

TOTAL PHOSPHORUS CONTENT IN THE WATERS OF THE ARABIAN SEA ALONG THE WEST COAST OF INDIA

by V. N. SANKARANARAYANAN and C. V. GANGADHARA REDDY, *Biological Oceanography Division, National Institute of Oceanography, Ernakulam*

(Communicated by Dr. N. K. Panikkar, F.N.I.)

(Received 14 November 1968)

Total phosphorus estimations are made on samples collected along four sections, perpendicular to the coast between Bombay and Cochin, during the 25th cruise of INS *Kistna* in March 1965. The results reveal considerable variability in the regional and depthwise distribution of the same. Higher concentrations are encountered in the upper 800 m in the northern sections (off Bombay and Karwar) than in the southern ones (off Mangalore and Cochin) while at deeper levels (> 800 m) the trend is reverse. Off Cochin greater concentrations ($> 10 \mu\text{g-at/l}$) are found below 800 m as compared with 2-4 $\mu\text{g-at/l}$ found at the same depths in the other regions. Percentage of organic phosphorus is in general very high in the surface (upper 200 m). Even at 1,000 m mineralization of organic phosphorus is not complete and at majority of the stations the composition amounted to 20-30 per cent of the total phosphorus. Distinct convergence of the waters is indicated almost all along the coast over the mid-shelf, extending towards the slope region. Probable factors governing the distribution of total phosphorus are discussed.

INTRODUCTION

The significance of the total phosphorus concentration in the sea as an index of potential fertility of waters and for identifying different water masses as tracer has been emphasized earlier (Redfield *et al.* 1937; Armstrong and Harvey 1950; Bush *et al.* 1955; Rochford 1958). While considerable information is available on inorganic phosphate content of the waters in the Arabian Sea, very little is known on the distribution of total phosphorus. Earlier studies on the total phosphorus of the west coast of India were made by Seshappa and Jayaraman (1956) and Rao (1957). The present account is based on the observations made in March 1965 during the 25th cruise of INS *Kistna* which was undertaken as part of the Indian Programme of the International Indian Ocean Expedition.

METHODS

Location of the stations from where samples of water were collected for the analysis of nutrients has been indicated in Fig. 1. The four sections, perpendicular to the coast, run approximately (1) off Bombay, (2) off Karwar,

(3) off Mangalore and (4) off Cochin. Water samples were collected in clean heavy polythene bottles and were preserved by freezing at -10°C for subsequent analysis at the shore laboratory.

Total phosphorus was estimated by the method described by Hansen and Robinson (1953), digesting the organic matter with perchloric acid. Inorganic phosphates were estimated by the method adopted by Wooster and Rakestraw (1951).

RESULTS AND DISCUSSION

The distribution of total and inorganic phosphorus along the four sections has been represented in Figs. 2-7. Detailed discussion of inorganic phosphates

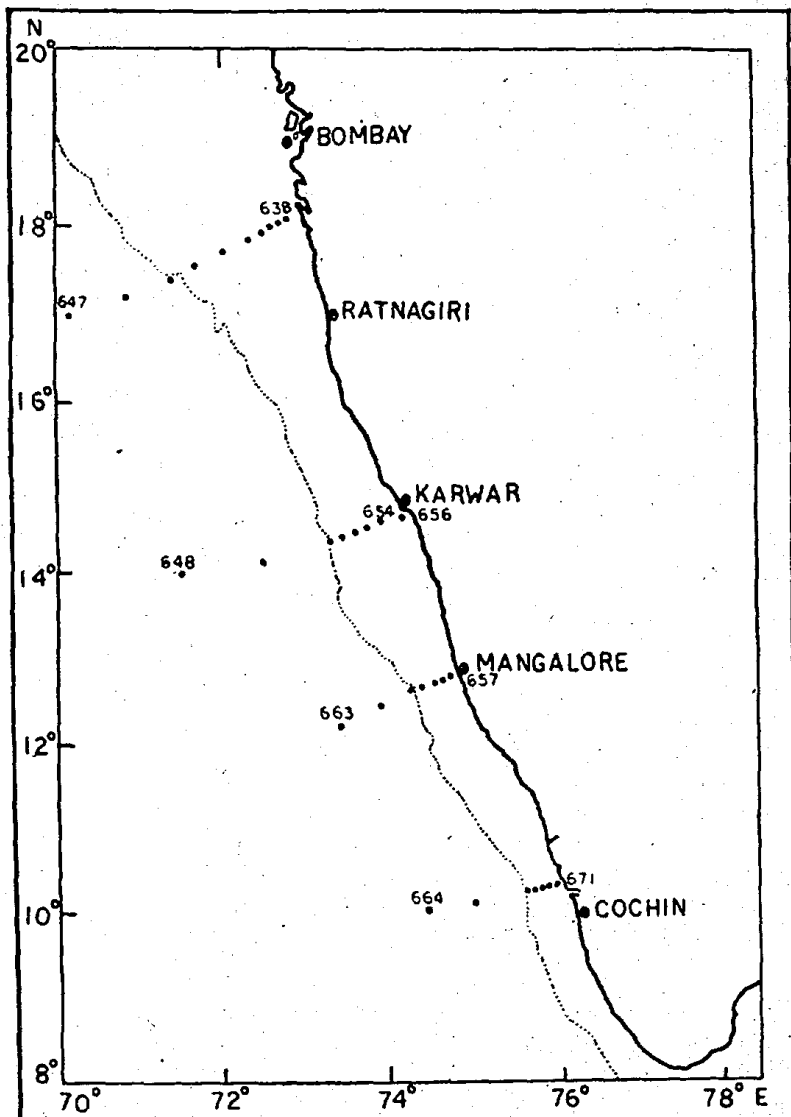


FIG. 1. Showing station locations.

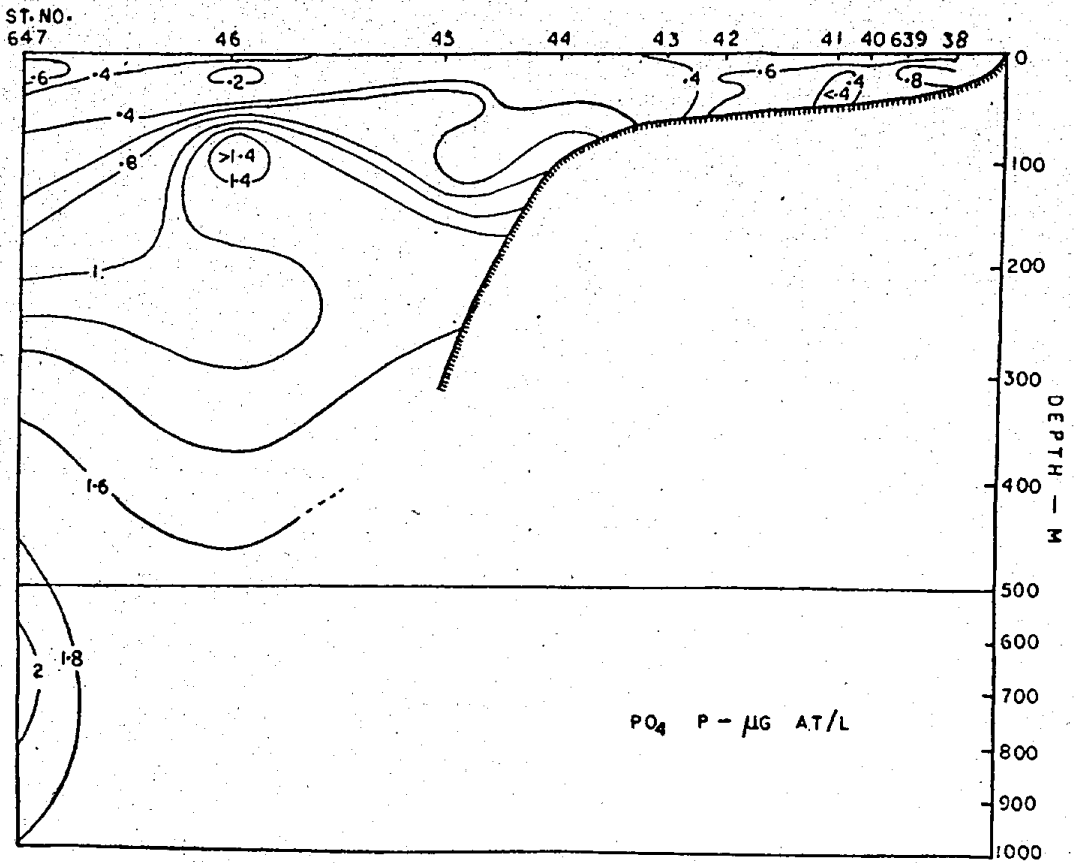


FIG. 2. Showing distribution of phosphate-phosphorus off the Bombay Coast.

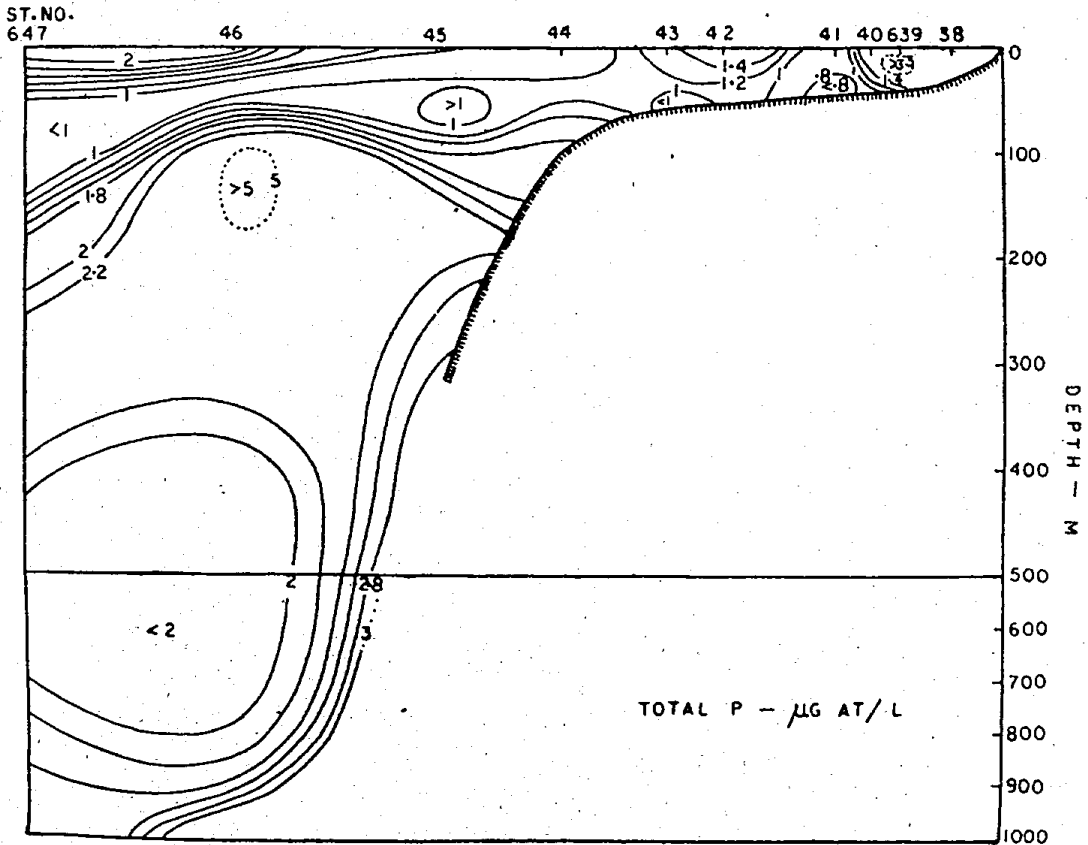


FIG. 3. Showing the distribution of total phosphorus off the Bombay Coast.

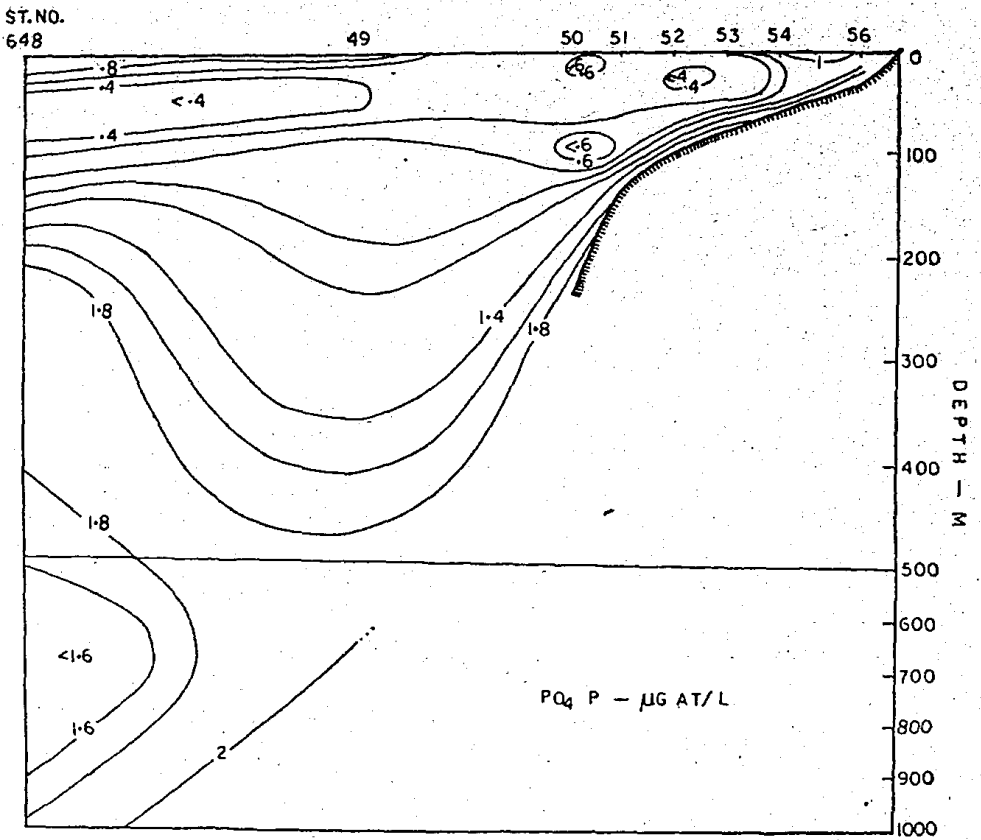


FIG. 4. Showing the distribution of phosphate-phosphorus off the Karwar Coast.

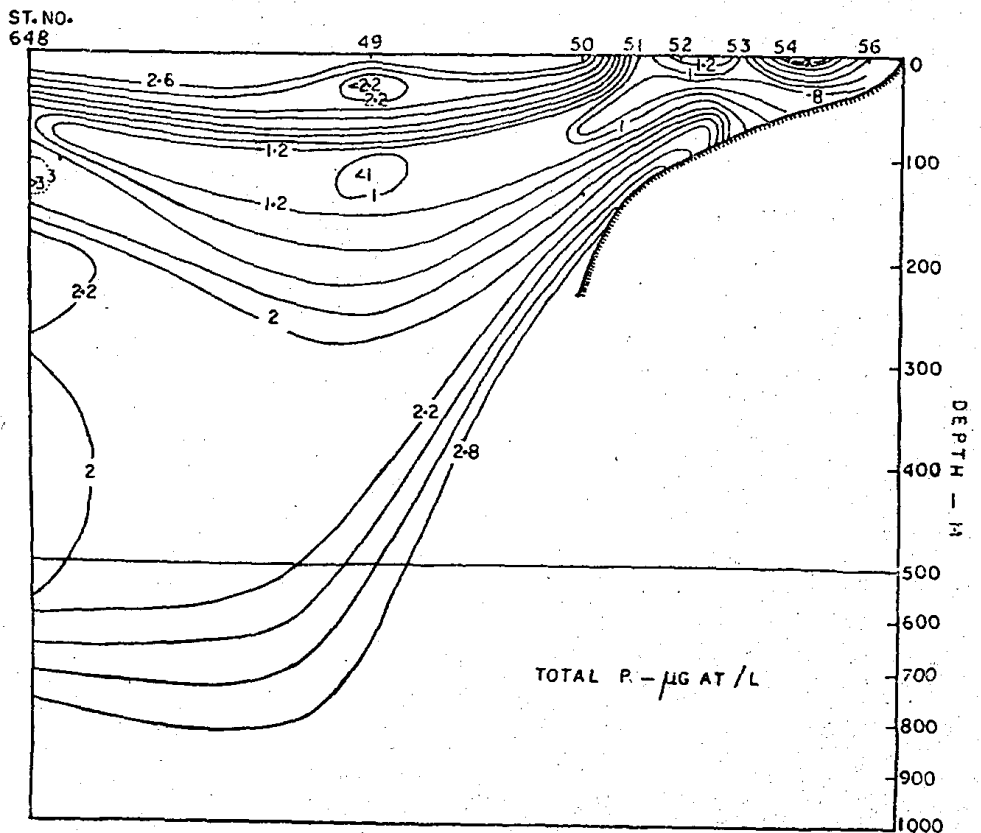


FIG. 5. Showing the distribution of total phosphorus off the Karwar Coast.

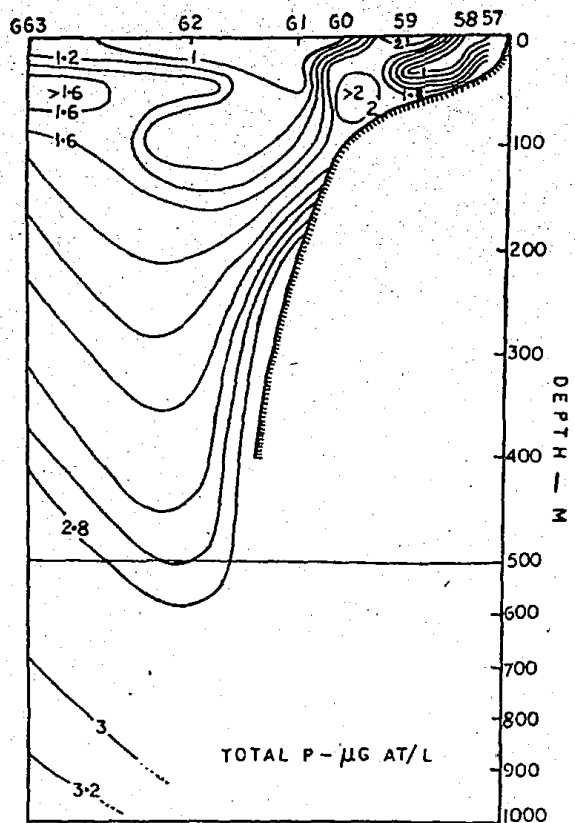
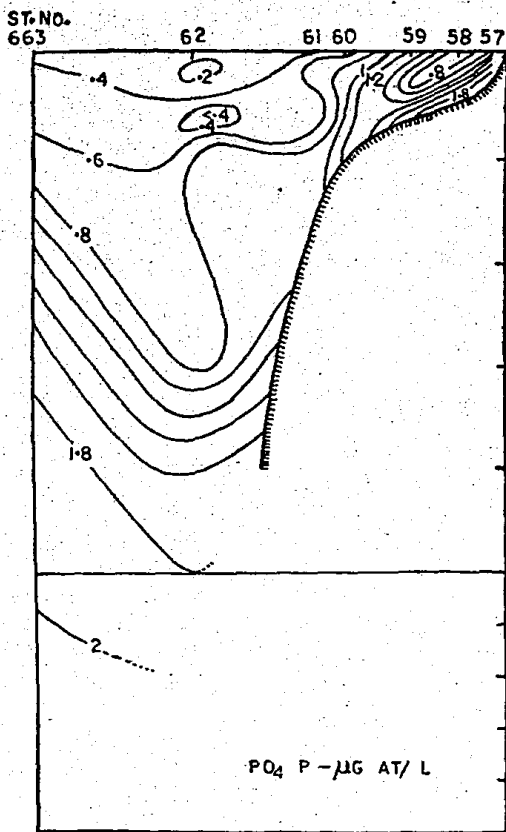


FIG. 6. Showing the distribution of phosphate-phosphorus and total phosphorus off the Mangalore Coast.

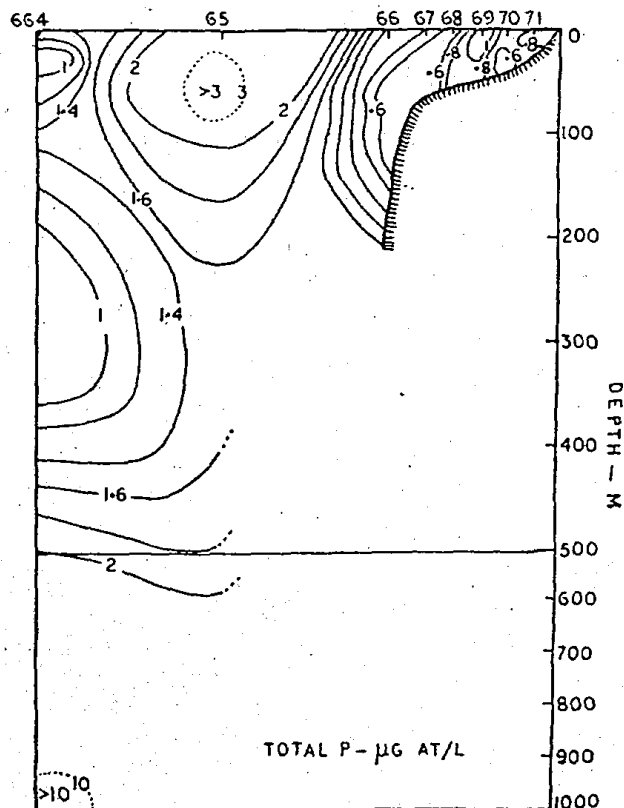
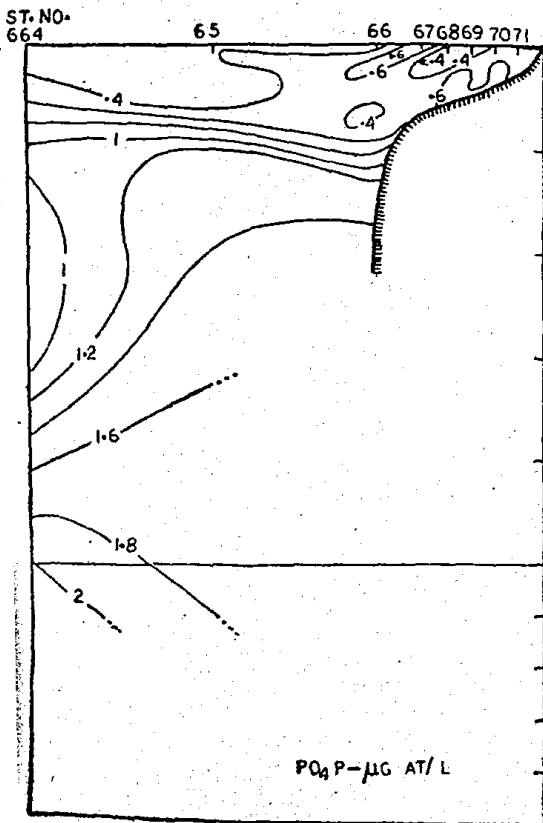


FIG. 7. Showing the distribution of phosphate-phosphorus and total phosphorus off the Kerala Coast.

will be presented along with other nutrients elsewhere. An examination of the profiles will indicate that there is a close similarity between inorganic and total phosphorus distributions in the three sections except along Cochin where similar distribution is restricted to the shelf region only. Total phosphorus values in the upper 1,000 m show wide variations. The range in the concentrations in the upper 500 m is 0.44–8.2 $\mu\text{g-at/l}$ and at deeper levels it is 1.4–16.7 $\mu\text{g-at/l}$. It may, however, be mentioned here that concentrations exceeding 6 $\mu\text{g-at/l}$ were recorded only off Cochin. Higher concentrations are normally encountered in the surface waters (upper 10 m) and in deep waters (below 500 m) with maximum in the latter. One characteristic feature in all the sections is the random cellular distribution of total phosphorus in the mixed zone (upper 100 m), containing either high or low concentrations. This feature can possibly arise due to entrapment of water bodies containing widely different concentrations of living and dead organic matter including soluble fractions during the process of mixing. This type of distribution is more pronounced in the shallow regions of the shelf.

Depthwise distribution of total phosphorus is irregular particularly in the upper 100 m and is more uniform below 500 m. Surface concentrations are generally increasing towards offshore. Clear maximum of total phosphorus is absent in the upper 1,000 m and from the available data of deeper levels (below 1,000 m) at few stations, it appears that its greater accumulation may be in between 1,000 m and 1,500 m.

Regional variation of the total phosphorus concentrations shows diverse trends. The concentrations in the upper 800 m are higher in the northern sections (off Bombay and Karwar) than those in the southern sections (off Mangalore and Cochin), but at deeper levels the trend seems to be reversed. Maximum surface concentration (4 $\mu\text{g-at/l}$) is found off Karwar in the offshore region. Off Cochin a greater concentration ($> 10 \mu\text{g-at/l}$) is found below 800 m as compared to the 2–4 $\mu\text{g-at/l}$ found at the same depths in the other regions.

In the surface waters of the offshore region generally organic phosphorus forms the major fraction of the total. Apart from some random values of very high concentrations at few depths the organic phosphorus generally tends to decrease from 100 to 1,000 m. Even at 1,000 m the inorganic phosphorus was never equivalent to that of total phosphorus and the organic phosphorus amounted to 20–30 per cent of the total phosphorus. A comparison of the average organic phosphorus values in the shelf waters of different regions will reveal that maximum levels occur around Bombay (64 per cent of the total phosphorus). Along the Cochin area, it comes next (40 per cent) and off Karwar and Mangalore the concentrations are low, about 36–37 per cent of the total phosphorus. In waters beyond the shelf the percentage of organic phosphorus tends to increase gradually towards the south and the delineation becomes fairly marked between the northern and southern sections. The

average contents of organic phosphorus in the slope waters off Bombay and Karwar are 46 and 48 per cent of total phosphorus and off Mangalore and Cochin these are 54 and 56 per cent respectively.

The foregoing account indicates considerable variation in the regional distribution of the total phosphorus and its major fractions and even in a particular section the variations in the horizontal and vertical distributions are quite significant. Contrary to the fact that total phosphorus may serve as a useful index to identify water masses in general, the present data suggest that the total phosphorus loses its true conservative nature in the shallow and productive regions (shelf and slope) of the sea. Rochford (1958) during his investigations on the East Australian water masses in relation to total phosphorus observed that, in the region of turbulence extending to the bottom, anomalies in the distribution of total phosphorus occur. The high productive nature of the shelf and slope waters along the west coast of India perhaps renders the total phosphorus more a non-conservative property due to irregular distribution of all forms of organic matter aided perhaps by the random movement of the waters. Nevertheless the distribution of total phosphorus in the present instance broadly indicates only certain very distinct water movements and the fertility of the regions.

An examination of the total phosphorus data will reveal that the waters of the upper 800 m in the northern sections (off Bombay and Karwar) have a very high concentration of total phosphorus, much of which is in the organic form. In the southern sections (off Mangalore and Cochin) on the other hand the total phosphorus concentrations are relatively low and, excepting for the inshore region, the organic phosphorus remains predominant. Another notable feature is the total phosphorus concentrations in the slope region being consistently higher than those of the shelf and very high accumulation of total phosphorus ($> 10 \mu\text{g-at/l}$) is found off Cochin at 1,000 m and below. This high accumulation of total phosphorus (organic phosphorus 80 per cent) in the slope waters below 300 m is quite significant and it appears to have a good bearing on the fertility of the region in general (McGill 1964; Ryther and Menzel 1965). The high concentrations seem to be consistent with higher productivity of the region as a result of upwelling occurring during the southwest monsoon period. The particulate organic matter produced in the surface waters seems to be sinking to deeper layers without being mineralized completely. Total mineralization may be obliterated, perhaps, by the relatively lower oxidative nature of the water column. The high total phosphorus values in the upper 800 m in the northern section might also be related to the abundance of plankton and fish generally reported to be occurring during this period suggesting the probable sources for the standing levels of high phosphorus concentrations. Moreover the shelf, which is wide and shallow in the north, permits mixing to a considerable extent, distributing

phosphorus components from the sediments over a wide area. Examination of the vertical profiles indicates distinct convergence of the surface waters from the mid-shelf region extending over to a large area towards the slope region all along the coast. This feature is also in accordance with the distribution of other hydrographical factors. A general feature noticeable in the convergence regions is the presence of cells of high total phosphorus, comprising 60-80 per cent of organic phosphorus indicating the concentration of phosphorus of planktonic or detrital origin. From the standing levels of low inorganic and high total phosphorus in the surface layers, it could be inferred that the rate of regeneration is perhaps slow at least during the period under report and much of the regeneration activity appears to be limited to deeper layers as evidenced by greater accumulation of inorganic phosphates at these levels. However, mineralization is not complete even to 1,000 m at majority of the stations indicating the presence of significant quantities of organic phosphorus, which seems to be relatively more resistant to oxidation. This feature corresponds to some extent with those of recent investigations in the Pacific (Strickland and Austin 1960) and Atlantic (McGill 1964). Former authors suggest the presence of 'microstructure' of organic phosphorus distribution: a residuum which is highly resistant to process of mineralization. However, in the present instance, the presence of relatively high proportion of organic phosphorus at some locations suggests the possibility that the entire portion may not be the microstructure, but perhaps reflects on the general physical, chemical and bacteriological conditions of the upper 1,000 m controlling the rate of regeneration. The standing oxygen levels at these deeper layers are also too low to meet the oxygen demand for complete mineralization of the organic phosphorus and it is considered that some factors including the observed sinking phenomenon of the waters might be largely responsible in aiding faster sinking rate of particulate matter through the active regeneration zone (approximately between 200 m and 500 m characterized by low percentage of organic matter, Rochford 1962). More detailed investigations on the vertical distribution of different forms of phosphorus as a function of time may throw more light on this aspect.

ACKNOWLEDGEMENTS

The authors wish to express their grateful thanks to Dr. N. K. Panikkar, Director, National Institute of Oceanography, for his guidance and encouragement and to Shri R. Jayaraman and Dr. S. Z. Qasim, Scientists, National Institute of Oceanography, for helpful discussion.

REFERENCES

- Armstrong, F. A. J., and Harvey, H. W. (1950). The cycle of phosphorus in the waters of the English Channel. *J. mar. biol. Ass. U.K.*, 29, 145-162.
- Bush, A. J., Lenczar, R. E., Murray, J. E., and Soule, F. M. (1955). International ice observation and ice patrol service in the North Atlantic Ocean Season of 1953. *Bull. U. S. Cst. Guard*, 39, 138.

- Hansen, A. L., and Robinson, R. J. (1953). The determination of organic phosphorus with perchloric acid oxidation. *J. mar. Res.*, 12, 31-42.
- McGill, D. A. (1964). The distribution of phosphorus and oxygen in the Atlantic Ocean, as observed during the I.G.Y., 1957-1958. *Progress in Oceanography*. Vol. 2. Pergamon Press, London.
- Rao, S. V. S. (1957). Preliminary observations on the total phosphorous content of the inshore waters off Calicut. *Proc. Indian Acad. Sci.*, 45, 77-85.
- Redfield, A. C., Smith, H. P., and Ketchum, B. H. (1937). The cycle of organic phosphorus in the Gulf of Maine. *Biol. Bull., mar. biol. Lab., Woods Hole*, 73, 421-423.
- Rochford, D. J. (1958). Total phosphorus as a means of identifying East Australian water masses. *Deep Sea Res.*, 5, 89-110.
- (1962). Hydrology of the Indian Ocean. II. The surface waters of the South-east Indian Ocean and Arafura Sea in the spring and summer. *Aust. J. mar. freshwat. Res.*, 13, 226-251.
- Ryther, J. H., and Menzies, D. W. (1965). On the production, composition and distribution of organic matter in Western Arabian Sea. *Deep Sea Res.*, 12, 199-209.
- Seshappa, G., and Jayaraman, R. (1956). Observations on the composition of bottom muds in relation to phosphate cycles in the waters of the Malabar Coast. *Proc. Indian Acad. Sci.*, 43, 288-301.
- Strickland, J. D. H., and Austin, K. H. (1960). Forms of phosphorus in NE Pacific waters. *J. Fish. Res. Bd Can.*, 17.
- Wooster, W. S., and Rakestraw, N. W. (1951). The estimation of dissolved phosphates in sea water. *J. mar. Res.*, 7, 49-55.