

Particulate organic carbon and particulate humic material in the Arabian Sea

Sugandha Sardessai, V V S S Sarma & M Dileep Kumar
National Institute of Oceanography, Dona-Paula, Goa, 403004, India

Received 5 November 1997, revised 29 October 1998

Variations in particulate organic carbon (POC) and particulate humic material (PHM) were studied in winter (February-March 1995) and intermonsoon (April-May 1994) seasons in the Arabian Sea. Higher levels of POC were found in the north than in the southeastern side of the Arabian Sea close to the coast caused by higher biological production as a consequence of winter overturning. The PHM showed significant aggregation between 100 and 200 m during winter and was negligibly low towards north and relatively more towards south indicating accumulation of humic material. In contrast, PHM occurred in north than in south in intermonsoon. The north-south trends could be seen in POC and PHM along 64°E in the Arabian Sea. The POC levels were lower in the Central Arabian Sea in winter, than in intermonsoon, its concentration increasing slightly towards north in accordance with the microzooplakton and bacterial production. The abundance of PHM seems to be related to the intensity of biological activity, the nature of organic material and the spatial and temporal variations in biochemical conditions.

The particulate and dissolved organic carbon (POC and DOC) together constitute a minor fraction of total organic carbon of seawater, yet they are very important components in the transformation of carbon. Particulate organic carbon (POC) occurs in degradable and refractory (non-degradable) forms, the latter is mainly constituted by carbon present in humic material. Further POC can be of living or non-living (detrital) nature where the latter fraction may contain the refractory substances that result either from recycled marine matter or from terrestrial sources. The particulate humic material (PHM) is a measure of the extent of organic matter humification and aggregation in the water column before reaching the bottom and the addition of humic material through other sources like terrestrial inflow in the water column.

The temporal and spatial variations in POC and PHM depend largely on the nature and extent of primary and secondary producers. The sinking POC fluxes in the Arabian Sea seems to be controlled by the seasonally variable surface production due to changing circulation patterns¹. On the other hand DOC is found to exhibit large north-south gradients with relatively higher levels in the southern Arabian Sea, perhaps due to increased refractory nature towards the equator². In the water column, POC shows a general increase in the offshore direction³. However, the refractory nature of POC in water column is unknown, except for that in marginal sediments of the eastern Arabian Sea, north-south gradients are prominent in organic carbon (OC) and humic fractions with decreasing trends northward⁴. In this paper we attempt to highlight the particulate humic material (PHM) signatures in the water

column which are indicative of the accumulation of the fraction of non-living POC including those released by microorganisms in the form of exopolymers. This study is carried out in the Arabian Sea during intermonsoon and winter seasons, in relation to physical, biological and chemical properties and forms a part of the JGOFS (India) programme.

Materials and Methods

Water samples were collected at different locations in the Arabian Sea (Fig. 1) during the cruises of *ORV Sagar Kanya*, SK 91 (April-May 1994) and SK 99 (February-March 1995), representing the intermonsoon and winter season respectively. Sample collection was made by a Seabird CTD rosette system or hydrography using 12/30 l Go Flo bottles. Oxygen was analysed by Winkler titration (intermonsoon) and by colorimetry (winter). Nitrate and nitrite were estimated onboard ship using a Skalar autoanalyser. Nitrate deficits (DEL N) were estimated according to Naqvi *et al.*⁵. About 2.5 to 5 liters of seawater samples were filtered for POC and PHM through precombusted GF/C (1µm) filters. The POC was analysed by the method described by Parsons *et al.*⁶ and PHM was analysed by the method described by Martin & Pierce⁷ and modified by Hair & Basset⁸. Briefly the filter papers after filtration were washed 2 to 3 times with distilled water and dried at 60°C. The filters were crushed and extracted repeatedly with 0.5 N NaOH and the extract was made up to 15 ml. The absorbance was measured by spectrophotometer (Jasco, Model 7800) at 520 nm.

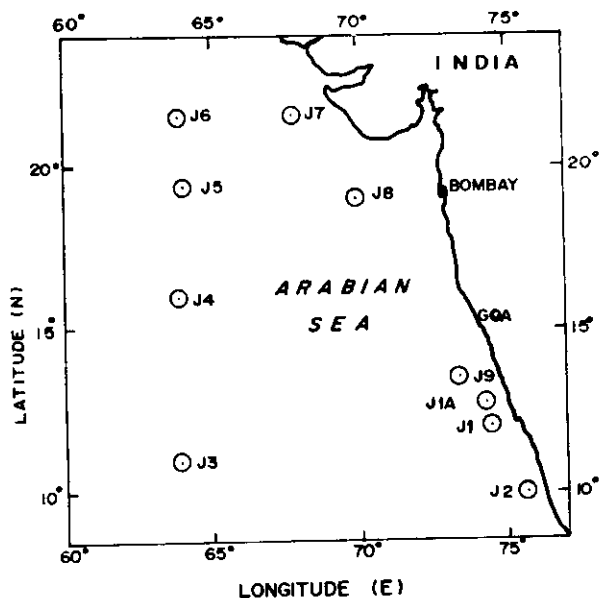


Fig. 1—Map showing station positions (J1, J3, J4, J5, J6, J7—intermonsoon; J2, J3, J4, J5, J6, J7, J8, J9— winter season)

Results and Discussion

Figure 2a shows the variations in POC along the western continental margin of India during winter. The POC levels were relatively higher in the north in general and at 19° N (J8) in particular ($48\text{--}112\ \mu\text{g C l}^{-1}$). Nutrient rich waters from the base of the mixed layer are brought to the surface, in the northern region of the Arabian Sea due to winter convection⁹. This leads to higher biological production in this region. Primary production is reported to be $807\ \text{mg Cm}^{-2}\text{d}^{-1}$ at a nearby station in this region¹⁰ (21°N and 67°E). In the south (sts J2 and J9) the POC ranged from 26 to $73\ \mu\text{g C l}^{-1}$ in the mixed layer in accordance with the low primary production of $200\ \text{mg C m}^{-2}\text{d}^{-1}$ reported at st. J2. While studying the abundance of picoplankton Ramaiah *et al.*¹¹ reported lower values in the coastal waters in south than in north of 15°N during winter.

The PHM also exhibited clear north-south gradients (Fig. 2b). At both the northern stations (north of 15°N) where POC was high, the PHM was below detection limits. This provides evidence for the higher labile nature of POM in the north than that in the south. Further, this phenomenon is supported by higher bacterial abundance observed at station J7 and J8 compared to that at st. J2 during this season¹¹. The variations in PHM (Fig. 2b) indicate aggregation of particles enriched in humic material between 100 and 200 m during winter. Interestingly, the accumulation of PHM and humification seems to be more in the southern coastal region, where PHM reached $1.9\ \mu\text{g l}^{-1}$ at 10°N. Sardesai⁴ observed patches of high concentration of organic carbon and humic acids in the sediments south of 15°N in the Arabian Sea and attributed

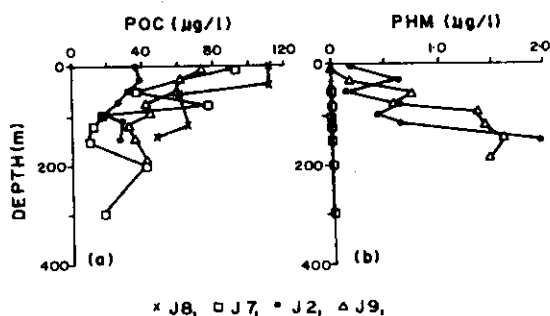


Fig. 2—Vertical profiles of (a) POC and (b) PHM during winter along the western continental margin of India

those to the preservation of organic carbon due to lower microbial activity and oxygen deficient conditions. Relatively lower concentrations of organic carbon and humic acids have been found in the sediments north of 15°N in the Arabian Sea⁴. The presence of high concentration of PHM below the mixed layer (Fig. 2b) reflects the accumulation of humic material probably due to decreased bacterial activity.

The vertical profiles of POC and PHM at the northern (J7) and southern (J1) stations during the intermonsoon season are shown in Fig. 3. The POC showed maximum concentration at about 60 m at J7 and no specific trend below this depth. The PHM did not exhibit any trend either and does not seem to be correlated to POC. At st. J1 also the POC reached a maximum at 60 m but with a gradual decrease down to 200 m. Unlike in winter season where aggregation of PHM was found around 100 m, the concentration of PHM was insignificant at st. J1 during the intermonsoon except at 300 m. The higher POC levels and negligible humification at J1 during the intermonsoon season may be a consequence of high bacterial production¹¹ at st. J1A during intermonsoon revealing efficient recycling of labile POC and non production of recalcitrant carbon in the area. The bacterial production rate was much lower at st. J7 resulting in significant humification of organic matter. The column productivity during this period was $281\ \text{mg Cm}^{-2}\text{d}^{-1}$ at st. J1 whereas it was $306\ \text{mg Cm}^{-2}\text{d}^{-1}$ at st. J7.

The north-south POC distribution along 64°E shows a distinctly different behaviour during winter and intermonsoon seasons (Fig. 4). The oceanic POC along 64°E was higher during intermonsoon and lower during winter except at st. J6 (21°N) (Fig. 4), a reverse trend to that of the primary production. Higher production in the north driven by winter convection has probably resulted in the exception at 21°N. These seasonal variations in POC are in concurrence with biological and chemical observations. Microzooplakton showed higher population in intermonsoon than in winter¹². In the central and eastern Arabian Sea microzooplakton is reported¹² to vary from 7

to $36 \mu\text{gC l}^{-1}$ (average $19 \mu\text{gC l}^{-1}$) during intermonsoon whereas during winter it ranged from 4 to $22 \mu\text{gC l}^{-1}$ (average $10 \mu\text{gC l}^{-1}$). Southern stations showed relatively higher biomass than the northern stations. Further, biological production in intermonsoon has been found to be dominated by bacteria since phytoplakton production account for only about 2% of the bacterial production¹¹. Heterotrophic bacteria also have been identified as one of the major biomass components in the euphotic zone of oligotrophic waters^{13,14} and constitute a major fraction of POC in the ocean^{14,15}. Apparently, relatively higher POC levels in intermonsoon could have been due to abundant bacterial and microzooplakton population in relation to those in winter. However, Rosso & Azam¹⁶ using epifluorescence microscopy technique, showed that only <5% of the bacteria were attached to particles and 98% of the cells passed through $1 \mu\text{m}$ Nucleopore filters. Marine

aggregates have been found to harbour dense bacterial population¹⁷; but such populations of bacteria are few in number and contribute only a trivial fraction (<0.5%) of the total bacteria. In view of these facts we believe that, during our filtration through GF/C filters, bacterial population, though high in intermonsoon, might not have contributed significantly to the high POC contents in this season. Nevertheless, the rapid bacterial turnover during intermonsoon should have sustained higher abundance of flagellate and ciliates during this period resulting in the dominance of these protozoans in microzooplakton population. Microzooplakton abundance was generally higher in the upper 100 m water column and hence seems to be a major contributor to the POC in the intermonsoon season. Alternately, marginally lower levels of POC in the oxygen minimum zone particularly in winter indicate increased amounts of organic matter oxidation. This is evident by the distribution of dissolved oxygen (Fig. 5) and nitrate deficit (DEL N) values (Fig. 6). The former exhibited the lowest concentration and the latter the highest in these layers in winter than in intermonsoon. Besides total carbon dioxide has also been found to be higher in winter than in intermonsoon substantiating increased remineralisation in winter and towards north¹⁸.

Variations in the PHM during winter and intermonsoon along the 64°E are shown in Fig. 7. The surface levels of PHM are relatively low ($<0.2 \mu\text{g l}^{-1}$) in the north particularly in winter. Besides, PHM is relatively less at all depth levels in winter than in intermonsoon. This is in concurrence with the POC trends in Fig. 4. The lower levels in winter and especially in the north strongly suggest the labile nature of POC in the north and particularly in

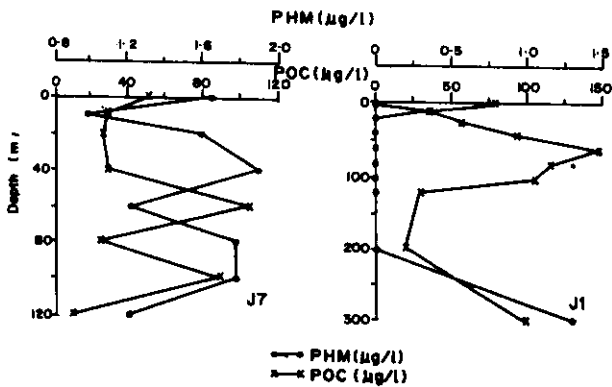


Fig. 3—Profiles of POC and PHM concentrations at stations J7 and J1 during intermonsoon

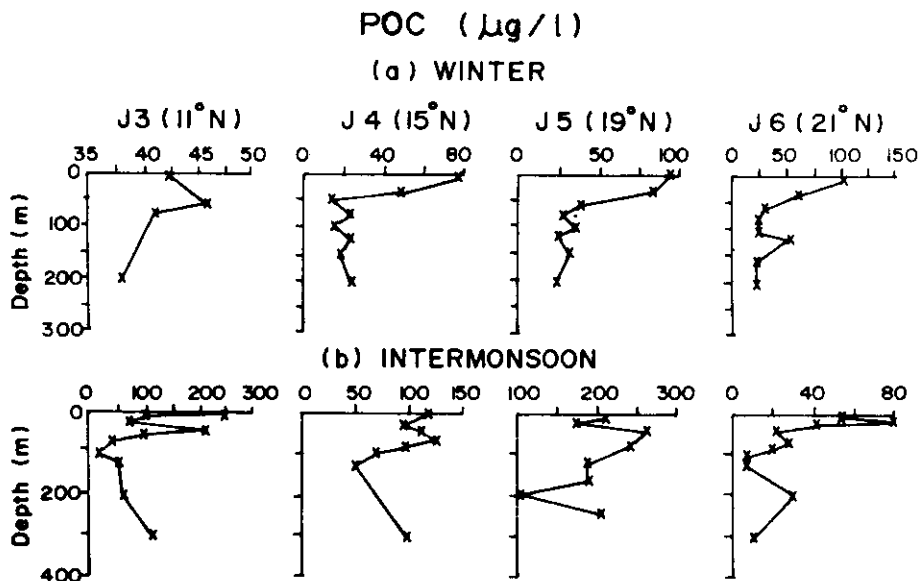


Fig. 4—POC ($\mu\text{g/l}$) profiles during winter and intermonsoon along 64°E

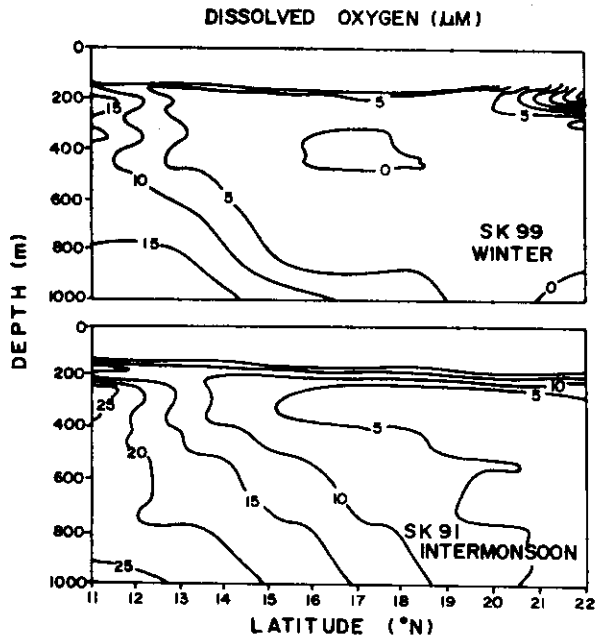


Fig. 5—Distribution of dissolved oxygen (μM) along 64°E in winter and intermonsoon seasons in the Arabian Sea (oxygen levels of $<25\ \mu\text{M}$ only are shown to highlight the oxygen deficient conditions)

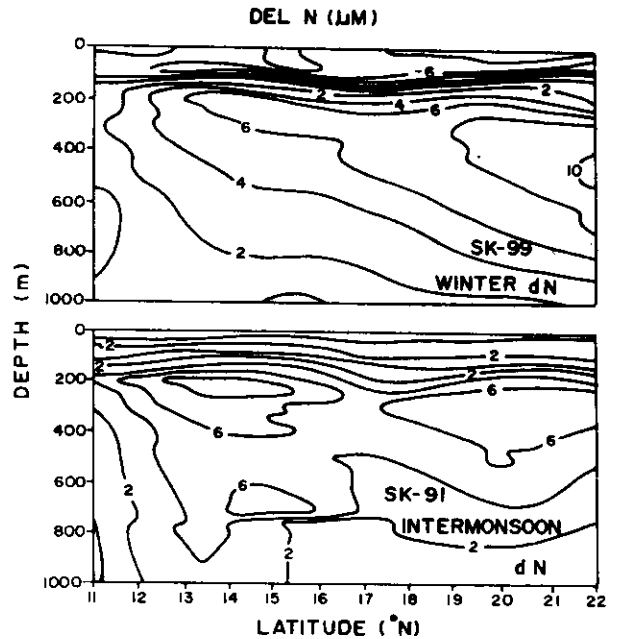


Fig. 6—Distribution of (DEL N μM) along 64°E in winter and intermonsoon seasons in the Arabian Sea

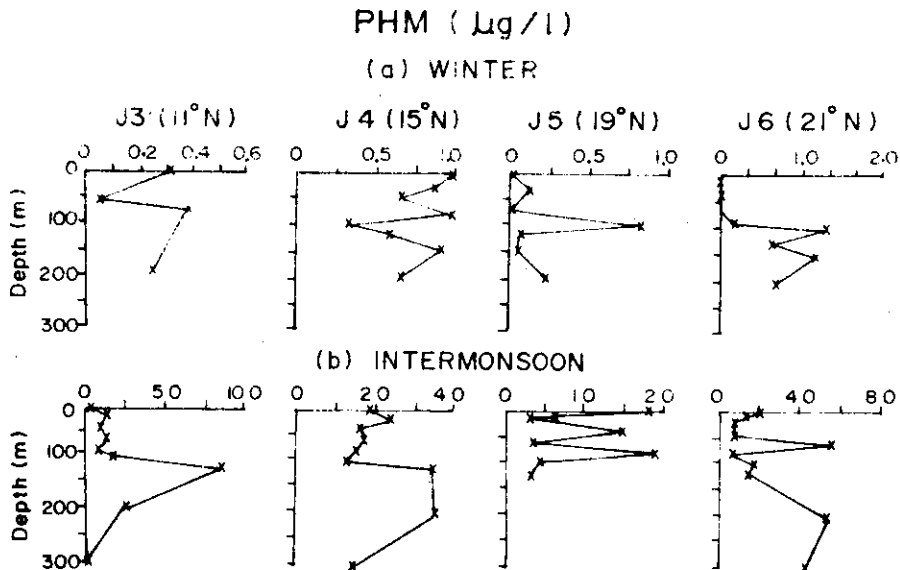


Fig. 7—Vertical profiles of PHM during (a) winter and (b) intermonsoon seasons along 64°E

winter, when we observed blooms of productivity due to winter convection. This is in excellent agreement with chemical signatures noted in Figs 5 and 6 and total and partial pressure of carbon dioxide reported by Sarma *et al.*¹⁸. Consequently, enhanced levels of PHM in the south are due to intense humification which is more pronounced during intermonsoon. This humification could be due to the aggregation of recycled refractory marine material. The high bacterial production towards the south during

intermonsoon seems to have increased microzooplankton population¹² (microbial loop). High productivity regions are expected to produce organic materials that are highly labile in nature. Hence, the PHM in Fig. 7 agrees well with the trends in bacterial and microzooplankton production. This study together with earlier studies² indicates that refractory organic material accumulates in the Arabian Sea both in dissolved and particulate forms and is related to spatial and temporal variations in biochemical conditions.

From the foregoing it may be concluded that higher primary productivity due to winter convection sustains higher POC in the coastal areas whereas lower POC is attributable to lower primary production. The PHM concentration is controlled by bacterial abundance and the labile nature of POC. The oceanic POC was sustained by higher microzooplankton and bacterial production and humification of organic carbon is related to biochemical conditions in the Arabian Sea.

Acknowledgement

Authors thank the Director, for providing facilities to carry out this work. This work was carried out under the JGOFS (India) programme funded by DOD. The facilities provided by DOD are gratefully acknowledged. This is NIO contribution no. 2593.

References

- 1 Haake B, Ittekkot V, Rixen T, Ramaswamy V, Nair R R & Curry W B, *Deep-Sea Res*, 40 (1993) 1323.
- 2 Kumar M D, Rajendran A, Somasunder K, Haake B, Jenisch, A, Shuo Z, Ittekkot V & Desai B N, *Mar Chem.*, 31 (1990) 299.
- 3 Bhosle N B, Dhople V M, Wagh A B, *Proc. Indian Acad.Sci.(Earth Planet. Sci.)*, 97 (1988) 35.
- 4 Sardessai S, *Oceanol. Acta.*, 17 (1994) 263.
- 5 Naqvi S W A, Noronha R J, Somasunder K & Sen Gupta R, *Deep-Sea Res.*, 37 (1990) 593.
- 6 Parsons T R, Maita Y & Lalli C M, *A manual of chemical and biological methods of sea water analysis* (Pergamon) 1984, 63.
- 7 Martin D F & Pierce Jr R J, *Environ. Lett.*, 1 (1971) 49.
- 8 Hair M E & Basset C R, *Estuar. Coast. Mar. Sci.*, 1 (1973) 107.
- 9 De Sousa S N, Kumar M D, Sardessai S, Sarma V V S S & Shirodkar P V, *Curr. Sci.*, 71 (1996) 847.
- 10 Bhattathiri P M A, Pant A, Sawant S, Gauns M, Matondkar G P, Mohanraj R, *Cur. Sci.*, 71 (1996) 857.
- 11 Ramaiah N S, Raghukumar S & Gauns M, *Curr. Sci.*, 71 (1996) 878.
- 12 Gauns M, Mohanraj R & Madhupratap M, *Curr. Sci.*, 71 (1996) 874.
- 13 Fuhrman J A, sleeter T D, Carlson C A & Procter L M, *Mar. Ecol. Prog. Ser.*, 57 (1989) 207.
- 14 Cho B C & Azam F, *Nature*, 332 (1988) 441.
- 15 Cho B C & Azam F, *Mar. Ecol. Prog. Ser.*, 63 (1990) 253. 16.
- 16 Rosso A L & Azam F, *Mar. Ecol. Prog. Ser.*, 41 (1987) 231.
- 17 Alldredge A L, Youngbluth M J, *Deep-Sea Res*, 32 (1985) 1445.
- 18 Sarma V V S S, Kumar M D, George M D & Rajendran A, *Curr. Sci.*, 71 (1996) 852.