

## Geophysics

## Tracing water flow in the ocean

from Wolfgang Roether

CHLOROFLUOROMETHANES (CFMs), the gases used in refrigerators and aerosol cans, have recently acquired a bad reputation for the effect they may have on the ozone layer of the upper atmosphere. Harmful or not, their use does provide a scientific bonus; they make it possible to trace quantitatively the exchange of water between ocean surface and ocean interior, as documented in a recent article in the *Journal of Geophysical Research* by R.H. Gammon and colleagues<sup>1</sup>.

The work is important because the exchange of water influences climate — indirectly, by governing the rate at which the carbon dioxide from the burning of fossil fuels vanishes into the ocean, and directly, by determining the oceanic storage of heat over a time scale of some years.

Tracer substances like the CFMs have the unique advantage that their dispersion within the ocean will be directly analogous to that of CO<sub>2</sub> and heat. The measurements made by Gammon *et al.* in the north-east Pacific show, for example, near-constant values in a surface water layer 100 m or so deep, and beneath it an exponential decrease with depth to vanishing concentrations below about 600 m. This finding gives immediate proof that little fossil-fuel CO<sub>2</sub> could have penetrated beyond 600 m depth in that part of the ocean, over the few decades that both CFMs and fossil-fuel CO<sub>2</sub> have been present in the environment.

CFM is not the only man-made substance to be inadvertently released into the environment and used as a tracer of the movement and mixing of water in the ocean. The distribution of tritium, a by-product of the atmospheric nuclear weapon testing of the 1950s and 1960s, has been measured worldwide<sup>2,3</sup>, and results similar to those given in Gammon *et al.*'s article were reported a decade ago<sup>4</sup>.

Oceanic CFM measurements are, however, rather more special. The main reason for this is that the detection of tritium, at oceanic concentrations of 10<sup>-19</sup> (mol tritium per kg of water) or less, though possible by its radioactive decay, is difficult and can be performed by only a few land-based specialized laboratories. Oceanic CFM concentrations, at or below 10<sup>-12</sup>, on the other hand, can be measured with a gas chromatograph thanks to the invention of the electron capture detector by the UK scientist J.E. Lovelock<sup>5</sup>. This has made possible easy and low-cost oceanic CFM measurement. All that remains is its perfection — with contamination from CFM use as the remaining problem.

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Analysis on board ship, as Gammon *et al.* rightly point out, allows measurement immediately after bringing up water samples from depth and can thus guide further sampling effort during an oceanographic cruise.

Oceanic tracers have helped build-up better numerical ocean models. The oceanic distribution of the tracer represents the ensemble of water flow trajectories from the ocean surface where the tracer material entered from the atmosphere, integrated in time to the respective point in the ocean where the tracer is sampled several years later. The tritium and CFM distributions are both transient in nature, depending on

the history of their release into the environment, and are therefore very different from that of salinity, for example. From the available tritium and CFM observations, it is apparent that there are significant differences between their distributions, and both exhibit a remarkably clear structure. In future modelling efforts it may be possible to use both CFMs and tritium, and perhaps further tracers<sup>6</sup>, to produce a combination which gives particularly powerful observational constraints on ocean movement and mixing at upper and intermediate depths. □

1. Gammon, R.H., Cline, J. & Wisegarver, D. *J. geophys. Res.* **87**, 9441 (1982).
2. Fine, R.A., Reid, J.L. & Östlund, H.G. *J. phys. Oceanogr.* **11**, 3 (1981).
3. Sarmiento, J.L., Rooth, C.G.H. & Roether, W. *J. geophys. Res.* **87**, 8047 (1982).
4. Roether, W., Münich, K.O. & Östlund, H.G. *J. geophys. Res.* **75**, 7672 (1970).
5. Lovelock, J.E. *J. Chromatogr.* **1**, 35 (1958).
6. A major effort to collect such tracer data is now underway, for example, in the US Program Transient Tracers in the Ocean.

## Earth science

## Kimberlites revisited

from Chris Hawkesworth and Martin Menzies

THE volcanic rocks known as kimberlites, famous for the diamonds found in them, have long been important in the study of the upper crust. They have their origin some 200 km deep down in the mantle<sup>1</sup> and, fortunately for the Earth scientist, as they ascend from these great depths, they bring to the surface a sample of the rocks of the uppermost mantle and the continental crust.

So far, detailed geochemical analysis has been of these inclusions, or xenoliths, rather than of the kimberlite itself, for the kimberlite is very susceptible to near-surface alteration. Now this has all changed as underground samples of fresh kimberlite have become available; new work reported by M.T. McCulloch *et al.*<sup>2</sup> in this issue of *Nature* (p.400) and by C.B. Smith (*Nature*, in the press) shows that at least some forms of kimberlite provide potent evidence for the existence of an 'old' trace-element-enriched upper mantle.

Two important conclusions have emerged: first, there are kimberlites and kimberlites. Most of those analysed previously were non-micaceous, or 'basaltic' kimberlites which generally have low <sup>87</sup>Sr/<sup>86</sup>Sr and high <sup>143</sup>Nd/<sup>144</sup>Nd ratios<sup>4,5</sup>, similar to those of many ocean island basalts. Micaceous kimberlites and lamproites, by contrast, have much higher <sup>87</sup>Sr/<sup>86</sup>Sr and lower <sup>143</sup>Nd/<sup>144</sup>Nd ratios<sup>2,3</sup>, indicating they either were derived from, or at least contain a contribution from, a source region which was both 'old' and had relatively high Rb/Sr and low Sm/Nd ratios. Yet both groups are clearly derived from the upper mantle, as is shown by the presence of diamonds and mantle xenoliths; and their Nd contents, for exam-

ple, are too high for their <sup>143</sup>Nd/<sup>144</sup>Nd ratios to have been affected significantly by interaction with the continental crust. Thus the second conclusion: low <sup>143</sup>Nd/<sup>144</sup>Nd and high <sup>87</sup>Sr/<sup>86</sup>Sr ratios, which are too often regarded as reliable fingerprints of the continental crust, do exist in some portions of the upper mantle. How then can these results be reconciled with models of the sub-continental mantle developed from studies on basalts and mantle xenoliths?

Early suggestions that the sub-continental mantle might preserve fragments of comparatively 'pristine' or 'primitive' mantle material<sup>6</sup> were always likely to be greeted sceptically by the non-isotope fraternity. Particular geochemical compositions will presumably not survive for long in a convecting upper mantle, and while they may persist in the continental lithosphere, that is unlikely to be older than the age of the overlying crust. Thus continental magmatic processes probably sample both the lithosphere and the underlying convecting mantle. The former consists of old 'fossilized' mantle which, as illustrated by recent work on both mantle xenoliths<sup>7,8</sup> and Karoo volcanics<sup>9</sup> of southern Africa, may preserve a complex record of mantle events. In that area some relics of Archaean mantle have been recognized, but much of the lithosphere stabilized ~ 1.4–1.0 Gyr ago, at or soon after the locally widespread orogeny of the Namaqua–Natal Belt, and this was subsequently sampled by Karoo magmatism at ~ 190 Myr and remobilized by K-richite metasomatism in the

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