

## Fluxes of inorganic and organic particulate matter in the Arabian Sea off Bombay

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Sedimentation of organic and inorganic matter was determined at 2, 22, 42 and 62 m depths during 19 August to 30 September 1985 at a station in the Arabian Sea off Bombay. All the parameters measured of sedimented material increased with depth, probably due to resuspension. Decreasing ratios of particulate organic carbon (POC)/particulate organic nitrogen (PON); POC/particulate total phosphate (PTP); and PON/PTP suggest the mineralization and microbial growth on the sinking particles whereas, high ratios of POC/chlorophyll *a* equivalent indicate that less phytoplankton pigments are associated with the sinking particles. Settling particles had less organic carbon than suspended matter.

Settling or sedimenting particles in the marine environment consist of large particles such as zooplankton faecal pellets, moults, amorphous faecal matter, organic aggregates, macroscopic aggregates (marine snow) and mineral matter<sup>1-3</sup>. Any of these particles may be falling through the water column either for the first time (primary particles) or injected and re-packaged as new faecal material or resuspended after deposition on the sea floor. The quality and quantity of settling particles play an important role in serving as a source of food to heterotrophic and benthic organisms<sup>4</sup>. Further, study of these particles helps in understanding the sedimentary records, dissolution and adsorption processes occurring in the water.

There is no report on the particle flux in the coastal and shelf waters of the Arabian Sea. In this paper fluxes of TPM (total particulate matter), POM (particulate organic matter), PIM (particulate inorganic matter), POC (particulate organic carbon), PON (particulate organic nitrogen), PTP (particulate total phosphate), PBsi (particulate biogenic silica) and chl *a* equiv. (chlorophyll *a* equivalent) along with their concentrations at a station in the waters of Arabian Sea off Bombay are presented.

### Materials and Methods

Samples were collected at a station (N—19°20'; E—70°20') in the Bombay High area about 160 km off Bombay. The water column at the test site was about 80 m. Water samples were collected with Niskin and Nansen bottles. Temperature was recorded with reversing thermometer. Salinity and dissolved

oxygen were determined by standard titration methods<sup>5</sup>. Dissolved nutrients, chl *a*, phaeopigments, suspended matter (SM) and organic carbon of SM of the water samples were estimated<sup>5</sup>.

Settling particles were intercepted using cylindrical sediment vessels of PVC plastic. Each sediment trap had a diameter of 100 mm and height of 300 mm (height/diam., 3:1) as recommended<sup>6,7</sup>. Sediment traps were fixed on the steel wire rope and kept suspended in seawater at 2, 22, 42 and 62 m depths. Deployment and retrieval of the traps were done using pneumatically operated winch fixed on the nearby offshore platform. The traps were deployed for 42 d (19 August to 30 September 1985). At the time of immersion, the cleaned traps were rinsed with distilled water and 1 ml of chloroform was added at the bottom of the trap to reduce the degradation of trapped matter.

After recovery, trapped matter was divided into number of subsamples. The subsamples for TPM, PIM, POC, PON, PTP and chl *a* equiv. (chl *a* + phaeopigments) were filtered onto precombusted GF/C filter papers, whereas, for PBsi it was filtered on millipore filters. Filters along with the sedimented matter except for chl *a* equiv. samples, were dried at 40°C to constant weight. This dry weight of the trapped matter was used for computing particulate flux ( $\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ ).

POM of the trapped matter was determined<sup>8</sup> by weight loss on ignition at 450°C for 3h. Standard methods were followed for estimation of POC, PON, PTP and PBsi<sup>5,12</sup>. Coefficients of variation of 0.49, 2.08, 2.40, 4.24, 3.71 and 5.31% for 6 repli-

cate analyses of PIM, POM, POC, PON, PTP and PBsi respectively were observed.

**Results and Discussion**

Physico-chemical parameters measured at the sampling site are shown in Table 1. High salinity was observed in the upper 25 m of the water column. Thereafter, salinity decreased gradually with increasing water depth. A weak halocline was observed. A well defined thermocline was evident between 25 and 50 m suggesting the restricted mixing of the water column. The values of dissolved oxygen decreased with increasing depth below 25 m. Concentration of all the nutrients were high and generally increased with depth. High nutrients and low oxygen values below 25 m depth suggest degradation activity either in the water column or in the bottom sediments. Table 2 gives data of SM, POC and chl *a* for the water column.

Microscopic examination of the sedimented matter showed the presence of diatoms such as *Asterionella*, *Chaetoceros*, *Hyalodiscus*, *Navicula*, *Pleurosigma*, *Rhizosolenia* and *Coscinodiscus*. In addition to this zooplankton remains, amphipods, pieces of shells, sponge spicules and fragments of hydroids, bryozoans and large amounts of detrital matter were noted.

The flux in general increased with depth and fluxes at 62 m were a few times higher than those at 2 m in case of TPM and PIM (Table 3). Only marginal variation was observed for POC and chl *a* equiv. fluxes at 2 and 62 m depth. On the other hand fluxes of PON, PTP and PBsi increased by an order of

magnitude at 62 m. Increase in sedimentation with depth seems to be a regular phenomenon in many coastal waters<sup>13-15</sup>. The increase in sedimentation rate with increasing depth is usually interpreted as a result of resuspension, *in situ* autotrophic production and faecal pellet production by migrating zooplankton<sup>16,17</sup>.

More than 70 to 80% of settling matter remained after ignition at 450°C suggesting the inorganic nature of the material. Percent organic carbon of TPM was 4.59%, whereas the bottom sediment had 0.16%. This indicates that most of the organic carbon was removed at the sediment/water interface before deposition.

Dying cells and debris of phytoplankton are rapidly colonized and degraded by bacteria<sup>18</sup>. The degradation generally proceeds in 2 phases with rapid initial degradation of labile compounds followed by slower mineralization of more refractory fractions<sup>19</sup>. C/N ratio of detritus can show an initial decrease during decomposition reflecting generally low C/N ratio of bacteria. This initial phase of degradation of

Table 2—Vertical profile of suspended matter (SM) chl *a* and organic carbon of the seawater

Depth (m)	SM (mg.l <sup>-1</sup> )	Organic carbon		Chl <i>a</i> (µg.l <sup>-1</sup> )
		(mg.l <sup>-1</sup> )	(% of SM)	
0	9.30	0.664	7.14	0.015
10	0.85	0.230	27.05	0.039
25	1.85	0.603	32.59	0.077
50	1.20	0.288	24.00	0.288
65	1.80	0.508	28.00	0.057

Table 1—Vertical distribution of physico-chemical parameters of the seawater

Depth (m)	Temperature (°C)	Salinity × 10 <sup>-3</sup>	DO (ml.l <sup>-1</sup> )	Nutrients (µg-at.l <sup>-1</sup> )			
				NO <sub>3</sub> -N	NO <sub>2</sub> -N	PO <sub>4</sub> -P	SiO <sub>3</sub> -Si
0	28.7	37.50	4.87	1.39	0.06	0.23	3.05
10	28.6	37.24	4.87	1.77	0.03	0.24	6.15
25	28.5	36.50	4.87	1.39	0.01	0.30	3.05
50	22.7	37.50	2.26	8.83	0.18	0.56	13.29
65	22.4	36.24	1.85	8.85	0.08	0.56	15.29

Table 3—Daily sedimentation rates of total particulate matter (TPM) and its components obtained from sediment traps

Depth (m)	TPM a	PIM		PON		POC		PON		PTP		PBsi		Chl <i>a</i> equiv.*
		a	b	a	b	a	b	a	b	a	b			
2	1048	752	71.75	296	28.24	109.00	10.40	3.55	0.34	3.02	0.28	2.99	0.28	0.074
22	1004	758	75.49	246	24.50	80.18	7.98	13.93	1.38	19.03	1.90	6.18	0.61	6.103
42	3183	2572	80.80	611	19.19	165.63	5.20	32.62	1.02	25.47	0.80	17.69	0.55	0.119
62	3983	3250	81.59	733	18.40	183.20	4.59	47.04	1.18	76.96	1.93	25.61	0.64	0.030

a = Flux (mg.m<sup>-2</sup>.d<sup>-1</sup>); b = % of TPM; \*Chl *a* equiv. = Chl *a* + phaeopigments, expressed as mg.g<sup>-1</sup> wet wt of TPM.

Table 4—Ratios of various parameters of total particulate matter (TPM) collected by sediment traps

Depth (m)	POC/PTP	PON/PTP	POC/PON	POC/chl <i>a</i> equiv.	POC/PBsi
2	36.09	1.17	30.70	420.7	36.45
22	4.21	0.70	5.75	235.8	12.97
42	6.50	1.28	5.07	131.4	9.36
62	2.30	0.60	3.89	458.0	7.15

sedimented particles is very much evident from increasing PON flux and decreasing C/N ratio (Tables 3, 4). High flux of PBsi indicates resuspension of diatom frustules. The ratios of POC/PTP and PON/PTP are far too low (Table 4) than generally observed for phytoplankton, probably due to increased phosphorus assimilation by bacteria or precipitation of dissolved phosphorus and adsorption/desorption processes<sup>19</sup>. The ratios of POC/chl *a* equiv. were also very high (Table 4), which points to the fact that organic matter of plant origin was poor during the period of observation.

Values of SM and organic carbon (as % of SM) showed small variation below 25 m depth (Table 2). In contrast to this, TPM and organic carbon (as % of TPM) increased and decreased respectively with depth. This suggests that settling particles (TPM) have different properties than that of suspended particles (SM).

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