BIOGEOCHEMICAL CYCLES

Is the ocean losing nitrate?

Louis A. Codispoti

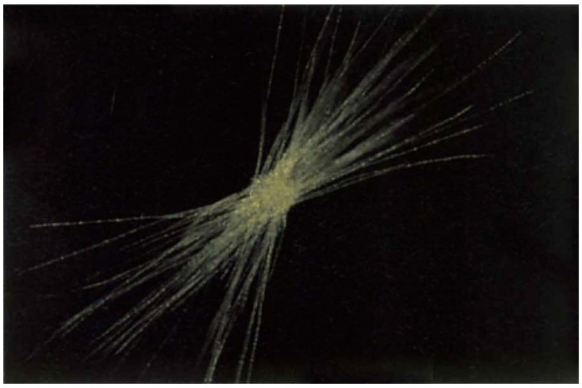
BECAUSE available fixed nitrogen is a major control on plant growth in the oceans, changes in the oceanic reservoir (which mainly consists of nitrate) may have serious consequences. On page 755 of this issue[1], Ganeshram *et al.* add to the evidence that the present-day ocean is losing fixed nitrogen. If this is indeed the case, it matters not least because less fixed nitrogen implies lower plant productivity, which in turn implies lower oceanic uptake of carbon dioxide. Together with work by Altabet *et al.*[2] published earlier this year, the new paper may finally convince those who have doubted the view that variations in oceanic denitrification rates can have a considerable effect on concentrations of atmospheric carbon dioxide.

Denitrification is the main sink for oceanic fixed nitrogen. This respiratory process can dominate under suboxic conditions (dissolved oxygen less than 1–2 per cent of saturation), and it converts oxidized forms of nitrogen, again mainly nitrate, to free nitrogen or nitrous oxide which most plants cannot use. The well-developed oxygen minimum zone in the eastern tropical North Pacific Ocean is one of three major identified sites of water-column denitrification, and Ganeshram *et al.* provide evidence for decreased denitrification in this region during glacial periods (we are currently in an interglacial). Their results are analogous to those of Altabet *et al.*[2] who studied the record in the Arabian Sea, another of the principal denitrification zones (the third is in suboxic waters off Peru).

In combination with studies that point to reduced sedimentary denitrification during glaciations[3] and a present-day oceanic fixed-nitrogen budget that may be in deficit[4], a picture emerges of a system that can oscillate from excess to deficit because of higher interglacial denitrification rates. Changes in the inventory of available fixed nitrogen could affect the ability of oceanic biological processes to sequester atmospheric carbon dioxide by causing increases or decreases in its photosynthetic uptake. A time-varying fixed-nitrogen inventory could, therefore, contribute to the atmospheric carbon dioxide variations observed in ice cores[5]. Higher levels of fixed nitrogen during glaciations would contribute to lower levels of atmospheric carbon dioxide, and vice versa.

This view contrasts with past ideas. Twenty-five years ago studies of the fixed-nitrogen budget in the ocean (estuaries not included) produced 'comfortable' answers. It was usually assumed that the budget was in a steady state, and the problem was finding a sink for the inputs because the sedimentation rate for nitrogen was too small. Estimates of the denitrification needed to balance the budget averaged about 100 Tg N yr^{-1} (1 Tg = 10^{12} g), and residence times for fixed nitrogen were set at around 10,000 years.

Because other factors might compensate for changes in denitrification, it is important to determine the state of the present-day fixed-nitrogen budget. If it can be shown to be in deficit by a significant amount, the hypothesis highlighted above (first stated by McElroy[5]) would withstand another test. Anthropogenic activities may have increased inputs to the open ocean (excluding estuaries) by about 50 Tg N yr^{-1} (refs 6, 7); but even if we include this anomalous several-hundred-year period in looking at the glacial–interglacial timescale, it is likely to be dwarfed by increasing estimates for marine denitrification. The recent literature[8] and a poll of colleagues suggest that the open-ocean denitrification rate is likely to be revised from about 120 Tg N yr^{-1} (ref. 4) to over 250 Tg N yr^{-1}. Although other sources and sinks will have modest effects, the issue is likely to boil down to whether or not nitrogen fixation by those few species of marine plants that can use free nitrogen gas is balancing denitrification.



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The single-cell marine alga *Trichodesmium*. Cells in the anoxic centre of a colony carry out nitrogen fixation.

Current estimates of oceanic nitrogen-fixation vary over more than an order of magnitude and are likely to be revised upwards from the 'accepted' value of about 25 Tg N yr^{-1} (ref. 6), so the possibility that the present-day oceanic budget is in balance cannot be excluded. Rates high enough to do this would, however, require a drastic rethinking of how the ocean works. Suppose we do find that the budget is currently balanced. Does this mean that after 25 years of effort we will have merely returned to the balanced budgets of the past? I think not, because with the greatly increased total input and output terms, relatively small negative or positive imbalances could be globally significant. At a minimum, the oceanic fixed-nitrogen budget would seem to be much more dynamic than "dreamt of in our philosophy", with a residence time that has decreased to about 3,000 years. This in turn has implications for the minimum timescales needed to produce significant variation in the budget, and therefore in the timescales over which changes could influence levels of atmospheric carbon dioxide.

The data on the distributions of nitrate and phosphate in the sea indicate a budget that is now in deficit or in a recovery phase from a past deficit. Nitrate is a more frequent limiting nutrient than phosphate[5], and nitrate/phosphate ratios in most of the ocean are less than the Redfield ratio (16/1 by atoms) of uptake by phytoplankton whereas high ratios are found in localized zones such as the Red Sea[9] (where we know that nitrogen fixation is more important than in most of the ocean). My guess is that once we find techniques to determine denitrification rates in oxygenated water, we will find that they are significant[10] and, once again, will have to revise the overall oceanic rates upwards. Consensus estimates for nitrogen fixation may also rise, but perhaps not as far as some are suggesting.

There is much more to do on all aspects of the budget including investigating the role of trace metals which may control primary production or nitrogen fixation (or both) under some circumstances[11]; in addition, increased denitrification could result if schemes to fertilize the ocean with trace metals led to an increased flux of organic material to depth, as this would increase subsurface respiration and decrease oxygen concentrations. However things pan out, it seems that interesting times lie ahead for those interested in the oceanic fixed-nitrogen budget. □

Louis A. Codispoti is at the Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529, USA.

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