-25‰ and is thus clearly distinguishable from that originating from the ocean.

Figure 2 shows a seasonally adjusted record of $\delta^{13}\text{C}$. Excursions towards lower values of $\delta^{13}\text{C}$ (notice inverted scale) are observed in 1983–84 and 1987–88 and also 1979–80, occurring at the same time as the anomalous increases in CO_2 (Fig. 1) after an ENSO event. The anomalies are small, comparable to the analytical precision, but it seems unlikely that they are an experimental artefact, as they are found in the individual isotopic records for both Mauna Loa and the South Pole. Thus, the isotope data suggest that the positive CO_2 anomalies are of biospheric origin.

Examining both the isotopic records and the records of CO_2 concentration allows both the biospheric and oceanic sources to be identified: from the anomalies in CO_2 concentration, the sum of biospheric and oceanic sources (or sinks) can be estimated, and anomalies in $\delta^{13}\text{C}$ allow the size of the biospheric contribution alone to be established. Keeling *et al.* have carried out a double deconvolution of the two records and obtained estimates for the 'anomalous' oceanic and biospheric CO_2 fluxes. Both fluxes are found to be large, up to 4 Gt C per year, and are out of phase: namely, biospheric release and oceanic uptake of carbon occur during and after an ENSO event, with the biospheric flux dominating, thus causing a net release of CO_2 to the atmosphere.

Is this result realistic? Qualitatively, it is certainly plausible. Ordinarily, surface waters in the equatorial Pacific Ocean have a high partial pressure of CO_2 (P_{CO_2}), with values 50–100 p.p.m. higher than in the atmosphere. This peak in P_{CO_2} is due to the upwelling of CO_2 -rich water from depths of 100 m to a few 100 m and the resulting degassing from the equatorial Pacific corresponds to a source of about 1 Gt C per year. During an El Niño event, upwelling stops and therefore the CO_2 outgassing ceases. Although this is directly supported only by a few P_{CO_2} measurements during the 1982 event, there is clear evidence from data on total carbon and on nutrients that P_{CO_2} must have decreased. This is confirmed by box model studies^{2,3} in which the physical, chemical and biological changes in the Pacific Ocean during an ENSO event are simulated. During such an event, the upwelling of water rich in CO_2 and nutrients into the equatorial surface mixed layer ceases; the temperature of the surface water increases and biological activity decreases (because of reduced availability of nutrients), as does the export of carbon by sinking organic particles. These last two effects would tend to increase P_{CO_2} in the surface water,

but the first — which dominates — leads to a decrease of P_{CO_2} . Although the two model studies^{2,3} differ in the details, both obtain the same decrease, about 0.4 p.p.m. (or 0.8 Gt C), in atmospheric CO_2 during an El Niño. The pattern of oceanic fluxes as predicted by the box models is in qualitative agreement with the pattern deduced by Keeling *et al.*, but their estimate of the oceanic CO_2 flux, up to 2 p.p.m. change within a year, is larger than can be explained by the models.

The biospheric contribution also seems plausible. During an El Niño, rainfall is

Fig. 2 Seasonally adjusted $\delta^{13}\text{C}$ values in atmospheric CO_2 , average of results from Mauna Loa and the South Pole¹. The vertical scale is inverted to facilitate comparison with Fig. 1.

reduced in many tropical regions; and the correlation between El Niño and the weak southeast Asian summer monsoon is striking (Fig. 1). Consequently, there is apparently reduced uptake of CO_2 by vegetation over large areas, so that the anomalous atmospheric CO_2 increase during an El Niño seems essentially to be due to a reduced biospheric CO_2 sink.

In view of the relatively small CO_2 signals involved, one may wonder whether the story is relevant to discussions on the carbon cycle — the ENSO-related anomalies can hardly lead to changes in atmospheric CO_2 that would influence the greenhouse effect. The observed anomalies of 1–2 Gt C per year do, however, correspond to several per cent of the total terrestrial net primary productivity. This is a significant perturbation, particularly because it has its origin in only a restricted part of the land biota, and is important enough to be studied in more detail. As usual, what are needed are further long-term high-precision records of $\delta^{13}\text{C}$ and CO_2 concentration from stations near tropical ecosystems, and direct P_{CO_2} observations in the equatorial Pacific Ocean during an El Niño. □

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Purifying earth

LAST week Daedalus proposed a novel deep-sea mining scheme, in which two boreholes were sunk in the sea floor to such a depth that the hot pressurized water would dissolve the rock between them. Thereafter, a convective flow would be established, with cold sea water sinking down one of the holes, and emerging from the other very hot, and saturated with minerals in solution. He now plans to try the same scheme on land.

DREADCO prospectors are studying hot-spring districts in Iceland and New Zealand, and the geothermal regions of southwest England, where hot rock is very near the surface. A borehole in such a region should soon reach a depth where water would boil but for the strong hydrostatic pressure above it. The hotter and more pressurized the water, the more ferocious it becomes as a solvent. Once the hole has reached a certain critical depth, it need only be kept full of water and it will dissolve its way deeper and deeper without further drilling. Two holes a suitable distance apart will ultimately join up by sideways diffusion of the water. A self-sustaining convective flow between them could then be easily established.

This simple arrangement would be a wonderful source of geothermal heat and deep-dissolved minerals. But Daedalus also sees it as a splendid new waste-disposal and sewage-treatment plant. Sewage, possibly loaded with suspended urban waste and industrial nasties like chlorinated residues, would simply be poured into the downflow pipe. In the heated and pressurized depths, all the solids would dissolve in the water and would begin to react with it and the surrounding rocks. Some of the metals in the waste, like sodium and aluminium, would probably be trapped by ion-exchange processes; others, like iron, copper, and manganese from spent batteries, would go to stable sulphide or carbonate minerals for reclamation. The organics, from paper and plastics to food waste and sewage solids, should hydrolytically oxidize, ultimately to carbon dioxide. All the waste of civilization would be disposed of simply and with total ecological rectitude!

The final outflow, with luck, would be a sterile solution of minerals in almost pure water. Once the minerals had precipitated out and the dissolved gases had fizzed away, it might almost be fit to drink! But even Daedalus is not quite so optimistic. He would prefer to arrange the pressure-gradient in the outflow so that the exit-water partly boils on its way up. The steam, after driving turbines for power, could be condensed to pure distilled water for domestic distribution. The residual mineral-loaded stream, concentrated by its partial evaporation, could be filtered to recover its metals.

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