Moss Landing Marine Laboratories

Vertical Transport and Exchange of Materials in the Upper Waters of the Oceans (VERTEX): Introduction to the Program, Hydrographic Conditions and Major Component Fluxes During VERTEX I

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ABSTRACT

This paper introduces VERTEX, a multi-disciplinary research program dealing with various aspects of particle transport in the upper, high-energy layers (0-2000 m) of the ocean. Background information is presented on hydrography, biological composition of trapped particulates, and major component fluxes observed on a cruise off central California (VERTEX I). Organic C fluxes measured with two trap systems are compared with several other estimates taken from the literature. The intent of this overview paper is to provide a common setting in an economical manner, and avoid undue repetition of background and ancillary information in subsequent publications.
INTRODUCTION

The mechanisms and rates of biogeochemical cycling of elements and organic compounds in the sea and the incorporation and flux of energy through biological compartments have interested oceanographers for years. Indeed, cycling and flux studies of one sort or another have involved almost every discipline of oceanography. However, the factors responsible for controlling the distributions of elements and compounds in oceanic water columns are poorly understood. This is especially true when considering the role of organisms and their remains in these cycling processes, in spite of the fact that everyone recognizes their importance.

Within the past few years, the development of particle traps has enabled the measurement of fluxes of materials, not only to the sea floor, but also within various portions of the water column. Recent advances in methodology and instrumentation have also made possible the accurate determination of a reasonably large suite of elements and compounds at the very low levels at which they exist in sea water. This combination of developments now enables oceanographers to measure rates of change and residence times in the water column by comparing fluxes at various depth intervals.

A group sharing mutual interests in studying these processes in the upper "high-energy" layers (0-2000 m) of the ocean was formed in 1979. The participants named the research program VERTEX, an acronym which stands for vertical transport and exchange of materials in the upper ocean. The overall objectives of the program are to: (1) accurately
determine the amounts of elements and/or compounds in the water column in both particulate and dissolved form; (2) measure the fluxes of these elements and compounds at selected depths using particle traps; (3) using the information gained in objectives 1 and 2, estimate residence times and rates of change; and (4) understand how the transport and exchange system works in general and in specific ocean regions.

The purpose of this paper is to introduce the VERTEX program and to provide background information on the first cruise (VERTEX I) which took place off central California in August-September 1980. This basic information will provide a common setting in an economical manner for future publications by the participants that will deal with various aspects of the program, such as primary production and C, H, N fluxes (Knauer and Martin, Moss Landing Marine Laboratories [MLML]), zooplankton (Small, Oregon State University), micro-organisms (Karl, University of Hawaii), marine snow (Silver and Gowing, University of California at Santa Cruz [UCSC]), hydrography and currents (Broenkow, MLML), trace elements (Bruland, UCSC; Martin and Knauer, MLML), natural series radionuclides (Bruland, UCSC); transuranics (Fowler, International Laboratory of Marine Radioactivity, Monaco), lipids (Wakeham and Farrington, Woods Hole Oceanographic Institution [WHOI]), organo-nitrogen compounds (Lee, WHOI) and higher molecular weight hydrocarbons (Risebrough, Bodega Marine Laboratory, University of California at Berkeley).
METHODS

**Particle Traps:** Two types of particle traps are used in the VERTEX program: large (0.25 m²) cone-shaped traps designed by Andrew Soutar of Scripps Institution of Oceanography (Fig. 1), and small (0.0039 m²) cylindrical traps designed by George Knauer of MLML (Fig. 2). The Soutar design, funnel-shaped particle interceptor traps (PITs), consist of a pair of teflon-coated fiberglass funnels with acrylic cod ends. The PIT collecting surface is a cellular grid array (square openings 1 cm on a side) where particle trap interaction (rejection vs entrapment) is believed to occur. PITs for organic material collections are of the same design, except that the cones are teflon-coated stainless steel and the cod ends are electro-polished stainless steel. Preservation in the trace element/radionuclide PITs is accomplished using buffered (pH = 8) formalin. The formalin-sodium borate solution in a 60-ml polyethylene bottle weighted with a teflon-coated magnet is placed in the PIT cod ends, where it slowly diffuses out through small holes in the bottle cap. Mercuric chloride is used for preservation in the stainless steel PITs. All interior PIT surfaces are thoroughly cleaned with either acid or organic solvents prior to launch.

The MLML traps (Fig. 2) consist of a frame constructed of high-impact PVC, which is fitted with 12 identical cylinders (ID = 7.0 cm; length = 60 cm). The mouth of each cylinder has a baffle system consisting of 16 smaller tubes (ID = 1.3 cm; length = 5 cm). The tops of the tubes are milled to a wall thickness of 0.06 mm to maximize open surface area. The cylinders are made of lucite with polyethylene cod
FIG. 1. Schematic drawing of the Soutar design particle interceptor traps. Traps were deployed by Bruland of UCSC and are referred to as UCSC PITs throughout the text.
FIG. 2. Schematic drawing of the MLML traps used during VERTEX I.
ends, except for those designed to collect materials for organo-nitrogen compounds, which consist of glass cylinders lined with teflon bags.

The MLML trap cylinders are filled with either a NaCl solution (Knauer, Martin) or a sucrose solution (Silver, Gowing) having a density ($\rho = 1.05 \text{ g cm}^{-3}$) greater than that of sea water. The solution maintains its integrity for periods of weeks, preventing significant exchange. The density solution also retains added preservatives and substances that dissolve from the trapped particles (e.g., Cd and PO$_4$; Knauer and Martin, 1981). Various preservatives or tracers are added to the gradient solutions, depending on the intended analyses or experiments (see Table 1).

A similar flotation system is used for the two trap systems (Fig. 3). The major portion of the array's weight is carried by submerged glass, hard-hat floats set at depth below turbulent wave action. Both arrays are equipped with spar buoys fitted with strobe lights and OAR radio transmitters. The MLML buoys are also equipped with an Argos satellite transponder.

Both the Soutar and MLML type traps were tested during the Sediment Trap Intercomparison Experiment (STIE; Spencer, et al., 1981), which took place in the Panama Basin from 28 July to 1 December 1979. Generally good agreement was obtained among the VERTEX traps and two other trap systems, those of Honjo (Woods Hole Oceanographic Institution) and Gardner (Lamont-Doherty Geological Observatory) (Fig. 4). This agreement is remarkable in view of the fact that the traps were of different design and size. For example, Honjo's traps have a 1.5 m$^2$ collecting surface in comparison to the 0.0039 m$^2$ for the MLML traps. The obvious loss of CaCO$_3$ in the MLML traps resulted from the
TABLE 1. Intended analyses, preservatives used, and investigators for the 12 MLML trap cylinders during VERTEX I.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Number of Samples</th>
<th>Preservative</th>
<th>Investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle Identification</td>
<td>1</td>
<td>Glutaraldehyde</td>
<td>Silver</td>
</tr>
<tr>
<td>C, N, H</td>
<td>2</td>
<td>Formalin</td>
<td>Knauer-Martin</td>
</tr>
<tr>
<td>Trace metals</td>
<td>3</td>
<td>Formalin</td>
<td>Knauer-Martin</td>
</tr>
<tr>
<td>ATP</td>
<td>2</td>
<td>Phosphoric acid</td>
<td>Karl</td>
</tr>
<tr>
<td>Uptake kinetics</td>
<td>1</td>
<td>$^{3}H$ adenine</td>
<td>Karl</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(no preservative)</td>
<td></td>
</tr>
<tr>
<td>Organic nitrogen</td>
<td>2</td>
<td>Chloroform</td>
<td>Lee</td>
</tr>
<tr>
<td>Radionuclides</td>
<td>1</td>
<td>Formalin</td>
<td>Bruland</td>
</tr>
</tbody>
</table>
FIG. 3. Flotation system used for both UCSC and MLML traps during VERTEX I.
FIG. 4. Major component fluxes (mg m$^{-2}$ day$^{-1}$) measured during Sediment Trap Intercomparison Experiment by Knauer and Martin (MLML), Honjo (WHOI), Gardner (LDGO), and Soutar (SIO). Figure drawn from data in Spencer, et al., 1981.
dissolution of CaCO$_3$ in the NaCl trap solution. CaCO$_3$ is now added to selected MLML trap cylinders to prevent this problem.

RESULTS AND DISCUSSION

Hydrographic Data

The study area was surveyed prior to deployment of the traps (17 to 21 August 1980) using a 20-station CTD grid centered on the intended trap launch site. Near-surface temperature and chlorophyll fluorescence were measured via continuous surface profiles among the CTD stations. The survey data showed a pattern typical of the late upwelling season (Lynn 1967) with cool (< 13 °C) temperatures and relatively high (> 20 mg m⁻²) chlorophyll levels in the nearshore waters (Fig. 5). The local center of strong upwelling is near Point Sur, and tongues of nutrient-rich, cool, high-salinity waters have been often observed penetrating into Monterey Bay from the south (Broenkow and Smethie, 1978). The surface temperature distribution was consistent with geostrophic flow at the surface (Fig. 6). The pre-deployment survey showed two eddies: cyclonic flow was centered at 37°N, 123°30'W, somewhat west of a surface temperature minimum; and an anticyclonic eddy was centered at 35°40'N, 124°W in an area of warmer surface waters. Flow between these two features was strong and onshore. To avoid the possibility of shoreward drift, the traps were launched south of the survey area rather than in the center of the shoreward flow, as originally planned.

Vertical temperature, salinity and dissolved oxygen distributions near the traps (Fig. 7) are representative of the California Current along the central California coast. Mixed-layer depths vary seasonally in the study area, from near zero during periods of intense upwelling
FIG. 5a. CDT Stations (+) and surface temperatures (°C). Trajectory of MLML PIT mooring shown by dashed line.
FIG. 5b. Surface pigments (mg m$^{-3}$) from *in vivo* fluorescence.
FIG. 6. Dynamic height anomalies (dyn mm) surface/1500 db, and trajectory of MLML PIT mooring.
--- Salinity (ppt) ---
32.5 33.0 33.5 34.0 34.5 35.0

--- Temperature (deg C) ---

Oxygen (µmoles/kg)

FIG. 7. Vertical temperature, salinity, and dissolved oxygen,
Station 28; 35°37.1'N, 123°40.8'W, 31 August 1980.
(generally in the spring and summer months) to nearly 100 m during the winter (Eber, 1977). The 20 to 30 m mixed layer depths observed during VERTEX I are typical of mid- to late-summer conditions. Minimum dissolved oxygen concentrations (about 12 µmole kg\(^{-1}\) or 4% saturation) were found at 750 m, and oxygen concentrations of < 10% saturation were present between 450 and 1200 m (Fig. 7). The intrusive features shown in the oxygen profile between 200 and 400 m are probably real (because they were observed at several nearby stations) and result from small-scale advective mixing processes.

Salinity distributions (Fig. 8a) show low salinity (33.2 < S < 33.7) surface waters formed in the transition zone between Pacific Subarctic and Pacific Equatorial Waters (Sverdrup, Johnson and Fleming, 1942). An interesting feature of the salinity distribution along the California coast is the presence of relatively high salinity "southern" water (Wickham, 1975) which flows northward along the continental slope in the California Countercurrent. The salinity and geostrophic flow sections across the study area (Fig. 8) show a small subsurface salinity maximum (S ~ 34.2) in the area of northerly flow nearshore. From spring to fall, the California Countercurrent is generally subsurface, with its core between 200 and 300 m (Wickham, 1975; Hickey, 1979), though occurrences of northerly flow at the surface may be observed whenever a favorable interplay of forces permits. McLain and Thomas (in prep.) suggest that the surface countercurrent is caused primarily by local onshore Ekman transport during winter, and by remote forcing due to poleward propagation of coastal trapped waves from the tropics.
(a) Salinity.
(b) Geostrophic flow (cm sec$^{-1}$). Northerly flow is hatched.
The MLML and UCSC trap moorings acted as 2000 and 1500 m-long (respectively) drift poles, and their trajectories were determined by the water column-mean velocity. (The ratio of the submerged and exposed surface area was 36:1 for the MLML trap line.) Both the MLML and UCSC moorings drifted in a clockwise sense around the anticyclonic geostrophic eddy (Figs. 6, 9). Because the MLML mooring was accurately tracked by 70 LORAN-C fixes during the 13-day deployment, and the UCSC array was located by only 16 such fixes, detailed current results are available only for the MLML trap array, on which two Endeco Type 741, neutrally-buoyant current meters were set at 150 and 1500 m. Broenkow (1982) found good agreement between daily-mean relative currents measured by the freely drifting meters when adjustments were made for trap array drift and the geostrophic currents near the traps on day 8 of the experiment. He showed that the daily mean mooring line drift rate varied from 4.2 to 11.4 cm sec\(^{-1}\) (mean 7.5 cm sec\(^{-1}\)) during the 13-day deployment. The relative velocities as measured by the current meters showed both tidal and inertial (20.5 hr) periodicity at 150 and 1500 m, and relative velocities at these depths were essentially out of phase by 180°. Gardner (1980a, b) has shown that currents can affect the performance and accuracy of certain particle interceptor traps to accurately catch sinking particles. Relative current speed measurements at 150 and 1500 m (PITs closest to the meters were at 100, 200 and 1400 m) showed that the instantaneous (based on a 2-minute recording interval) maximum current speed was 21 cm sec\(^{-1}\) at 150 m and 17 cm sec\(^{-1}\) at 1500 m. Thirty-minute sustained maximum velocities of 18.3 and 15.2 cm sec\(^{-1}\) were observed at these depths (Fig. 10). The bimodal (8 and 13
FIG. 9. Observed PIT positions 26 August to 8 September 1980. Dashed line is UCSC mooring; solid line is MLML mooring. Numbers show interpolated daily noon positions. Adapted from Broenkow (1982).
FIG. 10. Frequency for 30-min. average relative current speeds on MLML PIT moorings, 26 August to 8 September 1980.
(a) 150 m.
(b) 1500 m.
cm sec\(^{-1}\)) frequency distribution for the 150-m depth was caused by the water column acceleration following day 8 of the experiment (Fig. 10). At 1500 m, the modal relative speed was 5 cm sec\(^{-1}\). Mean relative current speeds during the experiment were 9.7 and 6.0 cm sec\(^{-1}\). In view of these velocities and the trap designs (MLML cylinders and UCSC cones, both with baffles), we believe it unlikely that horizontal water movements were significantly affecting trap accuracy, especially in light of the fact that they were free drifting (see Staresinic, Von Brockel, Snodlake and Clifford, 1982).

**Nutrients**

Nutrient profiles typical of the California Current were observed during VERTEX I (Fig. 11). Nitrate plus nitrite and silicate concentrations were near zero at the surface (0.1; 3.5 umol kg\(^{-1}\), respectively), while phosphate levels were relatively high (0.5 umol kg\(^{-1}\)). Typical increases with depth were observed for these nutrients; \( \text{PO}_4 \) and \( \text{NO}_3 + \text{NO}_2 \) maxima coincided with the oxygen minimum (Figs. 7, 11), while \( \text{SiO}_2 \) amounts increased continuously in the 2000-m water column. Ammonia concentrations (data not shown) were variable (0-0.9 umole kg\(^{-1}\)) throughout the water column, and no definite trend with depth was observed.

**Biological Composition of Trapped Particulates**

Amorphous organic detritus dominated the trapped particulate contents at all depths. Intact or readily recognizable fecal pellets were the next most common particles. Skeletal debris as well as apparently living organisms were also present at all depths. We now
FIG. 11. Vertical nutrient distributions (umoles kg$^{-1}$) at VERTEX I PIT site.
describe these major classes of materials based on examination of the samples using light and scanning electron microscopy.

Individual particles of amorphous detritus corresponded generally to one of the two major categories described previously as "flakes" and "flocs" (Wieve and Pomeroy, 1972). The flocs, or mucus-like aggregates, were similar in appearance to fragments from hand-collected specimens of marine snow, and were especially prominent in the upper 100 m, and again between the depths of 500 and 1100 m. At the other depths, the amorphous organic detritus was dominated by flake-like particles resembling flattened plates or membranes.

The sources of most of the flocculent detritus were not obvious, except for two types with distinctive mucus. One recognizable type was produced by the diatom Thalassiosira subtilis; T. subtilis colonies were abundant in the upper 100 m, and the mucus was found in small quantities to the bottom trap at 2000 m (Fig. 12a). (The taxonomic designation of T. subtilis for these specimens was confirmed by G. Fryxell.) Thick mats of threads (Fig. 12b) surround T. subtilis cells, and the persistence of the mucilage to depths is explained partially by the resistance of the threads to digestion, as evidenced by their presence within fecal pellets in the traps. A chitin-like composition may explain the chemical hardiness of these fibrils (Hasle, 1972). A second recognizable source of flocculent mucus was larvaceans. Larvacean houses (together with occasional specimens of intact larvaceans) occurred in modest numbers from the surface traps to those at 2000 m. In contrast to the flocculent detritus, the origins of the flake-like materials were never evident.
FIG. 12. (a) Fibrillar mat produced by *Thalassiosira subtilis* and *T. subtilis* cells from the 50-m trap;
(b) *Thalassiosira subtilis* entwined in fibrous mucilage;
(c) *Skeletonema costatum*, a common neritic diatom, from the 2000-m trap;
(d) *Strombidium* sp., an oligotrich ciliate from the 2000-m trap.
Phytoplankton associated with the detritus indicated three distinctive sources of materials in the traps. Traps from the upper 100 m contained an abundance of coccolithophores, dominated by *Emiliania huxleyi*, the primary coccolithophore of subarctic Pacific and north equatorial Pacific waters, and a common species of the central North Pacific (Okada and Honjo, 1973; Reid, 1980). The specimens of *E. huxleyi* in the traps within the euphotic zone, as well as those from greater depths, possessed coccoliths characteristic of cells from both warm and cold water environments, mixtures we have found previously from surface waters for the outer California Current at this time of year. *Thalassiosira subtilis*, the diatom forming mats of muclilage fibers discussed above, was another abundant species whose presence indicated warm oceanic water masses (Hasle, 1972). Moderate numbers of the very large diatoms *Rhizosolenia castracanei* and *R. imbricata var. shrubsolei* were also present in the upper traps. These diatom species occurred in intertwining "mats" of frustules in the water, associations especially characteristic of oceanic, nutrient depleted regimes and water masses of oceanic gyres (Alldredge and Silver, 1982). The combination of *E. huxleyi*, and *T. subtilis*, and *Rhizosolenia* species indicates inputs of materials to the traps from oceanic and outer California Current water masses.

A second source of materials in the traps was indicated by the presence of the heavily armored dinoflagellate, *Ceratium dens*. This species also occurred in considerable numbers in traps from the upper 100 m, and had been present in the Monterey Bay area for at least a month prior to the cruise, causing a "red tide". This dinoflagellate
species indicated a source of materials from inshore, near-surface waters of the central California coast during conditions of nutrient depletion that often occur after the relaxation of upwelling (Garrison, pers. comm.). Recognizable Ceratium debris disappeared almost immediately below 100 m, but fragments of Rhizosolenia occurred sparsely below the epipelagic depths, and coccolith debris occurred consistently and abundantly to the bottom trap.

At depths of 1100 m and below, a third source of material was indicated by the presence of new phytoplankton species in the traps. Populations that clearly were derived from communities like those in overlying waters were also present, and thus the mixture of the populations suggested inputs from different sources at depth. These new populations were dominated by Skeletonema costatum (Fig. 12c), a neritic diatom commonly characteristic of the early stages of upwelling in the nearshore area (Garrison, 1979). Alumino-silicate fluxes increased at these same depths (see below), indicating lateral input of terrigenous materials. The change in phytoplankton composition at these depths further suggests that these materials were originally from the coastal zone.

In addition to the skeletal and organic detritus discussed above, many heterotrophic protozoans, algae, and metazoans -- judged intact with light microscopy -- occurred in the traps. Ciliates were the most conspicuous forms (Fig. 12d) among the protozoans, but flagellates (including non-pigmented, naked dinoflagellates) were also moderately abundant. Most of the algae within the detritus were either in advanced stages of decomposition or consisted of empty-walled specimens, but
occasional specimens showed autofluorescence, indicating the presence of intact protoplasts with pigment.

Metazoans were present in all the traps, and were most abundant in the 50 to 200 m traps. In sediment traps, such organisms are usually interpreted as being "swimmers" (Knauer, et al., 1979), forms that swam into the traps on their own. However, it is probable that some of these, particularly the smaller forms, were associated with the detrital debris that sank into the traps, and were part of detrital food chains. Copepods were the most common swimmers in our samples, followed by ostracods and copepod nauplii. Larvaceans, gymnosomatous pteropods, polychaetes, hydrozoan jellies (including siphonophores), amphipods, and chaetognaths occurred in lower numbers.

The larvaceans are a particularly interesting group of "swimmers", because they bring with them their mucous houses, which are one of the most readily recognized forms of floc or marine snow. Because larvaceans are almost constantly in their houses as protection from predators (Alldredge, 1976), the larvaceans may actually inject this form of "detritus" when they swim into the traps. Larvacean houses were not numerous relative to other forms of detritus, and thus would not have introduced a significant amount of material into the traps during VERTEX I.

Major Component Fluxes

Major component fluxes estimated using the two trap systems are shown in Fig. 13 and Table 2. Total mass fluxes were similar at 80-100
FIG. 13. Major component fluxes (mg m\(^{-2}\) day\(^{-1}\)) measured with MLML (filled squares) and UCSC (open squares) trap systems during VERTEX I.
TABLE 2. VERTEX I major component fluxes measured with MLML and UCSC traps. Organic matter, CaCO$_3$ and alumino-silicate fluxes were estimated by multiplying organic C values by 2, Ca values by 2.5, and Al quantities by 12.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Total</th>
<th>Org. Mat.</th>
<th>CaCO$_3$</th>
<th>Al-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>720</td>
<td>440</td>
<td>89</td>
<td>3.3</td>
</tr>
<tr>
<td>80*</td>
<td>300</td>
<td>190</td>
<td>57</td>
<td>0.84</td>
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<tr>
<td>100</td>
<td>210</td>
<td>130</td>
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<td>200</td>
<td>160</td>
<td>88</td>
<td>53</td>
<td>8.5</td>
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<tr>
<td>250*</td>
<td>260</td>
<td>150</td>
<td>63</td>
<td>5.3</td>
</tr>
<tr>
<td>300</td>
<td>120</td>
<td>63</td>
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<td>700</td>
<td>120</td>
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<tr>
<td>750*</td>
<td>86</td>
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<td>900</td>
<td>150</td>
<td>61</td>
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<tr>
<td>1100</td>
<td>150</td>
<td>45</td>
<td>30</td>
<td>46</td>
</tr>
<tr>
<td>1700</td>
<td>100</td>
<td>30</td>
<td>29</td>
<td>39</td>
</tr>
<tr>
<td>2000</td>
<td>97</td>
<td>31</td>
<td>18</td>
<td>37</td>
</tr>
</tbody>
</table>

*UCSC traps.
m and 700-750 m, while the UCSC trap flux was about 2X higher than the MLML trap flux in the 200-300 m depth interval.

Organic matter fluxes were estimated by doubling the organic C flux. Good agreement was obtained between the two trap systems, with the exception of the 200-300 m depth interval, where the UCSC trap flux was about twice as high as the trend observed with the MLML traps. This may have resulted from incomplete removal of zooplankton which actively swam into the UCSC traps, or because of poor replication in the MLML C values at 100 and 200 m. Similar calcium carbonate fluxes were obtained with the two trap systems. The largest discrepancy was observed for alumino-silicate fluxes, estimated by multiplying the Al values by 12.1, based on Taylor's (1964) crustal abundance estimate for this element (8.23%). The MLML traps yielded fluxes about twice as high as those obtained by UCSC. At the present time, it is unknown whether overtrapping by MLML or undertrapping by UCSC is involved. Certainly the trapping of rarer larger particles is not involved because the probability of catching these particles in the MLML traps would be 64X less than in the UCSC traps based on collecting area (0.0039 vs 0.25 m²). The difference in alumino-silicate fluxes might be due to the fact that the MLML trap samples were concentrated via filtration, while the UCSC PIT materials were concentrated via centrifugation. If significant amounts of Al were associated with fine clay particles, it is possible that they were not concentrated via the latter technique. Nevertheless, the overall agreement between the two trap systems is quite good in view of their different sizes and geometries, the fact that this was the first time they were compared in the free-floating mode in the
California Current, and that different trap sample processing methods were employed.

Our VERTEX I organic C fluxes are compared with other estimates made in the Atlantic and Pacific (Fig. 14). To simplify this task, we did not include fluxes measured in the upper 300 m of the water column (e.g., Staresinic, Rowe, Shaughnessey and Williams, 1978; Zeitzschel and Zenk, 1978; Tsunogai, Uenatsu, Taneka and Harade, 1980; Sasaki and Nishizawa, 1981; Staresinic, et al., 1982), nor those measured in bays and enclosed basins (e.g., Bishop, Ketten and Edmond, 1978; Knauer et al., 1979; Crisp, Brenner, Venatesan, Ruth and Kaplan, 1979; Dunbar and Berger, 1981).

The data shown in Fig. 14 can be summarized as follows: Fluxes in the 300-1500 m portion of the water column range from 0.1 to 2.6 mmol C m\(^{-2}\) day\(^{-1}\). As expected, fluxes are generally highest in productive near-shore waters and lowest in oligotrophic open-ocean areas. The same applies to the 1500-4000 m depth interval, except that maximum fluxes are only half as high (1.3 mmol C m\(^{-2}\) day\(^{-1}\)). Available flux estimates for the 4000-6000 m portion of the water column are very low, on the order of 0.05 to 0.2 mmol C m\(^{-2}\) day\(^{-1}\). This summary is similar to that compiled by Suess (1980).

It appears that there is order of magnitude agreement in near-shore and open ocean C flux estimates. Hopefully, agreement will improve as more is learned about the physics governing the entrapment of particles, and the chemistry and biology occurring within the traps themselves.
FIG. 14. A comparison of VERTEX I organic C fluxes with previously published Pacific and Atlantic Oceans estimates. Data for upper 300 m of water column plus those for bays, basins, etc. are not included.

Legend Key:
(1) This paper, central California  
   A = MLML traps  
   B = UCSC traps
(2) Knauer, et al. (1979), northeast Pacific open ocean
(3) Honjo (1980)  
   A = central Sargasso Sea  
   B = tropical Atlantic  
   C = north central Pacific
(4) Spencer, et al. (1981), Honjo STIE data, Panama
(5) Honjo (1978), Sargasso Sea
(6) Deuser and Ross (1980), Deuser, et al. (1981),  
   Sargasso Sea, bar = seasonal range
(7) Rowe and Gardner (1979), northwest Atlantic Ocean
(8) Hinga, et al. (1979), north Atlantic deep-sea floor
(10) Bishop, et al. (1977), equatorial Atlantic
(11) Bishop, et al. (1980), Panama basin
(12) Cobler and Dymond (1980), Galapagos
(13) Wiebe, et al. (1976), Bahamas
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REFERENCES


