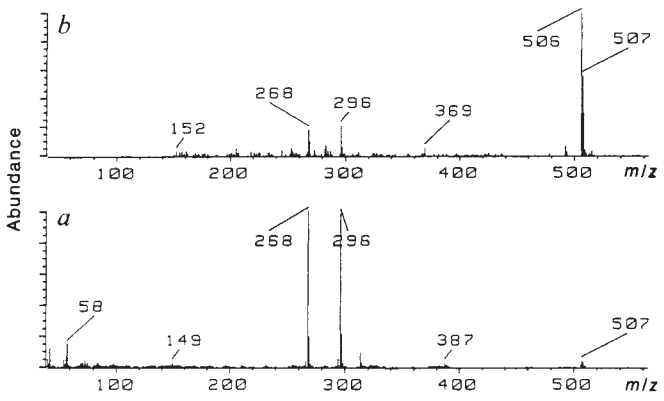

Fig. 3 Mass spectra of N-hexadecyl-N-methyl-N-octadecylamine (peak 9 in Fig. 2) obtained by *a*, EI at 70 eV, and *b*, PICI using 1.5 torr of methane in the ion source.

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), Antwerpen (Schelde estuary), Tarragona 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[12]. 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_p). 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 aromatic amines are well-known carcinogens[18], data on aliphatic amines are lacking. Investigation is now in progress to assess their accumulation in benthic biota and their ecotoxicity.

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Upward fluxes of particulate organic matter in the deep North Pacific

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The flux of particulate matter through the oceanic water column is a primary component in elemental cycling and is generally perceived as being in one direction: downward[1,2]. The organic matter constituting these particles is produced through photosynthesis in surface waters and either sinks directly as phytoplankton and products[3,4] or undergoes various trophic transformations through the water column. A large proportion of the particulate organic matter produced in surface waters is regenerated in the euphotic zone[5–7]. A fraction of this organic matter, however, leaves the surface waters and settles through the water column, generally decreasing in quantity and changing in quality with increasing distance from the surface[8–11]. Although the net transport of organic matter must be downward to fuel the lower portions of the water column, there is also an upward component to transport. Positively buoyant particles, including lipid-rich eggs, larvae and, possibly, carcasses of deep-sea animals are examples of particles which undergo upward transport[12,13]. A previous attempt to quantify the upward mass flux indicated rates of 1–4% of the downward mass flux[14]. Here we report the first evidence that there is a significant upward flux of particulate organic matter, up to 66.7% of the concurrently measured downward flux, at two stations in the deep North Pacific. Given this magnitude, the previously ignored upward flux of such organic matter must be considered in models of carbon and nitrogen cycling in the open ocean.

We concurrently measured the upward and downward flux of particulate organic matter (POM) at two stations in the North Pacific, each during two different seasons (Table 1). Station F was located in the relatively eutrophic eastern North Pacific on the western boundary of the California Current with an overall water of 4,400 m. Station CNP was in the oligotrophic central gyre north of the Hawaiian Islands with a water depth of 5,800 m[15].

The downward flux of POM, that is, particulate organic carbon (POC) and particulate total nitrogen (PTN), was significantly higher ($P < 0.02$) at Station F than at Station CNP when compared at combined depths and seasons (Fig. 1). The downward fluxes were higher in the autumn at F and higher in spring at CNP. The carbon/nitrogen ratios of this sinking particulate matter were lower at F than at CNP. The distinguishable fraction of this sinking material was composed of small fecal pellets, diatom frustules, foraminiferan tests and a few pteropod shells.

The upward flux of POM (POC and PTN) was similar ($P > 0.05$) at both stations when compared at the same distance above the bottom and at combined depths and seasons. The upward fluxes were higher in spring at both stations. Carbon/nitrogen ratios of the positively buoyant POM were higher at F than at CNP where the autumn ratios were noticeably lower (Table 1). This buoyant material was largely composed of small (< 2 mm diameter) transparent spheres, some with orange pigment (possibly eggs), and less abundant gelatinous masses. Particularly noteworthy were 10 larvae of a bathypelagic euphausiid (*Thysanopoda* sp.)[16,17] collected in the sediment trap 1,600 m above bottom in the spring at F (Table 1). These larvae (metanauplii and calyptopis I stages) do not have well developed appendages for swimming[18] and appear dependent on their yolk stores for positive buoyancy. We decided to remove these animals from

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[15] and are of similar magnitude to those reported previously for the eastern and central North Pacific[19,20]. 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)[14]. 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

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)

Collection period	Moored sediment trap				POC flux (mg C m^{-2} d^{-1})				PTN flux (mg N m^{-2} d^{-1})				C/N	
Dates	Time (d)	Depth (m)	Altitude (m)	Current speed (cm s^{-1})	*n*	Down	*n*	Up	*n*	Down	*n*	Up	Down	Up
Station F (32°50′ N, 124° W)														
Spring (1986)														
23 May–1 June	8.5	3,800	600	1.8 ± 1.0	1	1.03‡	1	0.08	2	0.17 ± 0.06	1	0.005	7.1	16.0
1 June–10 June	8.5	3,800	600		1	1.36‡	1	0.13			1	0.013		10.0
23 May–1 June	8.5	2,800	1,600†	2.7 ± 1.7	2	0.42 ± 0.16	2	0.16 ± 0.06	2	0.05 ± 0.02	2	0.01 ± 0.00	8.4	16.0
1 June–10 Jan.	8.5	2,800	1,600†		2	1.06 ± 0.33	2	0.25 ± 0.08	2	0.12 ± 0.04	2	0.02 ± 0.01	8.8	12.5
Autumn (1986)														
18 Nov.–30 Nov.	11.0	3,800	600	1.6 ± 1.2	1	2.30‡	2	0.03 ± 0.00	1	0.28	2	0.003 ± 0.00	8.2	10.0
30 Nov.–13 Dec.	12.0	3,800	600		2	2.03 ± 0.19‡	2	0.04	2	0.27 ± 0.05	2	0.004	7.5	10.0
								1.33*				0.16*		8.3
Station CNP (31° N, 159° W)														
Spring (1987)														
6 June–20 June	13.4	5,200	600	2.9 ± 2.0	1	0.87‡	2	0.17 ± 0.04	1	0.04	2	0.02 ± 0.01	21.8	8.5
20 June–3 July	12.1	5,200	600		2	0.49 ± 0.01‡	1	0.27	2	0.06 ± 0.001	1	0.03	8.2	9.0
Autumn (1985)														
8 Oct–22 Oct.	13.3	5,200	600	1.5 ± 1.2	1	0.20‡	1	0.13	1	0.02	1	0.02	10.0	6.5
22 Oct.–6 Nov.	14.0	5,200	600		1	0.28‡	1	0.04	1	0.03	1	0.01	9.3	4.0
11 Oct.–22 Oct.	11.0	4,200	1,600	1.8 ± 2.1	1	0.30	2	0.11 ± 0.08	1	0.03	2	0.02 ± 0.02	10.0	5.5
23 Oct.–6 Nov.	13.1	4,200	1,600		1	0.37	2	0.05 ± 0.00	1	0.05	2	0.005 ± 0.00	7.4	10.0

Upright and inverted conical sediment traps, each with a collection surface of 0.25 m^2 (ref. 27) and with sequencing collection cups[15] 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[31]. These samples were not analysed, however, because of the current controversy over an acceptable method[32]. 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 CHN analyser. The remaining three-quarters of each filter was used in other analyses not reported 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[28]. 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%[29].

* The (30 November–13 December) POM sample with a large gelatinous mass included in analysis.

† Each of these samples had euphausiid calyptopis I and metanauplius stages which were removed and are not included in these flux calculations.

‡ See ref. 30.

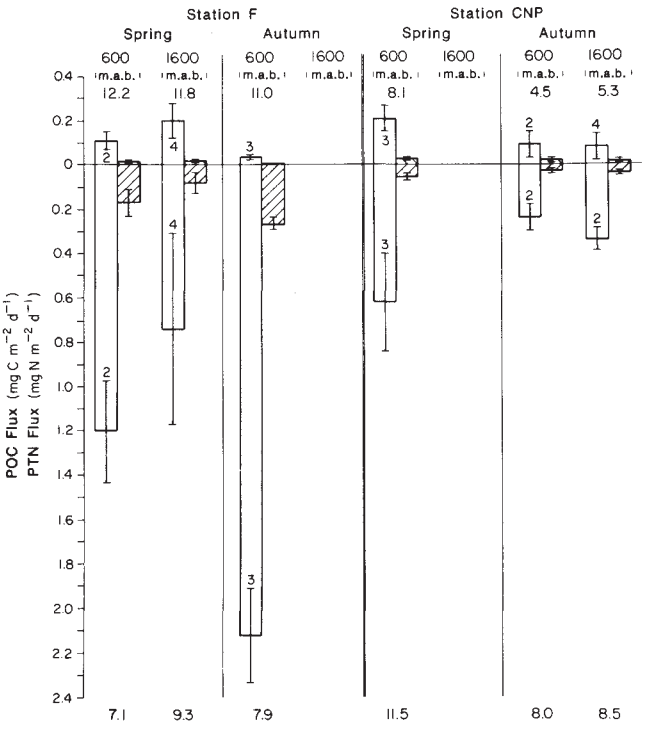

Fig. 1 Downward and upward fluxes of particulate organic carbon (POC) and particulate total nitrogen (PTN) measured at two stations, F and CNP in the North Pacific during spring and autumn at 600 and 1,600 m above the bottom (m.a.b.) (sampling was unsuccessful at 1,600 m.a.b. in autumn at F and spring 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[21]. The large contribution of wax esters to the upward flux suggests a crustacean source[14]. Planktotrophic development has been identified in a wide variety of deep-sea pelagic and benthic species[22–26]. However, the only quantitative evaluation of this mode of development to 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.

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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[1–3] 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[4], 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 'mature' oceanic crust, or crust from very small 'aborted' oceans[5], anomalous ocean structures[6] or marginal basins. The walls of fracture-zone valleys expose thick sections of oceanic lithosphere which are accessible to *in situ* observations and sampling[7,8], but this approach has been criticized because the pattern of faulting in fracture zones may disrupt the original statigraphy of the crust[9], and because the crust near fracture zones is anomalously thin[3,10,11]. 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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