been musing on the curious fact that electrons are blue. At least, a solution of sodium in liquid ammonia is blue; and its colour is attributed to dissolved electrons.

What happens when yellow sunlight shines into such a solution from one side? Each blue electron that absorbs a fast-moving yellow photon will recoil away from the light source, thus generating a tiny voltage. These collisional voltages will add in series all along the light path. Daedalus calculates that a metre of light path might generate up to 4,000 volts, easily extracted by wire-grid or transparent indium-oxide electrodes which would not obscure the light.

No electrochemical change should occur. Electrons would simply enter the ammonia solution at the anode, nearest the source of light, while an equivalent number would be 'plated out' onto the cathode on the shadow side. Liquid ammonia, of course, is rather awkward stuff. At ambient temperature its vapour pressure is about 10 atmospheres. But organic amine solvents like diaminoethane also form blue electron solutions, so Daedalus hopes that a more convenient and tractable electrolyte can be developed.

A liquid-phase photovoltaic cell should have many uses. Its voltage need not be limited by the extinction depth of its blue solution. A narrow cell, with light shining obliquely into it, could be arbitrarily long. Each diagonally entering ray of light would induce a voltage over its finite light path; the voltage components parallel to the cell axis would be summed over its entire length. So Daedalus hopes to develop a solar-powered overhead communication cable, a sort of electro-optic fibre. Direct sunlight would enter such a cable obliquely most of the time, though the voltage and even the polarity might change with the time of day. In cloudy Britain, the pipe would have to be fitted with closely spaced conical louvres so that even diffuse daylight would hit it obliquely. The cable could charge storage batteries to continue the service at night: indeed, with some cunning secondary-cell electrochemistry built into it, it might even act as a storage battery itself.

The inherently vast voltage generated by such a cable would be dropped to safe levels by the power drawn from it. But an open-circuit or lightly-loaded cable, with its even, linear summation of potential difference, could generate unprecedented voltages for high-energy physics research. Daedalus is dreaming of a trans-Australian cable from Darwin to Adelaide, generating gigavolts in the outback noonday Sun.

David Jones