The distribution of TAMs in surface sediments from the Mediterranean and North Sea coasts exhibited maximum concentrations at the vicinity of urban areas, namely Barcelona, Marseille (Rhone estuary), Antwerp (Schelede estuary), Taragona and Malaga, and decreased with increasing distance from the source (Table 1 and Fig. 1), indicating inputs of domestic origin. The vertical profile obtained in a sediment sample offshore from Barcelona (Table 1) indicates a more recent input than that of the LABs, use of which was introduced in the mid-1960s in developed countries. In turn, both markers decreased more rapidly with depth relative to another anthropogenic indicator, the unresolved complex mixture of hydrocarbons (UCM) attributable to petrogenic sources. A major sedimentary pathway for these pollutants could be the precipitation of particulate material in the water column. Although TAMs have been identified at similar high concentrations in both dissolved and particulate phases of the Barcelona sewage waters, they were found at much higher concentrations in particulates of coastal waters (Table 1). Such behaviour is very different to that of the UCM, probably because the two compounds have different sediment sorption partition coefficients ($K_{ow}$). Therefore, adsorption and precipitation seems to be an effective mechanism in transporting TAMs from the water column towards the sediment.

The risk associated with the presence of TAMs in the marine environment is still unknown. Although amino acid amines are well known carcinogens, data on aliphatic amines are lacking. Investigation is now in progress to assess their accumulation in benthic biota and their ecotoxicity.

M.V. thanks the Ministry of Education (Spain) for a PhD fellowship. This is a contribution to the EEC Project EROS 2000 and to the Spanish MEDPOL Programme.

Received 14 December 1988, accepted 6 January 1989.

our samples and they were not considered when calculating the upward flux of POM (see Table 1 legend).

Concurrently measured fluxes of POM (POC and PTN) were always higher in the downward than in the upward direction (Fig. 1). In the one concurrent data set of sufficient size for statistical comparison, at F, 1,600 m above bottom in spring, the POC and PTN fluxes were significantly higher \((P < 0.05)\) in the downward direction. Combining both depth measurements in a single season revealed significantly higher downward fluxes \((P < 0.02)\) of POC at F in spring and CNP in the autumn. Similarly, the downward fluxes of PTN were significantly higher \((P < 0.01)\) than the upward fluxes at F in spring but not significantly different \((P > 0.05)\) at CNP in the autumn. Carbon/nitrogen ratios of the upward flux of POM were consistently higher at F but always lower at CNP than the concurrently measured downward flux of POM.

Upward fluxes of POC constituted from 1.6% to 27% of the downward flux at F in the autumn and spring, respectively. Similarly, the upward flux of PTN ranged from 1.1% to 21.3% of the downward flux at the same station. In contrast, the upward flux of POM was more important at the oligotrophic central gyre station where the upward POC flux was 23.5–37.5% of the downward flux, while the upward flux of PTN was 37.5–66.7% of the downward flux.

Our measured rates of downward fluxes of POM fall within the range of values measured previously at these same stations\(^5\) and are of similar magnitude to those reported previously for the eastern and central North Pacific\(^9,10\). The only other measurements of upward flux of particulate matter in the open ocean were made on a 262-day deployment in an area 750 km north-west of F at a similar depth (4,215 m)\(^5\). The mean mass flux was 0.7 mg m\(^{-2}\) d\(^{-1}\), and was rich in hydrocarbons, fatty acids, wax esters and ketones. They found the upward mass flux was from 1–4% of the concurrently measured downward mass flux. It is difficult to compare this study with ours, as the methods were not described and neither total organic carbon nor nitrogen were reported. The relative proportion of the upward to the downward flux is comparable, however, to those we measured in the autumn but substantially less than those found in the spring at F.

The higher upward fluxes we measured in the spring at both stations may be a result of seasonal reproductive efforts by deep-sea animals with planktotrophic development to take advantage of increased primary productivity in the overlying

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**Table 1** Flux of passively sinking (down) and rising (up) small particulate organic carbon (POC) and total nitrogen (PTN) measured at 600 and 1,600 m above bottom at F (4,400 m depth) and CNP (5,800 m depth)

<table>
<thead>
<tr>
<th>Collection period</th>
<th>Moored sediment trap</th>
<th>POC flux (\text{mg C m}^{-2} \text{d}^{-1})</th>
<th>PTN flux (\text{mg N m}^{-2} \text{d}^{-1})</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dates</td>
<td>Time (d)</td>
<td>Depth (m)</td>
<td>Altitude (m)</td>
</tr>
<tr>
<td>Station F (32°50' N, 124° W)</td>
<td>Spring (1986)</td>
<td>23 May–1 June</td>
<td>8.5</td>
<td>3,800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 June–10 June</td>
<td>8.5</td>
<td>3,800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23 May–1 June</td>
<td>8.5</td>
<td>2,800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 June–10 Jan.</td>
<td>8.5</td>
<td>2,800</td>
</tr>
<tr>
<td></td>
<td>Autumn (1986)</td>
<td>18 Nov.–30 Nov.</td>
<td>11.0</td>
<td>3,800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30 Nov.–13 Dec.</td>
<td>12.0</td>
<td>3,800</td>
</tr>
<tr>
<td>Station CNP (31° N, 159° W)</td>
<td>Spring (1987)</td>
<td>6 June–20 June</td>
<td>13.4</td>
<td>5,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 June–3 July</td>
<td>12.1</td>
<td>5,200</td>
</tr>
<tr>
<td></td>
<td>Autumn (1983)</td>
<td>8 Oct.–22 Oct.</td>
<td>13.3</td>
<td>5,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22 Oct.–6 Nov.</td>
<td>14.0</td>
<td>5,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 Oct.–22 Oct.</td>
<td>11.0</td>
<td>4,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23 Oct.–6 Nov.</td>
<td>13.1</td>
<td>4,200</td>
</tr>
</tbody>
</table>

Upright and inverted conical sediment traps, each with a collection surface of 0.25 m\(^2\) (ref. 27) and with sequencing collection cups\(^5\) were moored at 600 and 1,600 m above the bottom at each station for periods of 8.5 to 14 days. Collection cups at the bottom/top of each upright/inverted sediment trap were sequenced with collection only at the moored depth, freely flushing on ascent and descent. These collection cups work equally well in either an upright or inverted position because of an angled sidearm entry, equidistant between the 2 ends of the capped plexiglass cylinder. The collection cups were filled prior to deployment with water obtained from the depth of deployment and filtered through pre-combusted GF/C (Whatman glass fibre) filters. One trap of each tandem set was poisoned with mercuric chloride to retard degradation during the collection period. There was no significant difference \((P > 0.05)\) between the POM flux measured in the poisoned and unpoisoned trap samples during the 12 collection periods, and hence they were considered duplicate samples. Samples of initial and final water from each collection cup were frozen for later determination of dissolved organic carbon and nitrogen to evaluate dissolution of particulate matter during incubation in the traps\(^3\). These samples were not analysed, however, because of the current controversy over an acceptable method\(^5\). The particulate samples from each collection cup were filtered through precombusted/pre-weighed GF/C filters and frozen for later analyses of POC and PTN in the laboratory. Before chemical analysis, whole animals ("swimmers") were removed from the filters. Filters from the upright traps were divided into quarters. One quarter of each filter was treated with HCl vapour to remove carbonates and analysed for organic carbon and total nitrogen using a Perkin-Elmer 240 CN analyser. The remaining three quarters of each filter were used here. Filters from the inverted traps were analysed whole as described above. Intra- and inter-station comparisons of POM fluxes were analysed with the Mann-Whitney U test with all significance levels chosen for two-tailed situations\(^5\). An SIO model (no. 6) current meter was concurrently deployed with the sediment traps at each depth to estimate the trapping efficiency. The mean current speeds given in Table 1 suggest trapping efficiencies >80%\(^5\).

\(^{\text{a}}\) The (30 November-13 December) POM sample with a large gelatinous mass included in analysis.

\(^{\text{b}}\) Each of these samples had euphausiid calyptopis stages which were removed and are not included in these flux calculations.

\(^{\text{c}}\) See ref. 36.
Fig. 1 Downward and upward fluxes of particulate organic carbon (POC) and particulate total nitrogen (PTN) measured at two stations, F and CNP in the North Pacific during spring and autumn at 600 and 1,600 m above the bottom (m a.b.) sampling was unsuccessful at 1,600 m a.b. in autumn at F and spring at CNP. Upward fluxes are represented above the zero baseline and the downward fluxes below the baseline. The open bars represent the POC flux and the shaded bars the PTN flux. Each bar represents the mean value with the number of measurements ± one standard deviation (the number of measurements of POC flux associated with each bar also represents the concurrently measured PTN flux). The carbon/nitrogen ratios are given above the upward fluxes and below the downward fluxes.

waters. The large number of larvae from the bathypelagic euphausiid, Thysanopoda sp., collected in the inverted sediment trap at 1,600 m above the bottom in spring at F suggests a contribution of planktotrophic development to vertical fluxes. One mesopelagic species of Thysanopoda (T. acutofrons) spawns in late winter with larvae present during the spring in the North Atlantic.\(^1\) The large contribution of wax esters to the upward flux suggests a crustacean source.\(^14\) Planktrophic development has been identified in a wide variety of deep-sea pelagic and benthic species.\(^12,13\) However, the only quantitative evaluation of this mode of development in the upward flux of POM has shown a minor contribution, based on studies of a dominant slope-dwelling species off California (manuscript in preparation).

Although our measurements have been made at abyssal depths, the importance of upward fluxes of POM need to be examined at shallower depths as well. The fluxes of POM have historically been considered in only one direction: downward. It is time that the fluxes of nutrients are re-evaluated in the context of biological processes associated with migrating animals and their products in upward and downward directions on a variety of temporal scales from diel to seasonal (for example, ontogenetic) migrations.

We thank R. Baldwin, J. Edelman, M. Laver, K. Robertson and R. Wilson for technical assistance during various stages of this research. The euphausiid larvae were identified by E. Brin- ton and M. Knight who enlightened us about these unique animals. F. Azam, R. Baldwin, A. Carlucci, R. Kaufmann and R. Epplle provided critical comments on the manuscript. This research was supported by grants from the NSF.

Received 21 November 1988; accepted 11 January 1989.


Direct observation of a section through slow-spreading oceanic crust

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Understanding the nature and composition of the oceanic crust has been a longstanding goal of Earth scientists. Seismic refraction experiments\(^1–9\) suggest a simple layered crust made of eruptive basalts underlain by a thick layer of doleritic and gabbroic intrusives and a peridotitic upper mantle. Other evidence comes from ophiolite complexes on land\(^10\), although generalizations based on ophiolites are uncertain because they may be dismembered and altered during emplacement, and it is not known whether they represent sections of mantle oceanic crust, or crust from very small "aborted" oceans, anomalous ocean structures or marginal basins. The walls of fracture-zone valleys expose thick sections of oceanic lithosphere which are accessible to in situ observations and sampling\(^11\), but this approach has been criticized because the pattern of faulting in fracture zones may disrupt the original stratigraphy of the crust\(^1\), and because the crust near fracture zones is anomalously thin\(^10,11\). Here we report the direct observation and sampling of a section of crust and upper mantle exposed at the Vema fracture zone in the Atlantic, using the French submersible Nautile.

The Vema transform fault\(^12\) offsets left laterally the axis of the Mid Atlantic Ridge (MAR) by about 320 km at 11°N

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