

Oceanography

Deep-sea carbon, a burning issue

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ONE of the most heated debates in oceanography concerns the origin and characterization of the organic matter fuelling respiration in the ocean's interior. With information obtained from sediment traps in the past decade, most oceanographers have assumed that organic matter in sinking biogenic particles fuels deep-sea respiration. Now Sugimura and Suzuki¹ have identified a large class of previously unknown organic compounds dissolved in sea water.

These compounds seem to be produced by biota at the ocean surface and are broken down and metabolized in the interior, much like the particulate organic matter caught in sediment traps. But unlike sinking particles, they must be advected, or mixed, into the interior. Because they are dissolved, the compounds can be transported laterally over long distances from their sources by ocean currents before being broken down. Large gradients of dissolved organic carbon (DOC) beneath the ocean surface seem to mirror the downward increase in the amount of oxygen consumed from the water, suggesting that deep-sea respiration is fuelled mostly by dissolved organic compounds.

High concentrations

Using a new technique for the oxidation of organic compounds in sea water, first described in an earlier study of dissolved organic nitrogen², Sugimura and Suzuki¹ report that surface-water dissolved-organic-carbon concentrations in the western North Pacific are 250–300 $\mu\text{mol kg}^{-1}$ in contrast to the previously accepted range³ of about 60–100 $\mu\text{mol kg}^{-1}$. Deep-water concentrations of 50–100 $\mu\text{mol kg}^{-1}$ are also well in excess of previously accepted values (30–50 $\mu\text{mol kg}^{-1}$). By fractionating the DOC into size classes, Sugimura and Suzuki show that more than 90 per cent of the additional DOC uncovered by their technique is composed of compounds with relative molecular masses over 20,000. Previous work⁴ established that most of the DOC in sea water had relative masses of less than 5,000. The newly discovered class of large compounds makes up most of the vertical gradient in DOC between surface and deep water.

The technique developed by Suzuki *et al.*² involves the injection of very small seawater samples, 100–200 μl , into a high-temperature catalytic combustion furnace. The most reproducible DOC measurements made previously were based on oxidation of several hundred millilitres of sea water, using high-intensity

ultraviolet light or wet oxidation with persulphuric acid³. Bulk DOC concentrations approaching the range reported by Sugimura and Suzuki have been measured using a dry combustion technique, in which sea water was evaporated to dryness and the organic matter in the remaining salts burned. The reproducibility of this technique is poor⁵, however, and the results were largely disregarded.

Previous work⁶ has shown that the radiocarbon age of deep-water DOC extracted by the wet-oxidation or ultraviolet techniques is about 6,000 yr. This indicates that much of the DOC is extremely resistant to microbial oxidation, and is cycled through the ocean many times. No one has yet attempted to measure the radiocarbon in the additional DOC extracted by Sugimura and Suzuki¹, but it is clear from the large DOC gradients in the thermocline of the ocean that the turnover time of this pool of material is no greater than the circulation time for water in the upper kilometre of the ocean — a few hundred years. The ultraviolet and wet-oxidation techniques seem to extract the most refractory DOC compounds in sea water. The additional DOC extracted by Sugimura and Suzuki appears amenable to microbial oxidation, yet, ironically, it is resistant to attack by ultraviolet light and strong chemical oxidants.

Dissolved organic matter is released by many organisms in the sea⁷, and microbiologists maintain that DOC provides the main substrate for bacterial growth in the ocean⁸. The primary dissolved organic exudates of phytoplankton and the main food sources for the bacteria are identifiable low-molecular-weight metabolites and polymeric carbohydrates⁷. These compounds are present in sea water in low concentrations, and most are produced and consumed within hours or days rather than years⁸. Most of the DOC oxidized from sea water using the bulk oxidation techniques is chemically unidentifiable and is often referred to as marine humus⁹. One of the most thorny questions about DOC concerns the transformation of the relatively simple compounds produced by marine organisms into the complex, long-lived compounds which form the bulk of the dissolved organic matter in the ocean⁷.

At a meeting* held to attempt an inter-calibration of different DOC extraction techniques, it was clear that Suzuki's oxidation column could extract large amounts of DOC from water samples previously irradiated with ultraviolet

light, but no one could fully reproduce his results. J. H. Martin and S. Fitzwater (Moss Landing Marine Laboratory) have since acquired some of Suzuki's catalyst and have analysed ocean samples off California. They report DOC concentrations in surface water above 200 $\mu\text{mol kg}^{-1}$ with minimum values in deep water of 70 $\mu\text{mol kg}^{-1}$ (J.H. Martin, personal communication). Although these values are of the same magnitude as those reported by Sugimura and Suzuki¹, the correlation between DOC and dissolved oxygen is quite weak compared with the correlation observed by Sugimura and Suzuki in the western North Pacific.

Variations

Martin and Fitzwater's results could indicate real oceanographic variability or could reflect problems with the technique. P. Brewer (Woods Hole Oceanographic Institution) points out that no one really knows at present what reactions are going on in the catalyst tube (personal communication). Until these reactions are understood more fully, reproducibility between laboratories may remain elusive.

The significance of Sugimura and Suzuki's work stems from the implications of an oceanic DOC pool which is larger and turns over faster than was previously believed. If the mean lifetime of the additional DOC is about 100 yr, the mean production rate of carbon would be about 1 $\text{mol m}^{-2} \text{yr}^{-1}$, which is comparable to particulate carbon fluxes at the base of the photosynthetic zone in the open ocean¹⁰. The production and dispersal of Sugimura and Suzuki's DOC thus represents a potentially significant fraction of the organic material exported from the upper ocean by the biota. A rough extrapolation from their published data shows that the ocean's DOC pool is about twice the size of the atmospheric CO_2 pool and about twice that of the plant carbon biomass on land¹¹. No one can say what constrains the size of the DOC pool. If the pool were to grow or shrink, the uptake or release of carbon should be reflected in changes in atmospheric CO_2 concentrations. □

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* US Global Ocean Flux Study workshop, Woods Hole, 17–20 November 1987.