

Chemistry & Hydrography of the Andaman Sea

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Data collected during cruises 51 and 52 of *R V Gaveshani* (Jan.-Feb 1979) indicate that watermasses on the eastern and western margins of the Andaman and Nicobar Islands have similar hydrographic features to a depth of about 1500 m; deeper watermasses in the central Andaman basin are separated from the rest of the region by shallow sills and are relatively stagnant. Distribution of nutrients and nutrients-oxygen relationships indicate silicate concentrations and stoichiometric relations which are different from those reported for the Arabian Sea. Rates of denitrification (which terminates at the stage of formation of ammonia), however, appear to be uniform in the northern Indian Ocean.

The Andaman Sea is one of the least explored regions of the Indian Ocean. Very few investigations have been conducted in this area since the pioneering work of Sewell¹⁻³. Studies have, however, been carried out on some aspects of its oceanographic characteristics in recent years⁴⁻⁷. The present work is, perhaps, the first attempt towards a comprehensive study of the chemical features of the Andaman Sea.

During cruises 51 and 52 of *R V Gaveshani*, a survey was conducted on the eastern and western sides of the Andaman and the Nicobar Islands. The area covered lay between lat. 6° and 14°N and long. 91° and 94°E (Fig. 1).

Materials and Methods

Water samples were collected from standard hydrographic casts using metallic Nansen bottles and the rosette samplers of the conductivity-salinity-temperature-depth (CSTD) profiling system, up to a depth of 2500 m from different stations (Fig. 1).

Temperature, salinity, pH, dissolved oxygen, phosphate-phosphorus, nitrate-nitrogen, nitrite-nitrogen, ammonia-nitrogen and silicate-silicon were measured on board. Temperature was read off reversing thermometers, salinity, pH, dissolved oxygen and nutrients were measured using standard analytical methods⁸.

Results and Discussion

Hydrography—To study the water characteristics, vertical variations of σ_t along 2 N-S sections on the eastern (Fig. 2A) and western (Fig. 2B) sides of the islands were plotted. Both the figures show a well-mixed surface layer to about 100 m. But mixing across this layer could be seen in the figures to about 150 m. Below this layer, sharp changes in values in both the figures indicate the presence of a watermass between σ_t 26 and 27 extending to about 400 m in thickness.

Depth of the isopycnal 27.5 is at about 1350 m in both the western and the eastern sections. Below this depth σ_t increases to 27.8 at about 2500 m on the western side whereas there is hardly any change on the eastern side at corresponding depths. This indicates that the sill depth between the Bay of Bengal and the Andaman

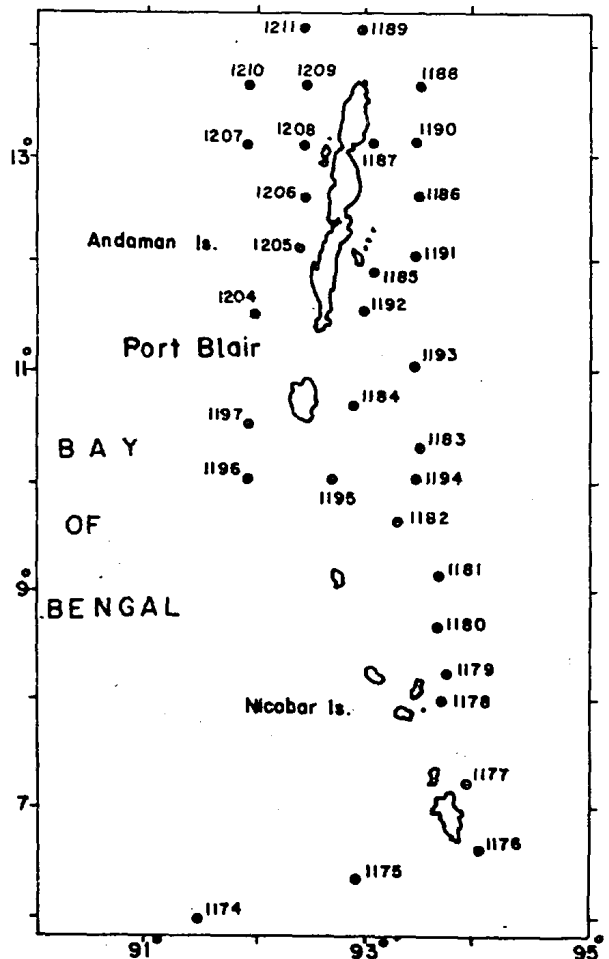


Fig. 1—Network of observation stations

Sea should lie at about 1300 m. as suggested by Ramesh Babu and Sastry⁷ and poor water exchange below this depth makes watermasses in the central region on the eastern side of the Andaman Islands relatively stagnant. Shallow sill depths at Duncan Passage, between South and Little Andamans, and at the Ten Degree Channel, between Little Andamans and Car Nicobar, also contribute to this phenomenon.

Thickness of the oxygen-minimum layer is about the same in both the transects, except the central region of the eastern section (Fig 3A and B). Oxygen values

lower than 0.2 ml/litre have been observed here, which are spread over a considerable depth. Even at the deeper layers, oxygen values are lower than those at the corresponding depths in other parts of the Andaman Sea. This indicates that the Central Basin of the Andaman Sea is cut off from its northern and southern regions by shallow sills, which result in poor water exchange and relatively stagnant water with low oxygen concentration.

It is, therefore, tentatively concluded that watermasses on the western and the eastern margins of

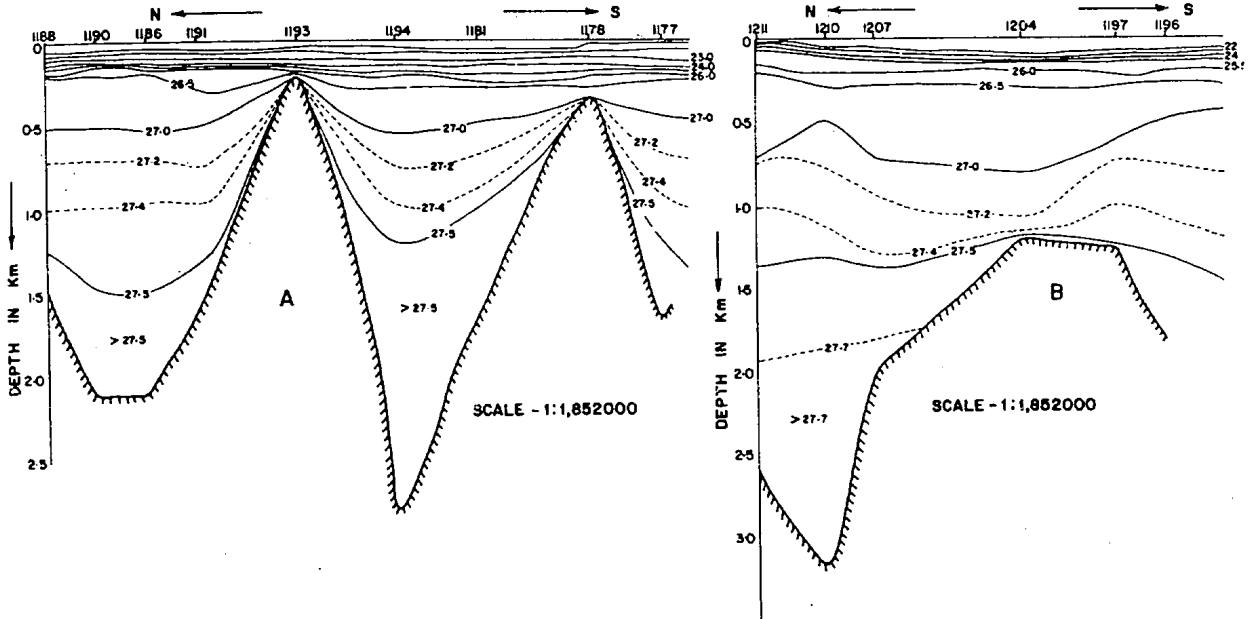


Fig. 2—Isopycnals along N-S transect east (A) and west (B) of the Andaman islands

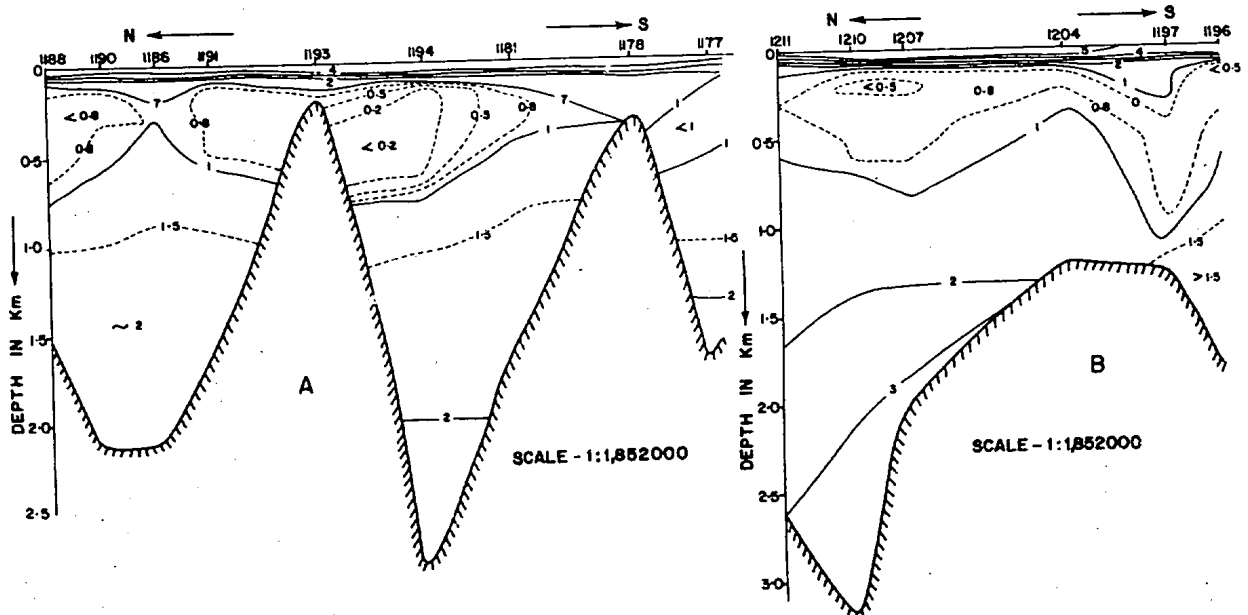


Fig. 3—Isoleths of oxygen along a N-S transect east (A), and west (B) of the Andaman Islands

Andaman and Nicobar Islands have the same characteristics to a depth of about 1500m. Water exchange between the Bay of Bengal and the Andaman Sea takes place through the Preparis Channel in a N-S direction. Deeper watermasses in the Central Andaman Sea are separated from the rest of the region by shallow sills and are relatively stagnant.

To examine the water characteristics further, silicate-density relationship at all the stations has been plotted. The watermasses from 0 to 100m have σ_t values ranging from 19.5-25 with silicate concentrations from 0 to 25 $\mu\text{g-at/litre}$. In the Arabian Sea, this range of silicate values was observed at 200m at σ_t range 22-26 (ref. 9, 10). The lower range in depth and σ_t values are presumably the effect of large river runoff with relatively higher concentrations of silicate. Watermasses from 101 to 500m have σ_t values from 25.5 to 27 with silicate from 25 to 50 $\mu\text{g-at/litre}$, which are similar to those in the Arabian Sea^{9,10}. At the depth interval 501-1000m, σ_t ranges from 27 to 27.4 with silicate range 30 to 75 $\mu\text{g-at/litre}$. The overlapping of values indicates considerable mixing between this and the overlying watermasses. Between 1000 and 1500m silicate range is 75-97.5 $\mu\text{g-at/litre}$ at σ_t range 27.3 to 27.8. This deeper layer in this region of the Bay

of Bengal has lower silicate concentration as compared to similar depths in the Arabian Sea.

Vertical distribution studies—To study the vertical variation of chemical properties in the regions of observation, 4 representative stations, viz. north (st 1211, east (st 1190), south (st 1175) and west (st 1207) were selected. Values for oxygen, phosphate-phosphorus, nitrate-nitrogen, silicate-silicon and pH at all these stations, plotted against depth, are presented in Figs. 4 and 5. The thickness of the oxygen minimum layer (< 1 ml/litre) varies from 150-600m at stations on the north, east and south of the islands with the lowest recorded at the station on the north (~0.1 ml/litre). At the station on the western side, however; the oxygen minimum layer extends from 100 to 800m which is very similar to conditions in the open Bay of Bengal¹¹.

Ranges of values for the nutrients are almost the same at all stations. However, at stations on the east and the south, a maximum each for phosphate-phosphorus and nitrate-nitrogen at an intermediate depth with almost uniform concentrations extending to the bottom are noted. A similar feature can also be observed for pH values. These indicate the stagnant nature of deeper waters at certain parts of the

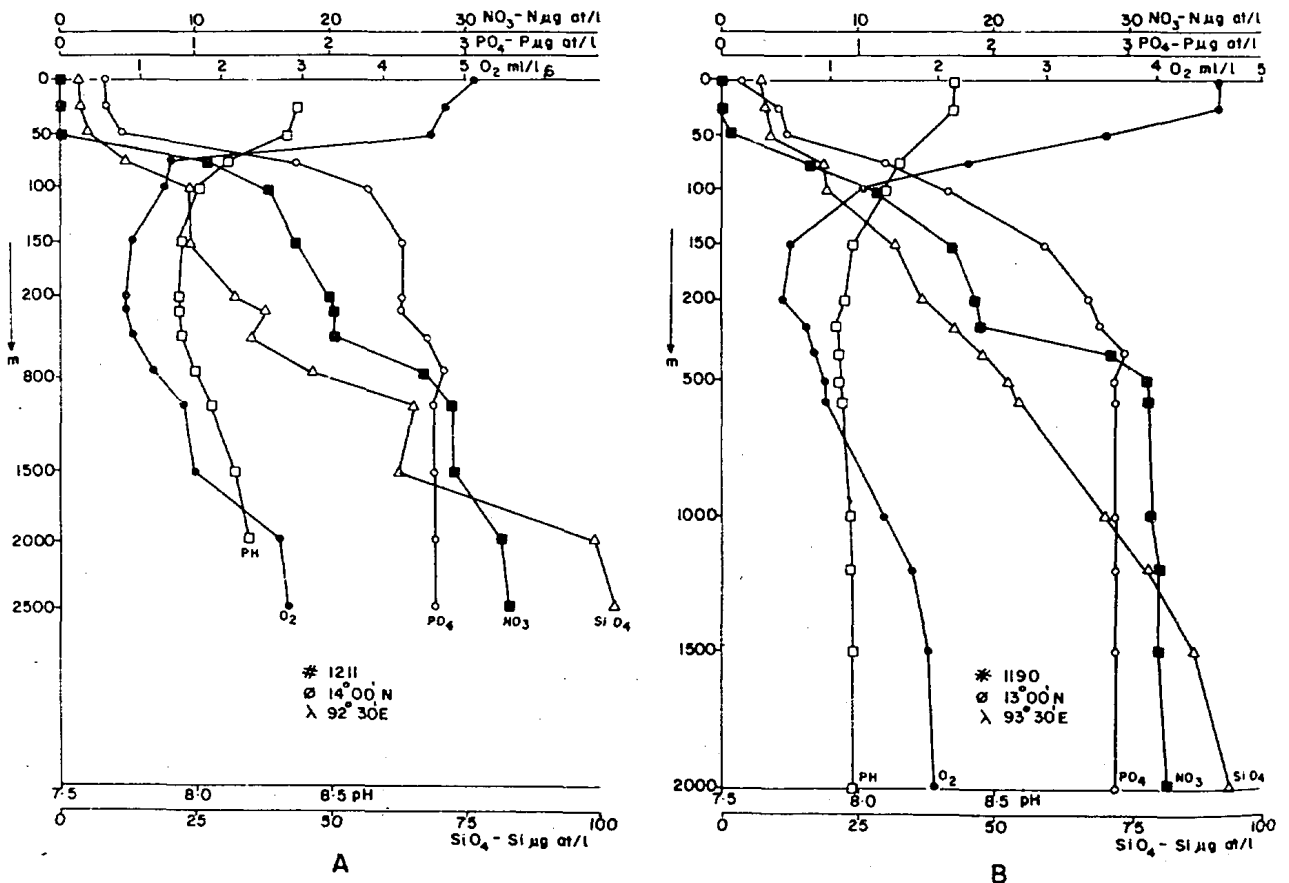


Fig. 4—Depth profiles of chemical properties at station north (A) and east (B) of Andamans

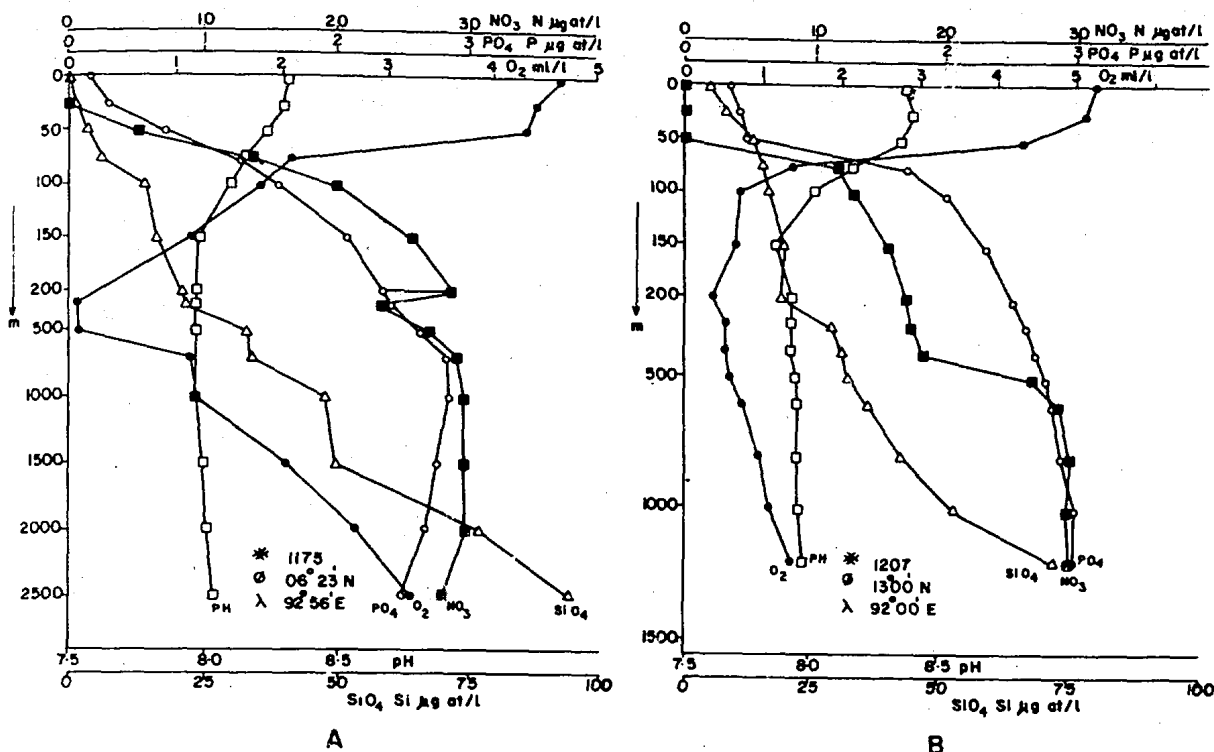


Fig. 5—Depth profiles of chemical properties at station south of Nicobar (A) and west of Andamans (B)

Andaman Sea, due to poor renewal of water over the sill depth.

The magnitudes of values for oxygen, phosphate-phosphorus and nitrate-nitrogen at these stations are relatively higher than those recorded for the corresponding depths in the Arabian Sea. The only exception is silicate-silicon which is lower in the Bay of Bengal, as a whole, than in the Arabian Sea. These indicate that the oxidation of organic matter in depths of Bay of Bengal, including the Andaman Sea, proceeds at a faster rate resulting in quick depletion of dissolved oxygen. Faster rates of oxidation and oxygen depletion result in the sinking of organic matter in undecomposed or partially decomposed state¹¹.

However, one feature appears to be common in the Figs 4 and 5. In the upper 50 m, nitrate-nitrogen is absent while some phosphate-phosphorus is still present in the water. At the stations nearer the coast, both nitrate-nitrogen and phosphate-phosphorus have been observed to be absent. This indicates that nitrate-nitrogen, in general, acts as a limiting factor for productivity in this region.

Oxygen-nutrients relationships—Examination of saturation values for oxygen reveals the different features (Table 1).

Conditions on the western side have been observed to be more or less normal for the open Bay of Bengal.

The ratios of change in the concentrations of nutrients and dissolved oxygen in water were then

Table 1—Percentage Saturation of Oxygen in Andaman Sea Waters

Area	Depth (m)	Percentage saturation (range)
West	0	-3-+15
	25	+1-+14
	50	-5-+10
East	0	-2-+8
	25	-8-+5
	50	-63-+5

calculated as described earlier^{9, 12}. For this purpose, values of AOU (apparent oxygen utilization), nitrate-nitrogen and phosphate-phosphorus, from the depth of a sharp increase of AOU to the depth of its maximum, i.e. from about 75 m to 1000 m depth, at all stations east of 91°30'E, were used for the calculations. Results obtained are $\Delta\text{AOU} : \Delta\text{P} = 252 : 1$; $\Delta\text{AOU} : \Delta\text{N} = 18 : 1$; and $\Delta\text{N} : \Delta\text{P} = 14 : 1$.

The intercept on the phosphate axis, during the calculation of nitrate-phosphate relationship, is 0.81 μg-at/litre. This phosphate concentration includes both oxidative and reserved fractions, used in the same sense as earlier¹¹, and indicates that some phosphate is left in the water when nitrate concentration approaches zero. The intercept on the phosphate axis, during the calculation of phosphate-apparent oxygen utilization relationship at 0.29 μg-at/litre indicates only the reserved fraction of phosphate as it is at zero

AOU. The balance 0.52 µg-at/litre is left at the surface when nitrate concentration approaches zero and should be of oxidative origin. This would mean that nitrate would act as a limiting factor for the production of phytoplankton in the Andaman Sea.

Silicate and oxygen utilization—From silicate concentrations of 0-150 µg-at/litre and AOU values of 25-500 µg-at/litre, the relationship between these 2 variables was deduced⁹

$$AOU = 32 + Si^2 / (0.12065 + 0.01025 Si + 0.00197 Si^2) \dots (1)$$

To test the present set of values, silicate concentrations are pooled into each 5 µg-at/litre intervals up to the concentration of 10 µg-at/litre and then into each 10 µg-at/litre intervals after calculating the averages for the corresponding AOU values. The values are fitted in Eq. 1; the results obtained are shown in Table 2.

A few zero values were observed in the surface layers at st 1206 on the western side of the Andaman Islands associated with super-saturation of dissolved oxygen. Instead of generalizing from one single set of values, we used the Eq. 1 as it is, where (AOU)₀ at 32 µg-at/litre corresponds to zero silicate, observed during ISMEX-73 (ref. 9).

Large positive differences between (AOU)_{calc.} and (AOU)_{obs.} in the upper 20 m can be noted from Table 2. This is the watermass which gets the maximum influence of river runoff. The difference in other ranges lies within the analytical and computational errors. The differences at higher concentrations of silicate agree well with the earlier observations^{9,10}. These are from samples collected at depths greater than maximum values of AOU. Below this, oxygen concentration increases steadily with much less

Table 2—Observed and Calculated Values of AOU at Different Silicate Concentrations

(Values are expressed in µg-at/litre)

Si		AOU		AOU _{calc.} - AOU _{obs.}
Range	Av.	Obs.	Calc.	
0-5	2.82	21	82	+ 61
5-10	7.23	116	208	+ 92
10-20	15.30	235	349	+114
20-30	25.24	432	422	- 10
30-40	34.51	470	454	- 16
40-50	45.16	480	475	- 5
50-60	54.13	481	486	+ 5
60-70	65.35	482	496	+ 14
70-80	75.20	463	502	+ 39
80-90	86.76	465	507	+ 42
90-100	94.88	433	510	+ 77
100-110	104.02	410	513	+103

increase in silicate characterising different water-masses. This gives an asymptotic relation between the 2 variables which has resulted in positive deviation in Table 2. The same range was obtained within 1500 m in the Arabian Sea¹⁰ while the present range is to a depth of 2500 m in the Bay of Bengal. This confirms the postulation made earlier, that silicate concentrations in the Bay of Bengal are less than those at the corresponding depths in the Arabian Sea.

Silicate-phosphate relationship—The slope of the regression line between 75 m and AOU maximum for silicate-phosphate relationship for the present set of values gives a ratio of 29:1 by atoms. In the Arabian Sea waters this ratio has been observed to vary from 36-40:1 by atoms^{9,10}. The lower value of the ratio in the present study is associated with the lower concentrations of silicate in the Bay of Bengal. There is no appreciable difference between the concentrations of phosphate-phosphorus in the 2 areas.

Biochemical relationships—Oxidative ratios have been used to deduce composition of plankton in the Arabian Sea¹² and have been applied in a generalized way to the Bay of Bengal¹¹. From a similar attempt in respect of Andaman Sea plankton, we get

$$\Delta AOU : \Delta C : \Delta Si : \Delta N : \Delta P = 252 : 98 : 29 : 14 : 1 \text{ by atoms} \dots (2)$$

From the relations given by Naqvi *et al*¹³ for the western Bay of Bengal we deduce

$$\Delta AOU : \Delta C : \Delta N : \Delta P = 260 : 105 : 12.4 : 1 \text{ by atoms} \dots (3)$$

Earlier Sen Gupta *et al*⁹ deduced the following atomic relation for the Arabian Sea

$$\Delta AOU : \Delta C : \Delta Si : \Delta N : \Delta P = 280 : 108 : 40 : 16 : 1 \dots (4)$$

which is very similar to the atomic relations in marine plankton, deduced by Fleming¹⁴

$$\Delta AOU : \Delta C : \Delta N : \Delta P = 276 : 106 : 16 : 1 \dots (5)$$

The Andaman Sea plankton atomic ratios (Eq. 2) are evidently in good agreement with those reported in the literature for other marine regions (Eqs 3-5).

Denitrification—The Arabian Sea and the Bay of Bengal have been observed to be areas where the process of denitrification takes place at an intermediate depth^{9-11,15}. This process has been identified to be at the stage of ammonia, without reaching its completion, in the Arabian Sea and at the concluding stage of gaseous nitrogen in the Bay of Bengal.

Assuming that the ratio $\Delta NO_3 : \Delta PO_4 = 94.5$ occurs during denitrification¹⁶ and that a maximum of 14 µg-at/litre of nitrate can be reduced during the process¹⁷,

it can be calculated that 13 $\mu\text{g-at/litre}$ of nitrate-ion is lost in the waters of the Andaman Sea. This amount of nitrate would have gone in the accumulation of 2.38 $\mu\text{g-at/litre}$ of ammonia¹⁷. The average concentration of ammonia between 75m and AOU maximum in this area has been 2.05 $\mu\text{g-at/litre}$ from the present set of data. This indicates that the process of denitrification in the Andaman Sea exists at the intermediate stage of ammonia without proceeding to its completion.

The average concentration of nitrate from 75m to the AOU maximum layer is 20.2 $\mu\text{g-at/litre}$ with hardly any difference between its concentrations in the waters on the eastern and western sides of the Andaman and Nicobar Islands. This would mean that about 39% of the available nitrate has been lost due to denitrification.

In other areas of the Bay of Bengal values of 40%¹¹, ranging from 30 to 40% at the depth interval 100-800m¹³ have been reported. In the Arabian Sea, denitrification ranges from 40-45%¹⁰. Thus, the rate of denitrification in the Andaman Sea is in good agreement with similar rates for other regions of the northern Indian Ocean.

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