

# DISTRIBUTION OF TOTAL PHOSPHORUS IN THE BAY OF BENGAL

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Data on total phosphorus incorporated in this paper deals with values obtained in the inshore waters of Bay of Bengal off the coast of Waltair for a period of two years (1961 to 1962) and also from the different regions of the Bay of Bengal obtained during March-April 1963 on board R. V. Anton Bruun in the International Indian Ocean Expedition. Surface average values of total phosphorus exhibit a seasonal variation from high values of 3.4  $\mu\text{g. at/l}$  (July 1961) and 3.02  $\mu\text{g. at/l}$  (June 1962) to low values of 0.99  $\mu\text{g. at/l}$  (April 1961) and 1.66  $\mu\text{g. at/l}$  (April 1962). Low values occur also in the October-December period. Total phosphorus values are high preceding the primary phyto-plankton bloom during March-April but decrease with the increase of standing crop and vice versa. High values of total phosphorus during the summer months (May-July) coincide with low values of inorganic phosphate on this coast. Average values in the surface water of the different regions of the Bay of Bengal reveal only a slight variation during March-April 1963 and show a tendency to increase in a south to north direction from the Nicobar sea towards the head of the Bay. The vertical distribution reveals that the total phosphorus content is generally low in surface water and increases with depth up to 500 meters after which the values decrease. Total phosphorus varies almost by a factor of 3 in the vertical distribution.

## INTRODUCTION

A study of the total phosphorus in the sea would help us to distinguish different water masses. There is also evidence that the total phosphorus content bears a relation to the productivity and general fertility of the waters. Hence it is expected that the mean concentration of the total phosphorus in the water column denotes the potential fertility of the water occupying any area of the sea, its changing concentrations providing a measure of changes from month to month and year to year in the supply of nutrient to the phytoplankton.

There is available considerable amount of literature on the distribution of total phosphorus and its significance in the different water masses of the world such as Kalle (1935, 1937) and Numann (1941 *cited by* Armstrong and Harvey 1950), Kedfield, Smith and Ketchum (1950), Ketchum, Corwin and Keen (1955), Rochford (1958), Takeda (1957) and Wardani (1960).

Sooryanarayana Rao (1957) pointed out that the total phosphorus values on the Malabar coast are high ranging from 1.2  $\mu\text{g. at/l}$  to 9.5  $\mu\text{g. at/l}$ . He compared these with the low values of 0.5—0.9  $\mu\text{g. at/l}$  in the Gulf of Mannar and Palk Bay on the East Coast of India. Jayaraman and Seshappa (1958) conducted analyses

of surface samples of the coastal waters collected during 1952-53 from 84 stations in the periods July-August (South West monsoon period) and in January-February (North East monsoon period) between latitudes  $8^{\circ}$ — $22^{\circ}$ N both on the East and West Coasts of India. They observed that the total phosphorus values were more than 3 times or sometimes nearly 40 times those of the values given by Armstrong and Harvey (1950) for the Western English Channel. Higher values of total phosphorus on the West Coast of India were found when compared with the East Coast in both the periods of observation.

#### MATERIAL AND METHODS

Sea water samples for routine work were collected from the surface once in ten days from January 1961 to December 1962 from a station (Fig. 1) located about

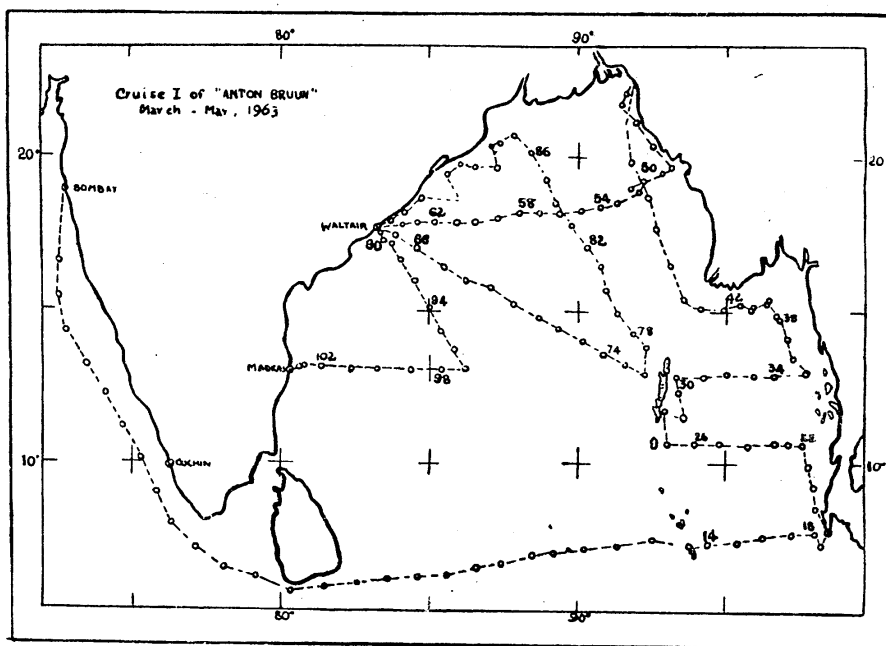


FIG. 1

5 km off the coast of Visakhapatnam opposite the entrance channel. The depth at this station was about 46 m.

A clean polythene bucket was lowered from the boat with the help of a cotton rope. The bucket was rinsed twice with the sea water sample and a bucketful of surface sea water was collected. The sea water sample was immediately dispensed into a 5 litre polythene carboy provided with a screw cap and the sample was preserved with Chloroform. Normally the samples were collected between 0730 and 0800 hrs and brought back to the laboratory for immediate analysis.

Sea water samples from different depths were collected by Nansenbottles coated on the inside by teflon. Two 75 ml samples were dispensed into 100 ml polythene bottles. Of these two samples, one was filtered through a millipore filter (for the estimation of the particulate organic phosphorus) and the other, sample unfiltered. Both the samples were preserved by freezing them at 15°C and were analysed later on a Unicam Sp. 600 Spectrophotometer. The total phosphorus content was estimated by the perchloric acid method described by Hansen and Robinson (1953), with the modifications suggested by Strickland and Parsons (1960).

SEASONAL VARIATION OF THE MONTHLY AVERAGE TOTAL PHOSPHORUS  
VALUES IN THE SURFACE WATER OFF THE COAST OF WALTAIR  
During 1961 and 1962

The monthly average total phosphorus content in the surface waters off the coast of Waltair during the years 1961 varied from 3.4  $\mu\text{g. at/l}$  in July to 0.71  $\mu\text{g. at/l}$  in December, thus showing a range of 2.69  $\mu\text{g. at/l}$ . The average value for the year was 1.7  $\mu\text{g. at/l}$ .

The total phosphorus value increased from January to February and decreased from February through April. From April to May there was a sharp rise in the values from 0.99  $\mu\text{g. at/l}$  to 2.94  $\mu\text{g. at/l}$ . During the months of May, June and July the values remained high and the peak value for total phosphorus for 1961 was attained in the month of July. From July to August the total phosphorus concentration showed nearly 50% decrease and thereafter a gradual fall was noticed through October. During November the value increased by a small quantity and then decreased slightly to touch the lowest value of 0.71  $\mu\text{g. at/l}$  in December. Thus the total phosphorus values exhibited a double oscillation during the course of a year.

During the year 1962 a gradual fall in the values was noticed from January till March, in which month the lowest concentration for this period was observed. Thus the lowest concentration for the January-April period was reached a month earlier than in 1961. In 1961 the total phosphorus content showed a considerable fall of 1.45  $\mu\text{g. at/l}$  from February to April, whereas the decrease was only 0.55  $\mu\text{g. at/l}$  for the same period during 1962. In both the years the trend in the variation from May to July was similar, showing high total phosphorus values and registering the maximum content for the year. The total phosphorus values declined from August to October in both the years. But the behaviour of the total phosphorus was slightly different between November and December. The values rose slightly by 0.6  $\mu\text{g. at/l}$  from November to December in 1962 whereas they were seen to fall by a similar value during 1961.

The trend in variation and the magnitude of concentration of total phosphorus were in general identical in both 1961 and 1962, exhibiting high concentrations during summer months (May-July) when the inorganic phosphate values remained rather low. It is of interest to note that the average total phosphorus

content for an year showed little variation in 1961 and 1962, though the range in variation during 1962 was higher than in 1961. Armstrong and Harvey (1950) and Ketchum *et al.* (1955) have pointed out that total phosphorus is a more conservative property than inorganic phosphate and the integral mean concentration in the water column is not subject to great seasonal changes.

The only year-round data available from the surface waters on the Indian Coast for comparison with the present observation come from Sooryanarayan Rao (1957) for the West Coast of India. In general, the total phosphorus content in the surface water of the West Coast is higher than on the East Coast. The monthly average values for the West Coast showed a variation from 1.5  $\mu\text{g. at/l}$  in June to 9.46  $\mu\text{g. at/l}$  in August. High values of about 6.0  $\mu\text{g. at/l}$  are noticed during January-March and July-October. High values of the total phosphorus coincide with high inorganic phosphate values during the South-west monsoon period on the West Coast whereas on this coast the relationship between total and inorganic phosphate in this season is inverse. On the West Coast of India during the South-west monsoon period surface waters are very rich in organic phosphate content because of the agitation of the water column and the release of phosphate from the bottom muds. The inorganic fraction of the total phosphorus during this period rises to about 30% on the average whereas during the pre and post-South-west monsoon period i.e. January-March and October-December respectively, the percentage of inorganic phosphate in total stands low at 10% off Malabar Coast. But off Waltair no enrichment of the surface waters by inorganic phosphate seems to take place during the South-west monsoon period and as such the inorganic phosphate values remain very low and it forms on the average only 10% of the total phosphorus. The high total phosphorus values in this period are due to large quantity of dissolved organic phosphorus compounds which constitute 80%—90% of the total phosphorus. On the East Coast high plankton productivity occurs during the March-April period, and the organic phosphorus compounds released into the water as a result of death and decay of the plankton population accumulate in the water during May-July period. But on the West Coast, the phytoplankton peak production has been shown to occur during the South-west monsoon period of June to August and as such the organic phosphorus compounds are seen to accumulate in the water there during the months of October-December.

Thus it may be pointed out that on the Waltair coast, the high total phosphorus values during the South-west monsoon period are due to high dissolved organic fraction about 90%, with only 10% of inorganic fraction whereas on the West Coast inorganic phosphate constitutes up to 30%. The low values of total phosphorus during January to April and September-December may be attributed to the utilisation of the inorganic phosphate by the phytoplankton population which is observed to reach major and minor peaks during these periods respectively.

The percentage composition of the inorganic phosphate in total phosphorus shows a seasonal variation. The percentage increases from, January (35) to April (71.8). During the months of May, June and July the values remain low between 8-15% and again increase to 37% in August. From August to November the values

fall from 37% to 10%. In December the values again registered a rise up to 32%. Thus it is of interest to note that on this coast the inorganic fraction which is mostly needed for phytoplankton production does not go beyond 40% of the total except during the period of March-April when it reaches 70% as a result of upwelling. In other words, much of the phosphorus in the surface water is in a dissolved organic state throughout the year.

The relationship between total phosphorus variation and phytoplankton production on this coast, reveals that the total phosphorus content of the surface water decreases with the increase of the standing crop of phytoplankton and vice versa. This observation agrees with the relationship obtained between the total phosphorus and the phytoplankton reported from the surface waters in the Pacific off the Eastern shore of Northern Honshu (Takeda 1957). But observation on the West Coast of India reveals a direct relationship between total phosphorus and phytoplankton, both during the South-west monsoon and post-monsoon periods.

#### DISTRIBUTION OF TOTAL PHOSPHORUS IN THE VARIOUS REGIONS OF THE BAY OF BENGAL DURING MARCH-APRIL 1963 (TABLE I)

##### *Nicobar sea:*

In the Nicobar sea, the surface total phosphorus values showed a gradual decrease towards the Thai Coast. The surface concentration in general is low and increases with depth. The increase in the first 100 meters is nearly twice and thereafter the values showed a gradual increase with depth. The highest values are observed at 500 meters at some stations and at 1000 meters at others. But at the shallow stations in this region total phosphorus is seen to attain the maximum value at 50 meter level.

Total phosphorus concentrations in the surface water of this area varies from 1.38  $\mu\text{g. at/l}$  to 0.35  $\mu\text{g. at/l}$ , thus showing a range of 1.03  $\mu\text{g. at/l}$ . The highest concentration encountered is 3.33  $\mu\text{g. at/l}$  at a depth of 50 meters at a shallow station (19). But in the deep waters, the maximum total phosphorus observed is 2.91  $\mu\text{g. at/l}$  at 500 meters at station 25.

It may be pointed out that the total phosphorus shows a distribution parallel to that of inorganic phosphate, being lower at the surface and increase with depth. The only exception to this trend is noticed below 500 meters at the stations where inorganic phosphate shows a slow increase and decrease of the total phosphorus. This may be due to reduction of organic phosphorus.

##### *Andaman sea:*

The total phosphorus shows little variation in the surface water of this area, the values ranging from 0.69  $\mu\text{g. at/l}$  to 0.46  $\mu\text{g. at/l}$ . The average surface concentration of total phosphorus also is low and is about 0.58  $\mu\text{g. at/l}$ , thus showing a lower value than the average content for the Nicobar sea.

The vertical distribution shows low values of total phosphorus in the surface water and the values increase gradually with increase in the depth. The decrease in the total phosphorus content beneath 500 meters is not more than 0.08  $\mu\text{g. at/l.}$

Highest concentration of total phosphorus observed in this area is 2.78  $\mu\text{g. at/l}$  at 500 meters.

*Off the coast of Burma:*

The surface values of total phosphorus in this region shows a variation from 1.5  $\mu\text{g. at/l}$  to 0.8  $\mu\text{g. at/l}$ , thus showing a range of 0.35  $\mu\text{g. at/l}$ .

The average total phosphorus content in the surface water is 1.0  $\mu\text{g. at/l}$  which is higher than the water in the Nicobar and the Andaman seas.

In general, the values are low in the surface and increase up to 500 meters reaching the maximum at this depth. Below 500 meters, the total phosphorus content falls by values ranging from 0.9  $\mu\text{g. at/l}$  to 2.0  $\mu\text{g. at/l}$  at different stations in this area.

At a shallow station (48) higher values are observed in the surface water and showed a slow decrease up to 10 meters and thereafter almost double to reach the highest value at the bottom (30 meters.)

The maximum concentration observed in this area is 5.4  $\mu\text{g. at/l}$  at 491 meters at station 54. This value happens to be the highest total phosphorus concentration registered in the Bay of Bengal investigated during this period.

*The rest of the Bay:*

The total phosphorus in the surface water of this area shows a variation from 1.51  $\mu\text{g. at/l}$  to 0.85  $\mu\text{g. at/l}$ , with a range of 0.66  $\mu\text{g. at/l}$  (Table I).

TABLE I

*Distribution of total, inorganic, dissolved organic and particulate phosphorus in the various regions of the Bay of Bengal during March-April, 1963*

Stn. No.	Depth (m)	Tot. p $\mu\text{g. at/l}$	Po <sub>4</sub> -P $\mu\text{g. at/l}$	Dis. org. P $\mu\text{g. at/l}$	Part. P $\mu\text{g. at/l}$
<b>NICOBAR SEA</b>					
14	1	1.03	—	—	—
	92	2.18	1.06	1.12	—
	480	2.48	2.37	0.11	—
	878	2.71	2.65	0.06	—
15	1	1.38	0.15	1.23	—
	84	1.98	1.13	0.85	—
	451	2.51	2.35	0.16	—
	919	2.68	2.68	0.00	—
16	1	0.35	0.09	0.22	0.04
	93	1.84	1.37	0.31	0.06
	284	2.59	2.29	0.29	0.01
	578	2.64	2.55	0.09	0.00
18	1	0.59	0.30	0.25	0.04
	50	1.72	0.14	0.52	0.06
	100	1.61	0.09	1.50	0.02
19	1	1.26	0.16	1.04	0.06

(Contd.)

## DISTRIBUTION OF TOTAL PHOSPHORUS IN THE BAY OF BENGAL

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Sta. No.	Depth (m)	Tot. p µg. at/l	Po4-P µg. at/l	Dis. org. P µg. at/l	Part. P µg. at/l
	50	3.33	0.44	2.85	0.04
20	0	1.12	0.00	1.05	0.07
22	0	1.00	0.04	0.89	0.07
23	1	0.92	0.04	0.80	0.08
	97	1.83	1.53	0.28	0.02
	292	2.51	2.23	0.28	0.00
24	0	1.20	0.00	1.15	0.05
25	1	1.15	0.02	1.09	0.04
	100	1.84	1.46	0.35	0.03
	500	2.91	2.53	0.32	0.06
	1000	2.71	2.73	0.00	0.00
26	1	0.91	0.00	0.88	0.03
	117	2.90	2.19	0.65	0.06
	474	2.78	2.53	0.23	0.02
	956	2.59	2.70	0.00	0.00
27	0	0.91	0.00	0.88	0.03
<b>ANDAMAN SEA</b>					
29	0	0.80	0.00	0.75	0.05
30	1	0.69	0.00	0.63	0.06
	100	1.89	1.32	0.49	0.08
	400	2.66	2.44	0.18	0.04
31	0	0.65	0.07	0.53	0.05
32	0	0.58	0.02	0.48	0.08
33	0	0.50	0.00	0.45	0.05
34	1	0.46	0.07	0.36	0.03
	100	2.00	1.86	0.09	0.05
	500	2.78	2.61	0.15	0.02
	1000	2.70	2.69	0.01	0.00
35	0	0.43	0.03	0.37	0.03
36	0	0.48	0.04	0.42	0.02
37	0	0.55	0.02	0.45	0.05
38	0	0.80	0.08	0.67	0.05
<b>OFF THE COAST OF BURMA</b>					
40	0	1.12	0.50	0.53	0.09
41	0	0.82	0.16	0.61	0.05
43	0	0.68	0.03	0.60	0.05
44	0	2.10	0.90	1.11	0.09
45	0	1.90	0.79	1.04	0.07
46	0	1.20	0.13	0.98	0.09
48	1	1.15	0.22	0.87	0.06
	10	0.83	0.24	0.50	0.09
	30	0.61	0.53	0.96	0.12
50	0	0.88	0.00	0.84	0.04
51	1	0.80	0.02	0.72	0.06
	92	2.76	1.81	0.89	0.06
	452	3.90	2.72	1.15	0.03
	941	3.01	2.89	0.12	0.00
52	0	1.02	0.00	0.98	0.04
53	0	1.00	0.00	0.97	0.03
54	1	1.05	0.27	0.73	0.05
	98	1.84	0.96	0.86	0.02
	491	5.40	2.51	2.89	0.00
	991	3.00	2.93	0.07	0.00
<b>THE REST OF THE BAY</b>					
56	1	1.10	0.06	1.01	0.03
	98	1.90	0.34	1.50	0.06

(Contd.)

Stn. No.	Depth (m)	Tot. p µg. at/l	Po4-P µg. at/l	Dis. org. P µg. at/l	Part. P µg. at/l
	493	4.60	2.72	1.84	0.04
	992	2.99	2.93	0.04	0.02
57	1	1.21	0.04	1.14	0.03
	98	1.52	0.94	0.57	0.01
	491	3.14	2.77	0.37	0.00
	991	2.99	2.94	0.05	0.00
58	1	1.49	0.04	1.39	0.06
	96	2.64	1.04	1.56	0.04
	482	3.18	2.71	0.45	0.02
	973	2.91	2.87	0.03	0.01
60	1	1.51	0.10	1.35	0.06
	98	2.07	1.12	0.94	0.01
	495	3.00	2.65	0.35	0.00
	995	2.87	2.87	0.00	0.00
61	0	1.51	0.08	1.39	0.04
62	0	2.00	0.44	1.53	0.03
63	0	1.82	0.14	1.63	0.05
65	1	0.85	0.13	0.64	0.08
	99	2.18	1.67	0.39	0.12
	495	2.99	2.77	0.22	0.00
67	1	1.38	0.22	1.10	0.06
	97	1.95	1.04	1.87	0.04
	487	3.10	2.75	0.34	0.01
	991	2.99	2.99	0.00	0.00
	1483	2.91	2.92	0.00	0.00
	2174	2.91	2.76	0.13	0.02
71	1	1.03	0.07	0.92	0.04
	94	1.65	0.21	1.42	0.01
	470	3.10	2.72	0.38	0.00
	944	3.10	2.94	0.16	0.00
	1426	2.80	2.81	0.01	0.00
	2680	2.90	2.53	0.31	0.06
72	0	1.00	0.07	0.87	0.06
73	0	0.98	0.02	0.91	0.05
75	1	0.92	0.03	0.84	0.05
	100	2.07	1.41	0.64	0.02
	300	2.64	2.57	0.07	0.00
	500	2.91	2.73	0.15	0.03
	800	2.88	2.76	0.10	0.02
	1000	2.85	2.86	0.00	0.00
	1500	2.62	2.61	0.00	0.00
	1800	2.62	2.62	0.00	0.04
	2200	2.50	2.51	0.00	0.02
	2600	2.64	2.44	0.18	0.02
	3000	2.41	2.40	0.01	0.00
76	0	0.90	0.06	0.75	0.09
78	0	0.95	0.06	0.85	0.04
79	1	0.98	0.03	0.91	0.04
	99	2.20	1.55	0.75	0.00
	498	2.99	2.86	0.13	0.00
	997	2.93	2.90	0.03	0.00
80	1	1.02	0.06	0.91	0.05
	99	2.35	1.72	0.63	0.00
	297	2.89	2.69	0.20	0.00
	496	2.99	2.91	0.09	0.00
	995	3.20	3.22	0.00	0.00
	1196	3.15	3.19	0.00	0.00
	1496	3.10	3.14	0.00	0.00
	1781	3.10	3.14	0.00	0.03
	2073	3.15	3.08	0.02	0.05

Contd.



Stn. No.	Depth (m)	Tot. p μg. at/l	Po4-P μg. at/l	Dis. org. P μg. at/l	Part. P μg. at/l
	2370	3.00	3.03	0.00	0.05
81	0	1.21	—	—	0.03
82	1	0.92	0.03	0.89	—
	94	2.18	1.66	0.52	—
	490	2.68	2.60	0.08	—
	987	2.99	2.94	0.05	—
84	0	1.45	—	—	0.07
87	0	1.52	0.31	1.06	0.15

The surface average concentration of the total phosphorus is 1.18 μg. at/l which happens to be the highest average value for the areas investigated during this period.

The vertical distribution of total phosphorus reveals that the surface values are low at all stations, and increase with depth reaching the maximum concentration at about 500 meters, below which the concentration shows only a slight fall.

The highest concentration recorded for this area is 4.6 μg. at/l at 493 meters at station 46. This value, though slightly lower than the value obtained off the coast of Burma, is however, comparatively high when the maximum concentration in the Nicobar and the Andaman sea is considered.

#### HORIZONTAL DISTRIBUTION OF TOTAL PHOSPHORUS IN THE BAY OF BENGAL DURING MARCH-APRIL 1963

The total phosphorus values at 1000 meters are ranged between 3.0 and 3.1 μg. at/l just for a short strip stretching from the central Bay towards the Burma coast, while in the rest of the Bay, the Andaman and the Nicobar seas the value are less than 3.0 μg. at/l.

At 500 meters however, the total phosphorus values near the head of the Bay are high and of the range of 3.6 μg. at/l. But, in the rest of the Bay the values continue to be between 2.5 and 3.0 μg. at/l. The disappearance of the previously mentioned strip stretching between the central Bay and Burma Coast at 1000 meter and its substitution by waters of relatively high total phosphorus may be discussed in the context of influx of large volumes of fresh water in this region. These fresh waters are likely to bring in considerable amounts of total phosphorus into the Bay but this effect is not observed beneath the 500 meters and this is justified further by the total phosphorus values at 100 and 1 meters depth.

The distribution of total phosphorus at 100 meters shows that the waters in the central Bay exhibit a range from 1.5 μg. at/l to 2.0 μg. at/l and these waters extend in a Northeast direction towards the Burma Coast. The concentration of total phosphorus in the waters off the Burma Coast is higher than 2.0 μg. at/l. However, the waters adjacent to the Nicobar islands are characterised by values slightly higher than 2.0 μg. at/l.

At surface, (1 meter depth) the waters along the East Coast of India from Visakhapatnam in a Northerly and then Northeasterly direction, exhibit total

phosphorus values between 1.5 and 2.0  $\mu\text{g. at/l.}$  The values are ranged from 1.0  $\mu\text{g. at/l}$  to 1.5  $\mu\text{g. at/l}$  in the waters of the Central Bay and extend towards the Burma Coast. Immediately below this area the waters are characterised by total phosphorus values varying from 0.5  $\mu\text{g. at/l}$  to 1.0  $\mu\text{g. at/l}$ . The values in the Andaman sea and slightly towards West and North of the Andaman islands are less than 1.0  $\mu\text{g. at/l}$  to 1.0  $\mu\text{g. at/l}$ . while the waters North-east of Nicobar islands and adjacent to the Tai Coast show more than 1.0  $\mu\text{g. at/l}$ .

Thus at 100 meters depth and surface the total phosphorus distribution suggests considerable mixing of waters with more or less complete isolation of high phosphorus water masses. We attribute this to lack of mixing between upper and deeper waters in the Bay as revealed by sharp Salinity gradients.

Average total phosphorus shows an increase in the values at 100, 500 and 1000 meter levels in a South to North direction. Between  $5^{\circ}$  and  $10^{\circ}\text{N}$  parallel the values at all the depths are low. They increase in between the latitudes  $10^{\circ}$  and  $15^{\circ}\text{N}$  and continue to increase between the latitudes  $15^{\circ}$  and  $20^{\circ}\text{N}$ .

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