

On Nitrogen & Phosphorus in the Western Bay of Bengal

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Received 8 June 1977; revised received 17 October 1977

Nitrate, nitrite, ammonia, total nitrogen, inorganic phosphate and total phosphorus concentrations have been estimated at some stations in the Bay of Bengal. Organic nitrogen and phosphorus have been detected up to 3000 m depth. This is due to the settling of unoxidized or partially oxidized organic matter indicating that oxidation processes are only partially regulated by the supply of oxygen. Presence of only 1 oxygen minimum in the Bay of Bengal, as compared to 2 in the Northern Arabian Sea, can be related to the difference in photosynthetic production between the 2 regions. Presence of denitrification in the low oxygen layers of the Bay of Bengal leads to the suggestion that this process is present all over the Northern Indian Ocean resulting in about 40% loss in the inorganic nitrogen compounds.

SIGNIFICANT volume of chemical oceanographic data, collected during the International Indian Ocean Expedition (IIOE) during 1960-65, on the distributional aspects of oxygen and several inorganic anions, considered as essential nutrients for algal growth, have been published. During the IIOE and afterwards, observations are concentrated mostly in the Arabian Sea. Of the two arms of the Northern Indian Ocean, the Bay of Bengal constitutes an interesting area and is one of the less investigated areas of the Indian Ocean.

Some observations on nutrients, like phosphate, nitrate and silicate, from the Bay of Bengal have been reported. But no observations on the total amounts, both inorganic and organic fractions, of these nutrients are made. It is well-documented from observations elsewhere that the total quantities of nutrients give a fair approximation of potential fertility and nutrient cycles in marine areas^{1,2}. The 'preformed' or 'reserved' fraction of phosphorus has been considered a conservative property of sea water and consequently has been used to characterize different water masses³.

During a cruise of *INS Darshak* in March-April 1975 along the western part of the Bay of Bengal an attempt has been made to study the cycles of nitrogen and phosphorus and their interdependence on different water types in the area. The attempt is not to throw any new light on the characters of these nutrient salts but to try and fill a part of the gap in our knowledge about the chemistry of this interesting marine area.

Materials and Methods

Water samples were collected from standard hydrographic casts, up to a maximum depth of 3 km, using transparent TPN samplers (Hydro Bios, Kiel, FRG), at stations in Fig. 1. Temperatures were measured using reversing thermometers and oxygen, phosphate-phosphorus, nitrate-nitrogen, nitrite-nitrogen and ammonia-nitrogen were measured on board using standard analytical

methods. Portions of the samples were preserved in well-cleaned stoppered polythene bottles and analyses for salinity, total phosphorus and total nitrogen were carried out at the shore laboratory later. Total phosphorus was measured by the standard method while total nitrogen was measured according to the method of Koroleff⁴.

Results and Discussion

General hydrographic features of the area — The Bay of Bengal is an area of positive water balance. Average annual excess of precipitation over evaporation⁵ is about 1500 km³. Average annual runoff from the rivers along the east coast of India has been estimated⁶ as about 1300 km³. It can be roughly assumed that another 50% of this volume can be added by the fairly large river systems of Bangladesh and Burma. It has been calculated⁷ that with all these additions the annual dilution

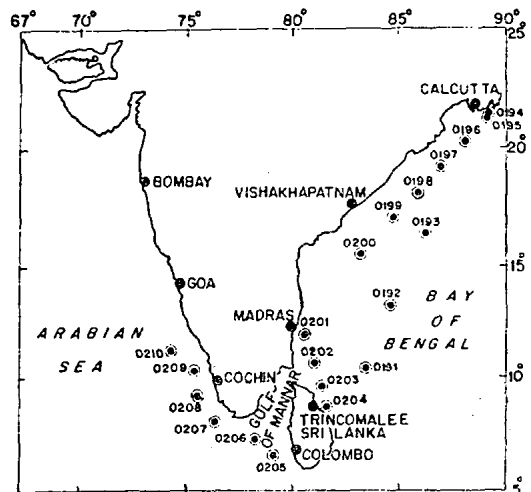


Fig. 1 — Position of stations

in the upper 25 m of the Bay is only 5.5% as it occupies an area of 2.2×10^6 km² (ref. 8).

During the SW monsoon (June-September) the prevalent wind system along the east coast of India will cause upwelling. But it is believed⁹ that this offshore drift is largely compensated by the river runoff and consequently the effect of upwelling will be weak. During the NE monsoon (October-December) the prevalent wind system cannot cause any upwelling along the Indian coast. However, upwelling may occur along the coast of Burma.

It has been suggested¹⁰ that a mixture of Red Sea and Persian Gulf waters may flow from the Arabian Sea to the Bay of Bengal going to a depth of 350-450 m as it moves northwards into the Bay. We have observed a water mass with temperatures 8.22° to 9.82°C lying between 800 and 1000 m at station 204 off Trincomalee (Fig. 1).

The rest of the water masses in the Bay of Bengal may be assumed to be the same as in the Arabian Sea, according to the classification of Ivanenko and Gubin¹¹.

Variations of nitrogen and phosphorus compounds — As the data are not sufficient to present spatial and temporal variations of nitrogen and phosphorus compounds values of all the relevant parameters depthwise from every station have been averaged and an attempt has been made to present a general picture of the variables.

Fig. 2 represents the depth profiles of nitrogen and phosphorus fractions. Total nitrogen shows a decrease from 35.1 µg-at/litre at the surface to 29.1 µg-at/litre at 25 m, whereas it is the reverse

with total phosphorus which shows an increase from 3 to 3.33 µg-at/litre between the two depths. Considerable amount of terrigenous humus (yellow substance, 'Gelbestoff') is carried to the Bay every year by the river run off. Humus-lignin is characterized by comparatively high hydrogen and nitrogen contents, probably devoid of phosphorus^{12,13}. The humic matter contains 5-10% nitrogen¹². It has been observed experimentally that between 17 and 30% of the particulate organic matter sediments at the confrontation of river water with sea water¹⁴. All these would mean that although a considerable part of the terrestrial material carried by the rivers is lost at its confluence with the sea yet its influence in the upper 25 m in the Bay of Bengal is discernible from the total nitrogen and total phosphorus concentrations. This is further evidenced (Table 1) by the high percentage of organic nitrogen at the surface which decreases at 25 m while the percentage of organic phosphorus retains more or less the values observed in normal oceanic surface water³, i.e. 2/3rd of the total phosphorus concentration. Thus the rivers opening out into the Bay of Bengal add more nitrogenous organic material than organic phosphorus.

Comparing the depth profiles of total nitrogen and total phosphorus one finds that the nature of variation in them is similar (Fig. 2) from 100 to 700 m. At 700 m total nitrogen shows a sharp decrease and maintains an almost uniform value till 1200 m below which it shows a slow increase till 3000 m. Total phosphorus, however, shows a steady decrease till 1500 m below which it maintains almost the same concentration down to 3000 m.

Depth profiles of inorganic and total nitrogen show inverse relations with each other — minimum values of the former are associated with maximum values of the latter and increase in one is associated with decrease in the other. For the phosphorus components, however, the relations are almost similar to each other. This indicates that the total phosphorus and total nitrogen concentrations are related to the availability of organic matter. Inorganic phosphate is dependent on the rate of oxidation of organic matter while inorganic nitrogen is dependent on this as well as on possible denitrification. Table 1 indicates that organic fractions of nitrogen and phosphorus constitute at least 1/3rd of their total concentrations between 1000 and 3000 m. This is not in agreement with the observations from some oceanic areas where total nitrogen and total phosphorus have been found to be almost equal to their inorganic fractions at such depths³. Photosynthetic production at the surface layers and the rate of decomposition deeper down decides the availability of organic material close to the bottom. Photosynthetic production, measured simultaneously during the cruise¹⁵, gives an average rate of 163 ± 64 mg cm⁻² day⁻¹. Oxygen concentration in the Bay of Bengal hardly exceeds 1 ml/l (89.3 µg-at/litre) between 100 and 1000 m (Fig. 3). Average rate of photosynthetic productivity in oceanic areas has been calculated as¹⁶ 137 mg cm⁻² day⁻¹. The rate in the Bay of Bengal is about 20% more. Because of the limitation in the availability of oxygen at depths decomposition appears as a slow process and

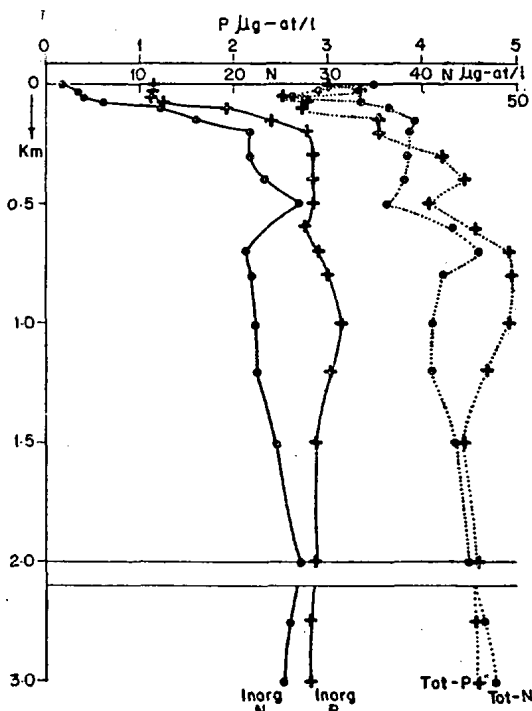


Fig. 2 — Depth-profiles of average values of total and inorganic fractions of nitrogen and phosphorus

organic matter sinks downward in undecomposed or partially decomposed state. Though oxygen concentration increases steadily below 1000 m in the presence of organic nitrogen and phosphorus indicates that here the amount of organic matter is not or only partially regulating the oxygen consumption.

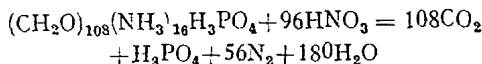
The presence of 2 oxygen minima have been identified in the eastern and northern basins of the Arabian Sea¹⁷. But in the Bay of Bengal only one pronounced layer, lying between 100 and 1000 m, with oxygen concentrations lower than 1 ml/litre could be observed (Fig. 3). Photosynthetic productivity in the above-named regions of the Arabian Sea has been observed¹⁵ to have an average value of 960 mg cm⁻² day⁻¹, which compares well with the calculated value of 820 mg cm⁻² day⁻¹ for upwelling

areas¹⁶. The first oxygen minimum in the Arabian Sea is regulated by productivity while the second one is controlled by the low oxygen contents in the North Indian Ocean Intermediate Water¹⁸. Thus it can be concluded that due to the compensatory effect of river runoff to upwelling the values for productivity in the western Bay of Bengal lie close to oceanic values though the area cannot be termed as oceanic in the real sense of the term. Further, the influence of the North Indian Ocean Intermediate Water does not appear to be very pronounced in this area resulting in one thick layer of low oxygen concentration instead of two oxygen minima as are present in the corresponding layers of the Arabian Sea.

Nitrate deficits (anomalies) and denitrification.— Deficits of nitrate and denitrification have been observed in the low-oxygenated waters of the Arabian Sea^{17,18}. Since in the Bay of Bengal similar water layers are also present it is thought that calculations of the above factors might be interesting in this area as well. In the Bay of Bengal both nitrite and ammonia have been found to be absent during these observations. It is, therefore, felt if denitrification occurs in the Bay of Bengal the process should reach its completion resulting in gaseous nitrogen.

We applied the relation as suggested by Cline and Richards¹⁹, and as applied earlier to the Arabian Sea^{17,18}, to calculate the nitrate deficits (anomalies). The depth profile of the reconstructed nitrate-anomaly, expressed as δN , is presented in Fig. 3. Waters in the Bay of Bengal appear to be deficient in inorganic nitrogen at all the depths from 25 to 3000 m. Maximum and minimum values of δN in Fig. 3 agree very well with those of inorganic nitrogen in Fig. 2. Corresponding to inorganic nitrogen maximum at 500 m and minimum at 700 m we find the reverse values for δN . This is, as expected, due to a deficit in inorganic nitrogen in sea water which can be caused only by denitrification. It can be seen in Fig. 3 that the maximum values of δN can be calculated only in layers of very low oxygen. Appearance of positive values of δN below 1500 m might be correlated with the observations made in the Northwestern Indian Ocean that the process of denitrification in intermediate waters extends as far down as 4°N latitude¹⁸.

The amount of nitrate lost by this process has been calculated. Applying the planktonic composition, $(CH_2O)_{108}(NH_3)_{16}H_3PO_4$, which has been suggested to be valid for the entire Indian Ocean¹⁸, we calculated the overall reaction for denitrification in the Bay of Bengal as



Assuming that the ratio $\Delta NO_3 : \Delta PO_4 = 9.4:5$ prevails during denitrification²⁰ and that a maximum of 14 μg -at/litre of nitrate-ion can be reduced during the process¹⁹ we calculated that 14.2 μg -at/litre of nitrate-ion is lost in the Bay of Bengal. This nitrate would have resulted in the accumulation of 2.6 μg -at/litre of ammonia¹⁹. Absence of ammonia indicates that it is oxidized, either chemically or

TABLE 1 — DEPTHWISE VARIATION OF ORGANIC FRACTIONS OF NITROGEN AND PHOSPHORUS IN WESTERN BAY OF BENGAL

Depth m	Organic-		Depth m	Organic-	
	N %	P %		N %	P %
0	95	61.2	600	45.8	39.3
25	88.3	66.1	700	53.7	41
50	85	55.7	800	48.2	39.7
75	81.8	55	1000	45.7	35.5
100	66.6	28.7	1200	45.2	35.9
150	59.5	31.9	1500	43.4	38.5
200	43.7	21.9	2000	40.1	36.7
300	43.6	32.3	2500	44.4	38.8
400	39.7	36.8	3000	47.3	38.9
500	25.6	30.2			

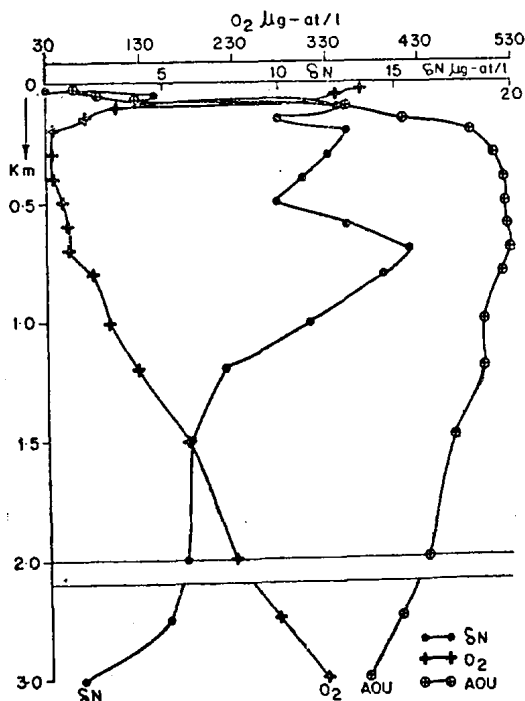


Fig. 3 — Depth-profiles of oxygen concentrations, apparent oxygen utilization (AOU) and nitrate anomalies (δN), calculated from values in Fig. 2

biochemically, to gaseous nitrogen or that it is assimilated by organisms. The average concentration of nitrate between 100 and 1200 m, which is the depth of the maximum oxygen utilization, is 21.2 $\mu\text{g-at/litre}$. This would mean that about 40% of the available nitrate has been lost due to denitrification. Applying the same relation to the values in the Northwestern Indian Ocean¹⁸ we arrive at a figure of 41% as the nitrate loss.

Thus, in the whole of the Northern Indian Ocean denitrification takes place at an intermediate layer resulting in the loss of about 40% of the available nitrate-ion.

Acknowledgement

The authors express their sincere thanks to Dr S. Z. Qasim for going through the manuscript suggesting valuable improvements; to Captain K. L. Chopra and his officers and men of *INS Darshak* and to their colleague Dr K. Radhakrishna for valued help during the shipboard work. One of the authors (R.S.G.) thanks his former colleagues at Oceanografiska Institutionen, Göteborg, Sweden, for very kindly providing the rare chemicals needed for the analyses of total nitrogen.

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