

## Relationship Between Nutrients & Dissolved Oxygen with Special Reference to Water Masses in Western Bay of Bengal

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Received 11 November 1977; revised received 18 January 1978

Interrelationship between the apparent oxygen utilization and changes of nitrate-nitrogen and phosphate-phosphorus in the Western Bay of Bengal has been studied using the data collected during the cruises of *RV Gaveshani* from August to September 1976. The atomic ratios obtained are:  $\Delta\text{AOU}:\text{AN}:\Delta\text{P} = 260:12.4:1$ . Nitrate values show deficit ranging from 30 to 40% in the depth range 100-800 m. This is in conformity with the earlier work and suggests that denitrification takes place in this region at intermediate depths. The reserved fraction of dissolved phosphorus ( $P_r$ ), in association with  $\sigma_t$ , is used for the classification of various water masses in the south-western Bay of Bengal. The various waters thus classified are (i) Indian Equatorial Water lying below 150-200 m; (ii) A mixture of Persian Gulf and Red Sea waters lying between 350 and 550 m and having low  $P_r$ ; and (iii) North Indian Deep water lying below 1000 m characterized by high  $P_r$  and oxygen.

THE Arabian Sea and the Bay of Bengal form the 2 arms of the northern Indian Ocean. But, whereas the former has been studied in considerable detail, the latter still remains as one of the least studied areas of the Indian Ocean. Even the data collected during the International Indian Ocean Expedition are largely used to study the distribution of nutrients only. The interrelationship between the dissolved oxygen and nutrients has not been studied so far in detail. In the past, attempts have been made to identify various subsurface water masses in this region based on temperature and salinity data<sup>1-4</sup>. Existence of Persian Gulf and Red Sea waters has been reported by Rochford<sup>2</sup> and Varadachari *et al.*<sup>3</sup>. However, a certain amount of uncertainty exists over the occurrence and distribution of these water masses in this region. Therefore, an attempt has been made here to identify the water masses using the relationship between reserved phosphate and sigma-t for this purpose. A similar approach has been found to be useful for other areas of the Oceans also especially when the temperature-salinity relationships of the different water masses are more or less similar<sup>5,6</sup>.

### Materials and Methods

Samples were collected during 7th to 9th cruises of *RV Gaveshani* (August-September 1976). Station locations are given in Fig. 1. Nansen bottles and transparent water samplers (Type Hydrobios, Kiel, West Germany) were used for the collection of samples. Temperature was measured using deep-sea reversing thermometers. Inorganic phosphate was estimated by the method of Murphy and Riley<sup>7</sup> and nitrate by the reduction method of Morris and Riley<sup>8</sup> as modified by Grasshoff<sup>9</sup>. Dissolved oxygen was determined by the Winkler method as modified by Carrit and Carpenter<sup>10</sup>. All the analyses were made on board the ship immediately after the

collection. Salinity was determined from the samples brought to the shore laboratory using Mohr-Knudsen titration technique.

### Results and Discussion

*Oxidative ratios* — To study the relationship between apparent oxygen utilization (ACU) and nitrate-

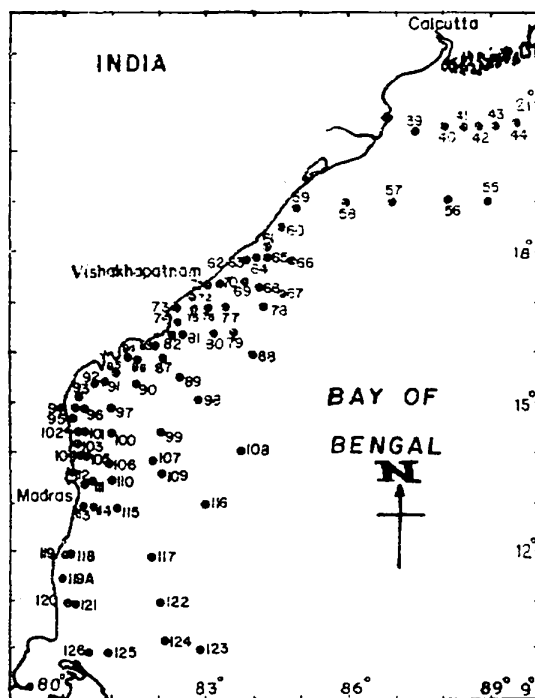


Fig. 1 — Station locations

nitrogen and phosphate-phosphorus, oxygen saturation values were determined from the oxygen solubility nomogram of Green and Carritt<sup>11</sup>. Observed oxygen concentrations were then numerically subtracted from these values to get the apparent oxygen utilization. The study was restricted to the depth from where there is a steep increase in AOU to a depth where AOU is maximum. This depth range was selected following the accepted ideas about the oxidation of organic matter in the Oceans<sup>12</sup>. In the Bay of Bengal, it was found to be within 75 to 800 m. The apparent oxygen utilization was plotted against the corresponding phosphate values pooled together for all the stations and the slope of the regression line was 260 and coefficient of correlation ( $r$ ) was 0.92 (Fig. 2). Similarly, nitrate-nitrogen was plotted against phosphate-phosphorus, and the slope of the regression line was 12.4 and  $r$  was 0.8 (Fig. 3).

Using these two the consolidated atomic ratio may be given as

$$\Delta\text{AOU} : \Delta\text{N} : \Delta\text{P} = 260 : 12.4 : 1 \quad \dots(1)$$

When nitrate-nitrogen was plotted against phosphate-phosphorus it is seen that there is always some phosphate present even at zero nitrate concentration (Fig. 3). It may, therefore, be inferred that, as in the Arabian Sea, nitrate is the limiting factor for primary production in Bay of Bengal also.

$\Delta\text{AOU} : \Delta\text{P}$  ratio obtained in the present work is close to the theoretical value of 276: 1 by atoms<sup>12</sup>. The low  $\Delta\text{N} : \Delta\text{P}$  ratio may be due to slow rate of nitrate regeneration and/or the process of denitrification which has been reported to take place in this region at intermediate depths<sup>13</sup>. An attempt has been made to estimate the amount of nitrate which appears to have been lost at various depth intervals as a result of this process. Following the procedure adopted by Cline and Richards<sup>14</sup> nitrate anomalies have been calculated using the following equation:

$$\delta\text{N}(\text{NO}_3)_{\text{exp}} - (\text{NO}_3)_{\text{obs}} \quad \dots(2)$$

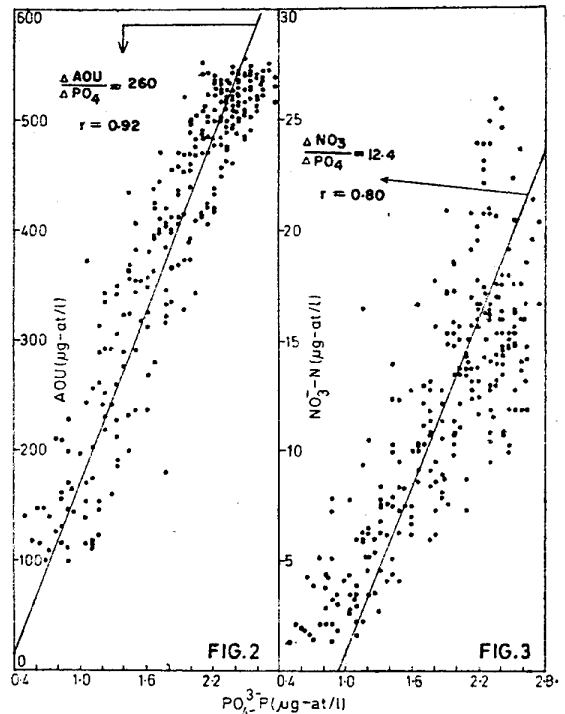
where  $(\text{NO}_3)_{\text{exp}}$  is the nitrate concentration expected before the onset of denitrification. Nitrite and ammonia have not been taken into consideration owing to their very low concentrations. The 1st term in the above equation is given by:

$$(\text{NO}_3)_{\text{exp}} = (\text{NO}_3)_{\text{ox}} \pm (\text{NO}_3)_r \quad \dots(3)$$

where  $(\text{NO}_3)_{\text{ox}}$  and  $(\text{NO}_3)_r$  are the oxidative and reserved fractions respectively. The relationship between  $N_r$  and  $P_r$  has been studied by several authors<sup>14-16</sup>. It has been found that the slope of the regression line does not vary significantly. Assuming that the value 12.2 reported by Sen Gupta *et al.*<sup>16</sup> for Arabian Sea is applicable to Bay of Bengal also and using the intercepts of AOU- $\text{NO}_3$  and AOU- $\text{PO}_4$  regression lines, we arrived at the following equation:

$$N_r = 12.2 P_r - 9.4 \quad \dots(4)$$

Values of  $N_r$  calculated using eq. (4) and those of  $N_{\text{ox}}$  using oxidative ratio have been substituted in eq. (3) to calculate  $(\text{NO}_3)_{\text{exp}}$ .  $\delta\text{N}$  was then combined with  $(\text{NO}_3)_{\text{exp}}$  to get the percentage fraction of the nitrate lost. The nitrate loss in the depth range studied varied from 30 to 40% — the minimum values obtained from 301 to 400 m and the maximum



Figs. 2 and 3 — Correlation between apparent oxygen utilization and phosphate-phosphorus (2) and between phosphate-phosphorus and nitrate-nitrogen (3)

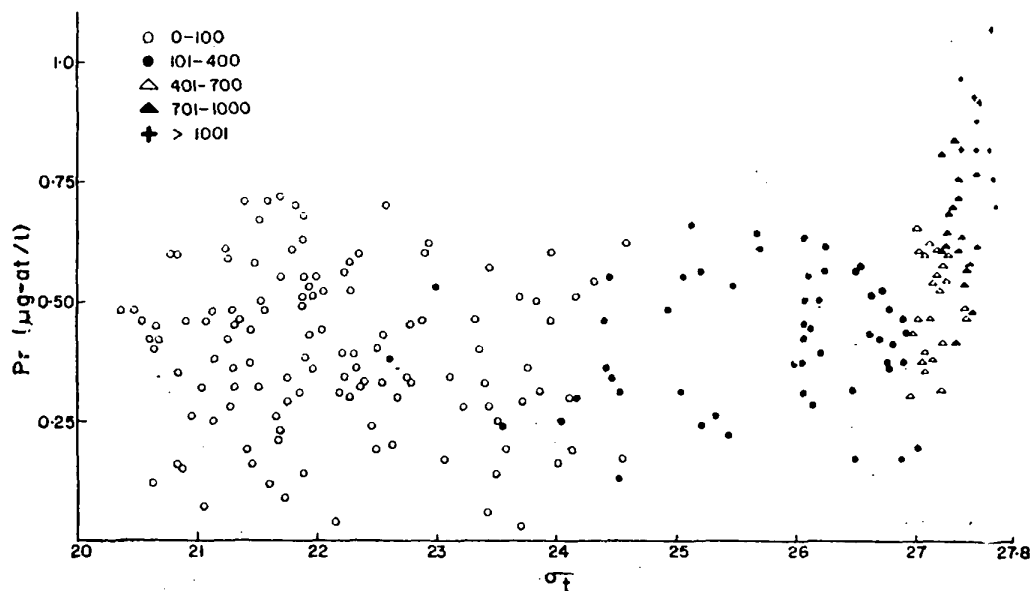
values from 401 to 500 m depth intervals. These are the depth ranges where intermediate oxygen maximum and second oxygen minimum are observed respectively in south-western Bay of Bengal resulting in a decrease or an increase in the degree of denitrification accordingly. The average value (36%) obtained for 100-800 m depth range is close to 40% reported by Sen Gupta *et al.*<sup>13</sup> for 100-1200 m depth range.

In the depth range studied, nitrite was almost absent. It was detectable only in the surface layers above the thermocline which may be the result of nitrification process. Absence of nitrite and low concentrations of ammonia (<2 µg at/litre) in the intermediate layers suggest that the reduction process is almost complete probably resulting in the release of gaseous nitrogen as suggested by Sen Gupta *et al.*<sup>13</sup>.

**$P_r$ - $\sigma_t$  relationship** — The oxidative fraction of the dissolved phosphorus ( $P_{\text{ox}}$ ) was calculated dividing the AOU by 260. This fraction was subtracted from inorganic phosphate to get the reserved fraction ( $P_r$ ).

$$\text{Thus } P_r = (\text{PO}_4^{3-} - \text{P}) - P_{\text{ox}} = (\text{PO}_4^{3-} - \text{P}) - \frac{\text{AOU}}{260}$$

This fraction was then plotted against  $\sigma_t$  for all the stations south of 16°N (Fig. 4). For the upper 100 m or so there is much scattering of the points. However, in the  $\sigma_t$  range of 21-22, high  $P_r$  values can be noticed. This  $\sigma_t$  range corresponds to the


 Fig. 4 — Relationship between reserved phosphate ( $P_r$ ) and  $\sigma_t$ 

South Bay of Bengal water characterized by high phosphate. Low AOU values result in high  $P_r$  values. In the Bay of Bengal, the predominant subsurface water mass is the Indian Ocean Equatorial water. This water mass occurs below  $24 \sigma_t$  and is found at a depth greater than  $100-150 \text{ m}^{14}$ .  $P_r$  values for this water mass have been found to vary between 0.25 and 0.65. Between 26.6 and 27.1  $\sigma_t$ , the points tend to cluster around low  $P_r$  values ranging from 0.25 to 0.55. A close look at the depths corresponding to these values indicates that the minimum values of  $P_r$  correspond to the depth range 350-550 m. We feel that at these depths there is a mixture of Persian Gulf and Red Sea waters entering the Bay at characteristic density levels as suggested by Rochford<sup>2</sup> and having very low  $P_r$ . Only one salinity maximum could be observed at these depths at most of the stations. Above 27.4  $\sigma_t$ ,  $P_r$  rises sharply and this may be associated with the deep water mass which originates in the Antarctic region and has been named North Indian Deep Water by Ivanekov and Gubin<sup>17</sup>. This water mass is found below 1000 m and is characterized by high oxygen and  $P_r$  because of high values of these parameters at the source.

#### Acknowledgement

The authors express their grateful thanks to Dr S. Z. Qasim, Director, for the encouragements and keen interest in the present work. They acknowledge

the help rendered by Dr R. Sen Gupta, Scientist, throughout the study.

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