

NUTRIENTS OF THE NORTH-WESTERN BAY OF BENGAL

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Studies on the distribution of phosphates, silicates and nitrates in relation to some hydrographical features of the north-western Bay between latitudes 16° and 19°N during the month of January showed marked regional variations. The distribution is found to be related to the prevailing currents. The chief feature of the region investigated is the commencement of coastal upwelling. The ascent of the sub-surface waters is weak and extends only up to 20 m below the surface. From the disposition of the isolines it appears that the vertical movement of the waters extends down to 500 m. Phosphate maximum is found between 600-800 m and the nitrate maximum between 300 and 800 m. The silicates, on the other hand, continue to increase with depth. The factors influencing the distribution of nutrients over the entire region have been discussed.

INTRODUCTION

While considerable information is available on the general oceanographic conditions in the Bay of Bengal, very little is known regarding the distribution of nutrient salts. Even the available data is centred around few regions, particularly off Waltair and Madras and most of the studies limit to near-shore areas (Jayaraman 1952; Ganapathy and Sarma 1958; Bhavanarayana and LaFond 1957; Varma and Reddy 1959). The Bay of Bengal especially the northern region is influenced by the discharge of large rivers and complex current patterns varying with monsoons. Since the distribution of nutrients and other hydrographical features are affected more by the dilution and currents, the general estuarine character of the Bay of Bengal limits the generalisation of characteristics based on meagre regional and seasonal studies. This feature is in contrast to the Arabian Sea, in which the riverine inflow is considerably less and the conditions are predominantly oceanic and relatively more stable. Therefore it is imperative that several distinctive small regional studies through different seasons are necessary to assess the hydrological characteristics of the Bay of Bengal as a whole.

During the International Indian Ocean Expedition (1962-1965) it was possible to cover several regions in the Bay of Bengal in different seasons and the present account on the nutrients in the north-western Bay of Bengal in relation to hydrographical factors, is based on the data collected during the 21st Cruise of I.N.S. Kistna in the month of January, 1965.

MATERIAL AND METHODS

Figure 1 shows station locations along the sections normal to the coast. Stations were selected from the regions (1) off False point (between Lat. 20°08' and 18°N and Long. 86°54' and 90°E), (2) off Gopalpur (between Lat. 19°09' and

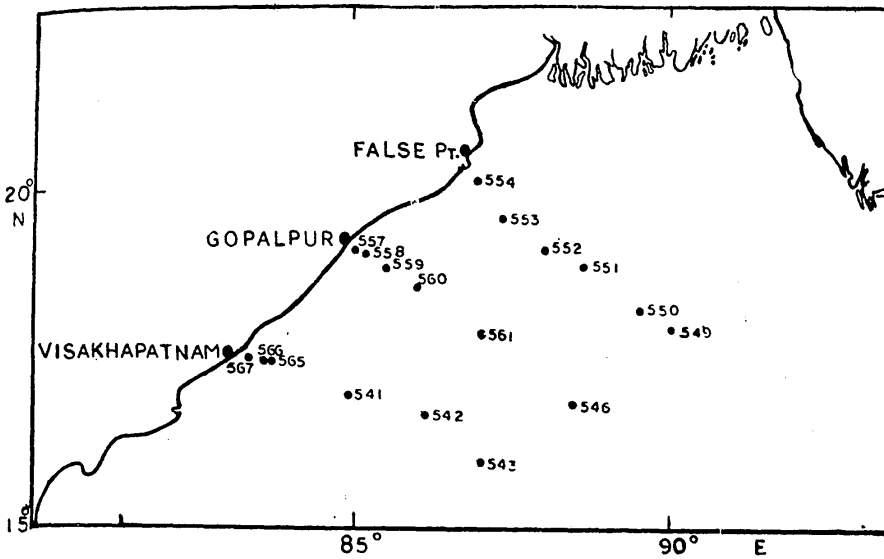


FIG. 1. Map showing the station locations.

16°53'N and Long. 85°02' and 88°20'E) and (3) off Visakhapatnam (between Lat. 17°32' and 16°N and Long. 83°29' and 87°N). Methods of chemical analysis of the water samples for phosphates and silicates were the same as reported earlier (Reddy and Sankaranarayanan 1966). Nitrates were estimated as described by Strickland and Parsons (1960) using Sulphanilamide and N-(1-naphthyl) ethylene diamine for the azodye formation and the extinction was measured at 543 m μ . Observations between depths 0-1000 m are presented.

RESULTS

Figures 2A, 3A and 4A show the vertical profiles of phosphates along the three sections. Phosphates in the mixed layer (upper 60 m), show some meridional and latitudinal variations. The concentrations are relatively higher in the shelf waters ranging from 0.3 to 1.1 $\mu\text{g at/l}$. The values tend to decrease towards the east registering less than 0.5 $\mu\text{g at/l}$ with the only exception in the northern part of the section (off False point) wherein the values show a rise at the eastern end of the section. Along the north-south direction, high values (0.5 to 1.1 $\mu\text{g at/l}$) exist in the south (off Visakhapatnam) and low values (0.3 to 0.58) in the mid-region (off Gopalpur). Phosphate discontinuity layer coincides with the thermocline topography and a common feature of the entire region is that the phosphate discontinuity layer shows a gradual coastward upslope from the mid section with varying intensities. In the north (off False point) the phosphate gradient layer tends to slope up towards shallower depths at the eastern end also. This feature is absent in the remaining

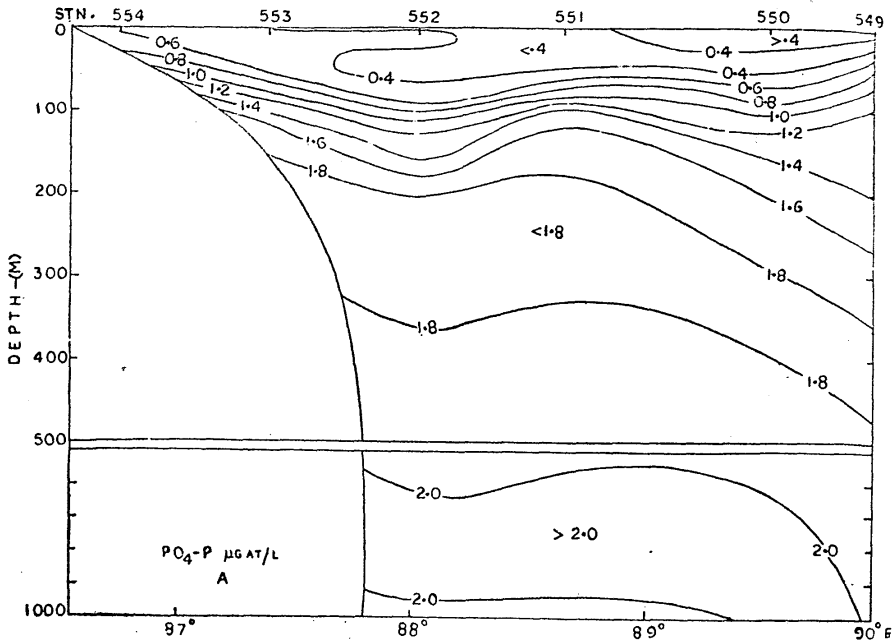


FIG. 2A.

FIG. 2 (A-F). Vertical profiles of properties along the section off False Point.

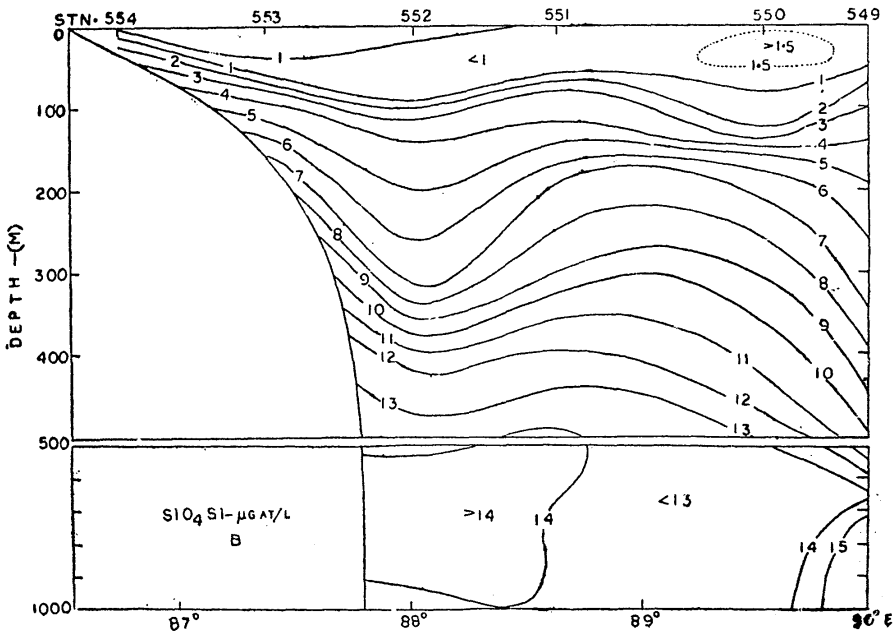


FIG. 2B.

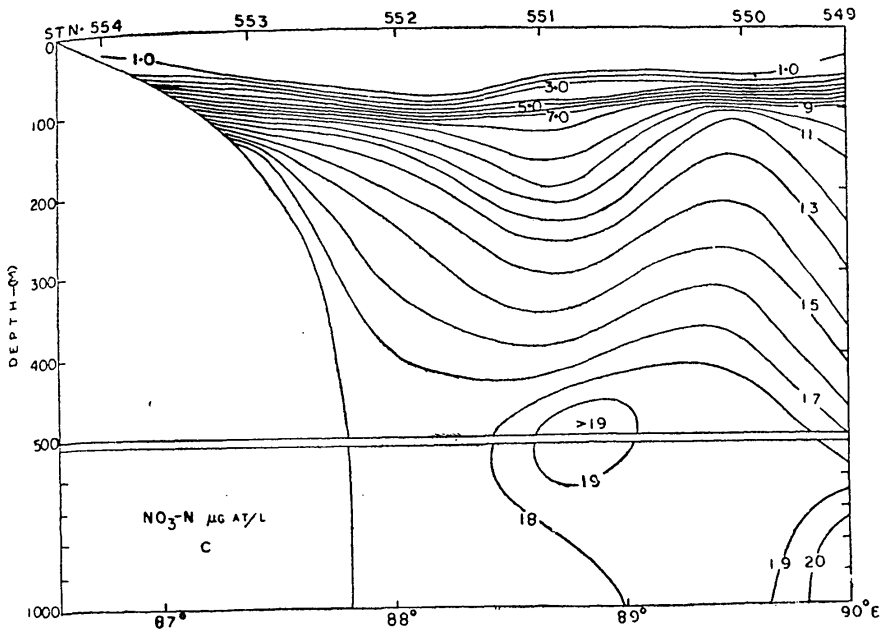


FIG. 2C.

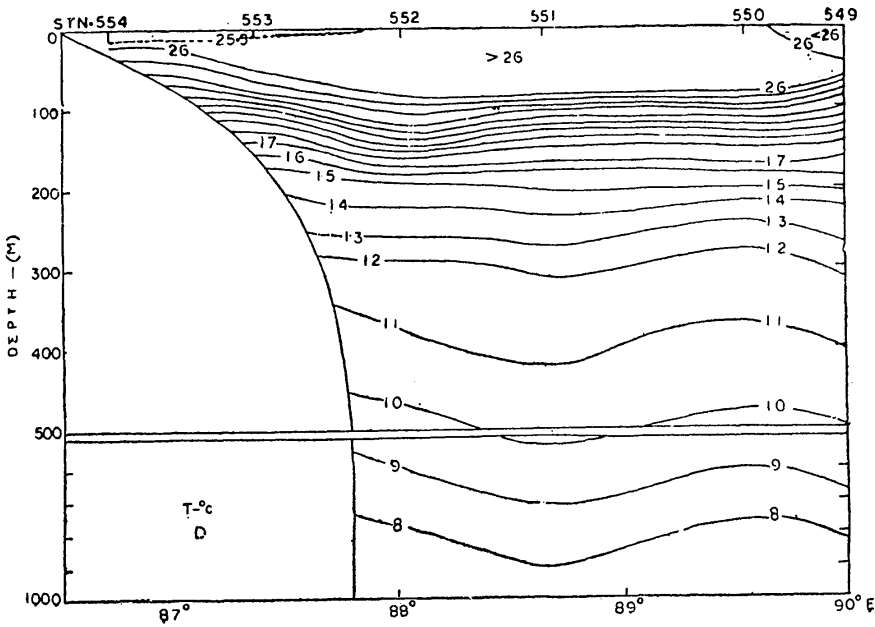


FIG. 2D.

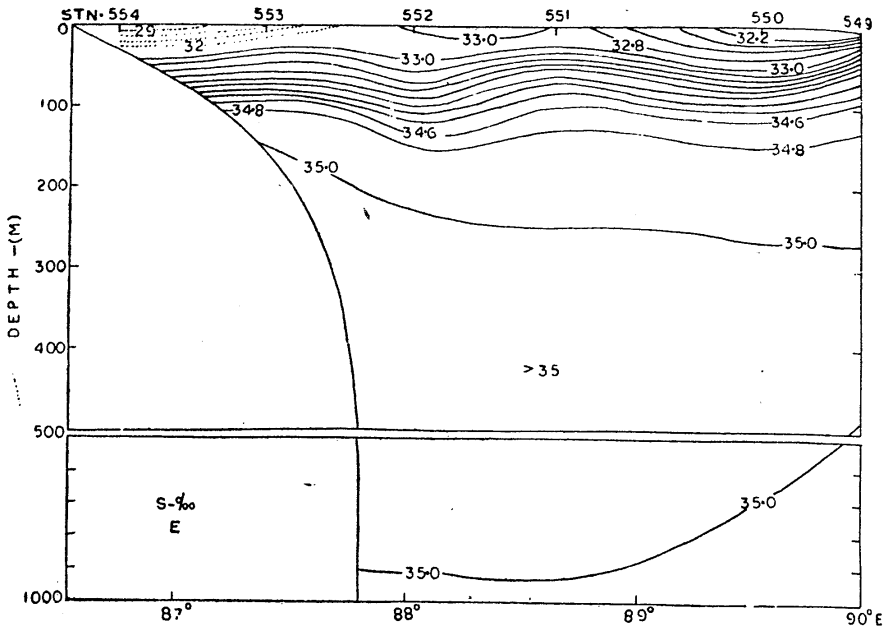


FIG. 2E.

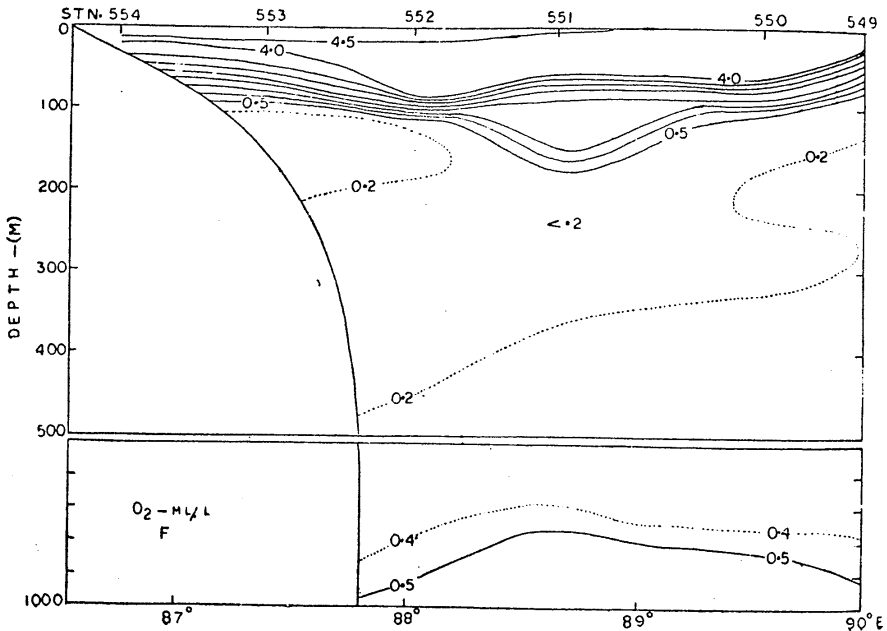


FIG. 2F.

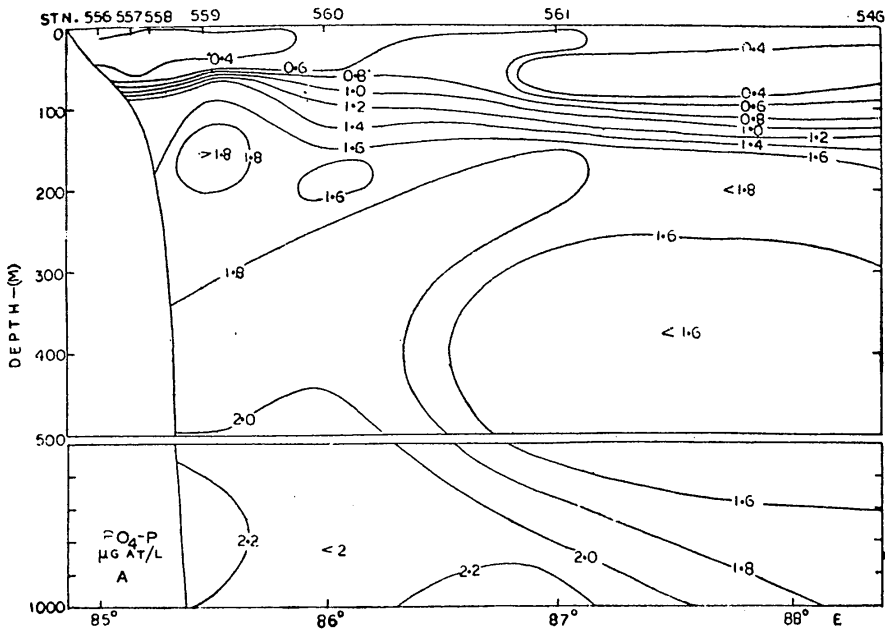


FIG. 3A.

FIG. 3 (A-E). Vertical profiles of properties along the section off Gopalpur.

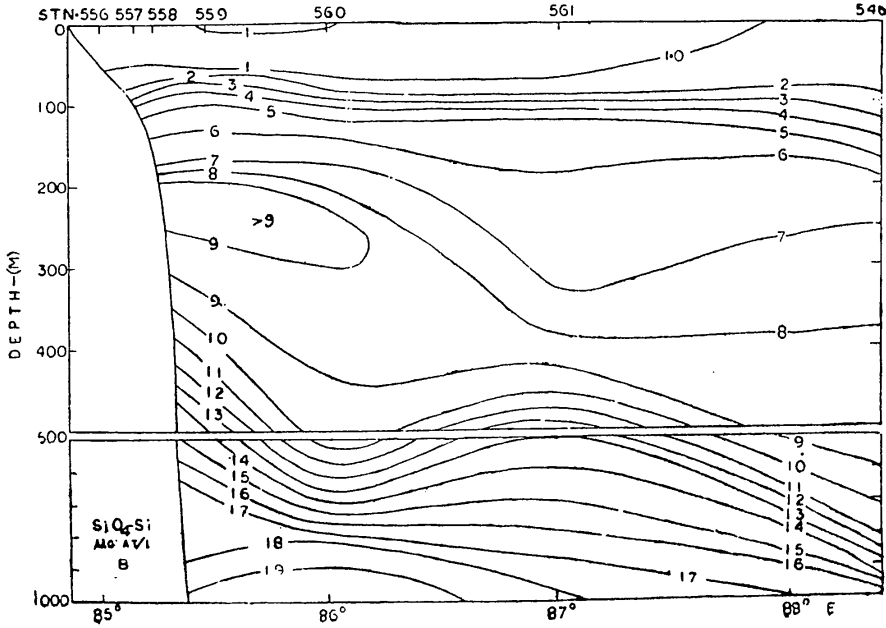


FIG. 3B.

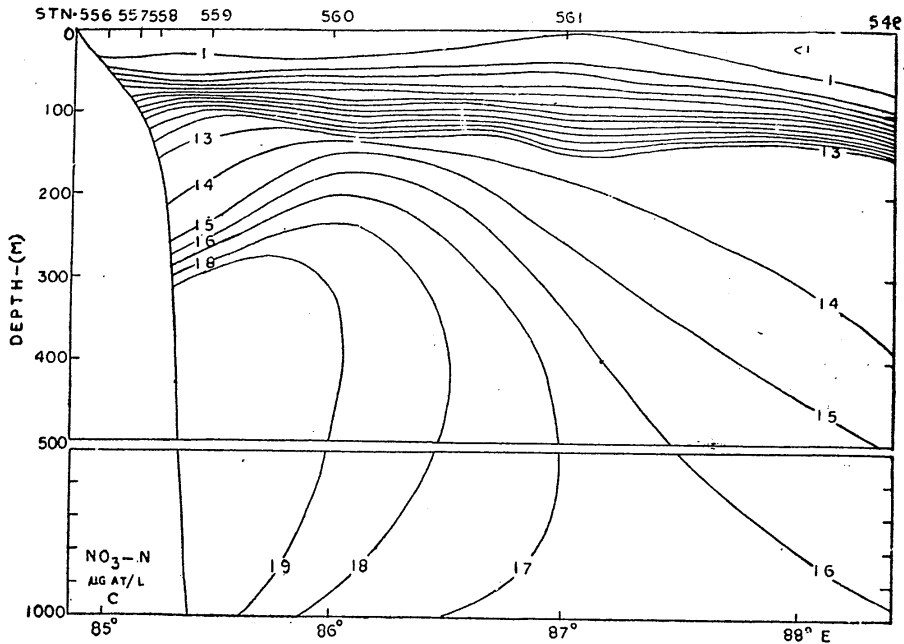


FIG. 3C.

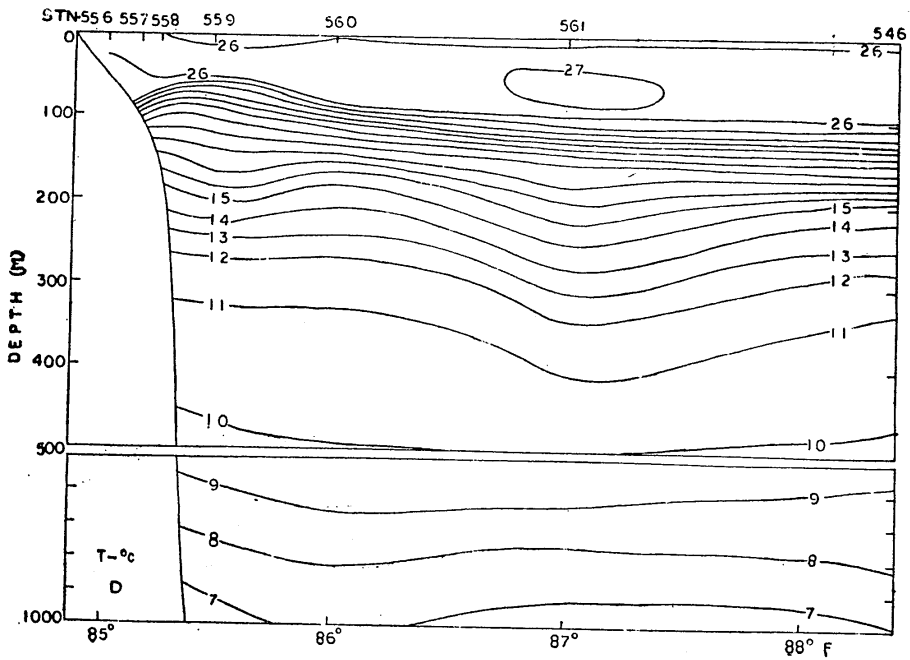


FIG. 3D.

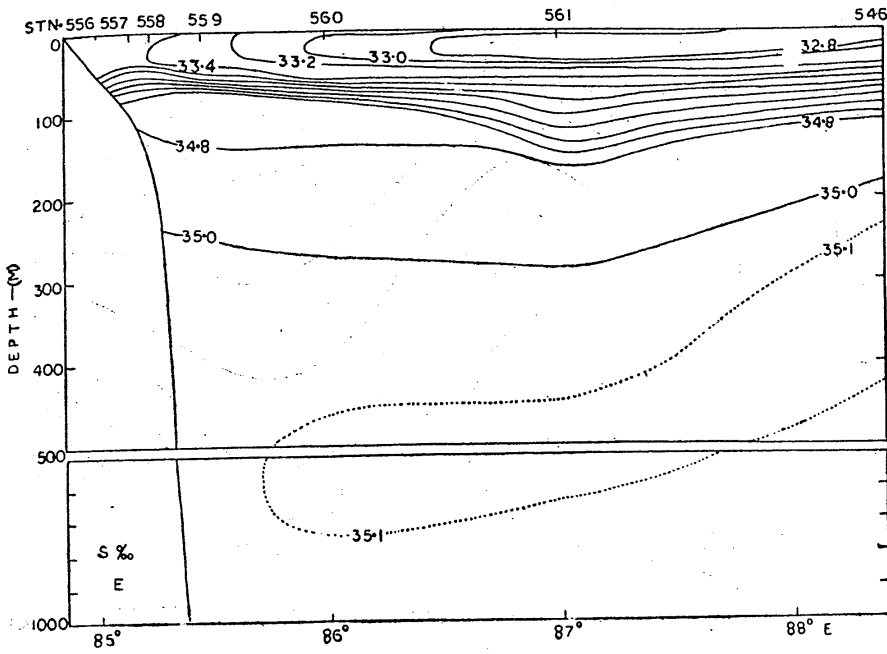


FIG. 3E.

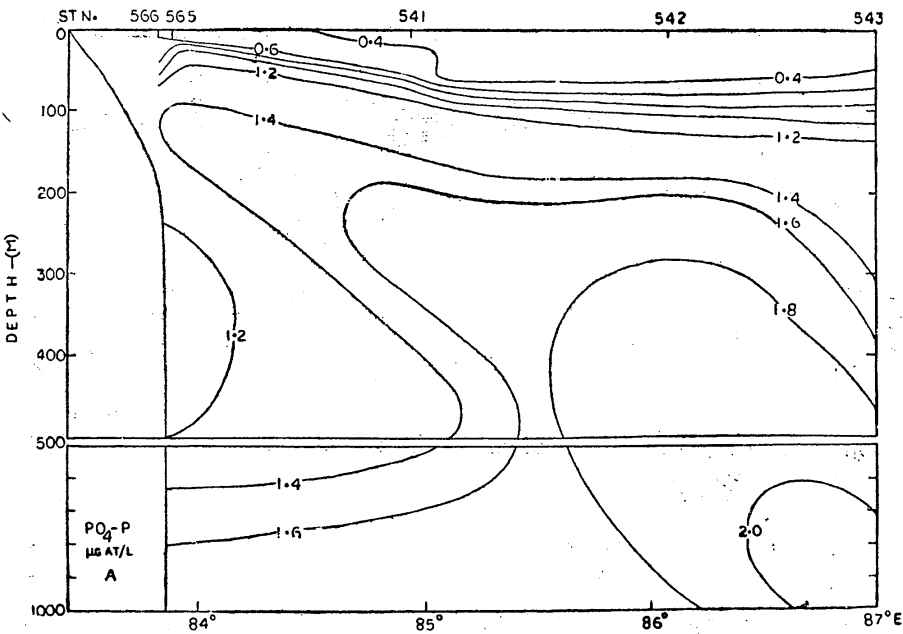


FIG. 4A.

FIG. 4 (A-F). Vertical profiles of properties along the section off Visakhapatnam.

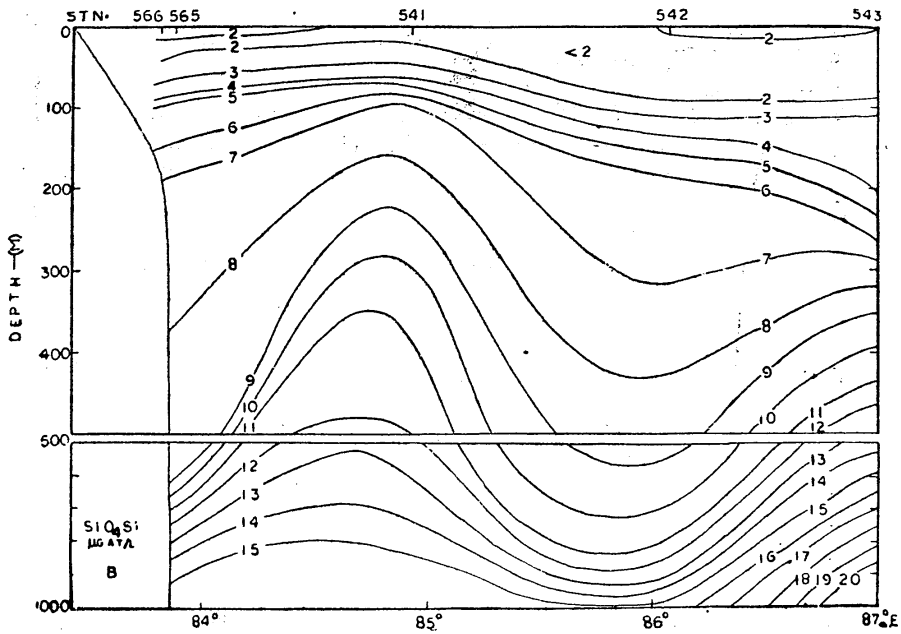


FIG. 4B.

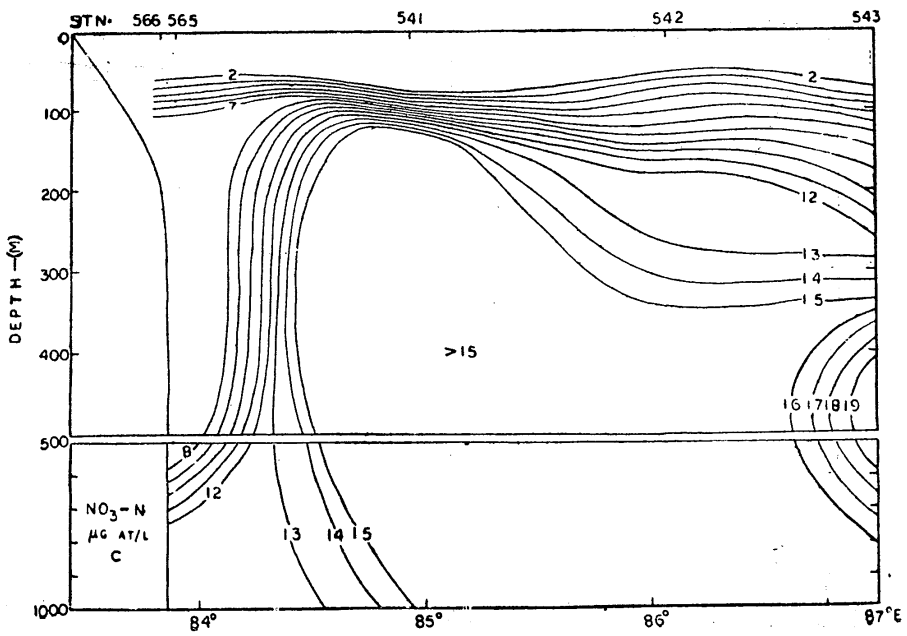


FIG. 4C.

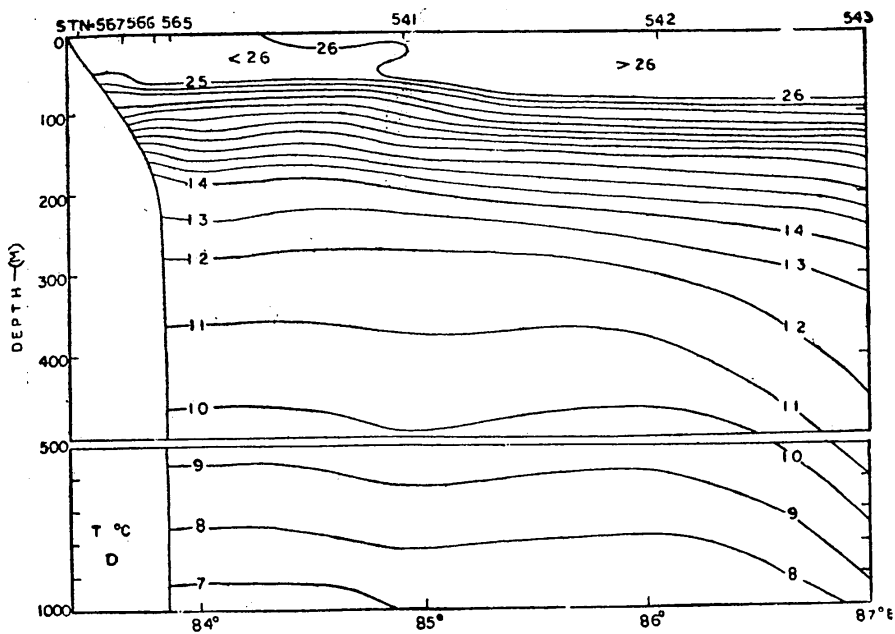


FIG. 4D.

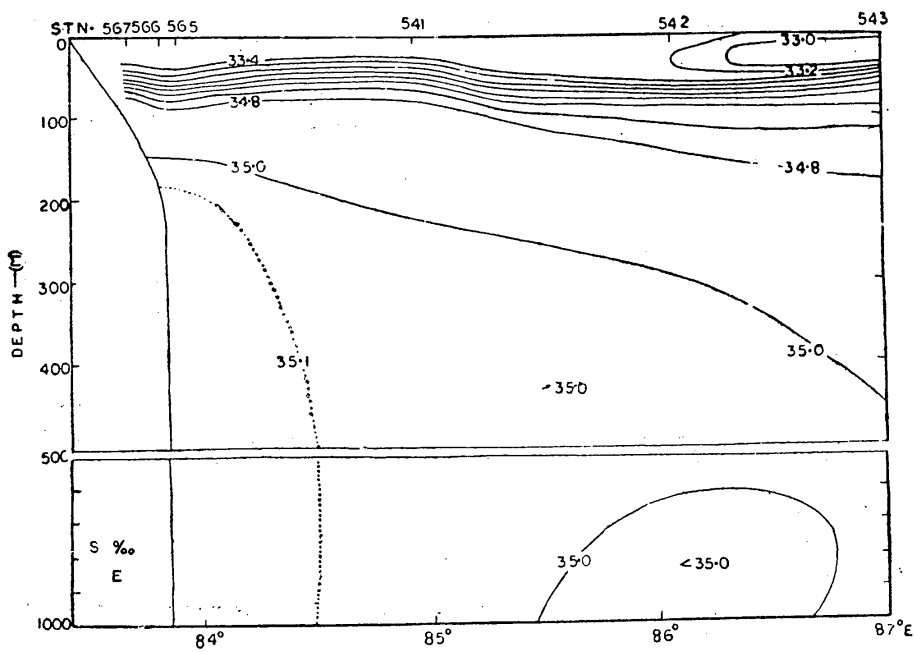


FIG. 4E.

southern sections. However, it may be noted that the subsurface waters do not reach the surface over the shelf excepting in the region off False point. The general ascent of the subsurface waters extends up to only 20 m in the southern sections. Below 200 m the distribution is more uniform, but the upward trend of the isolines is noticeable down to 500 m also and this feature is more pronounced in the south, off Visakhapatnam. Depth of phosphate maximum is found to be varying between 600 and 800 m.

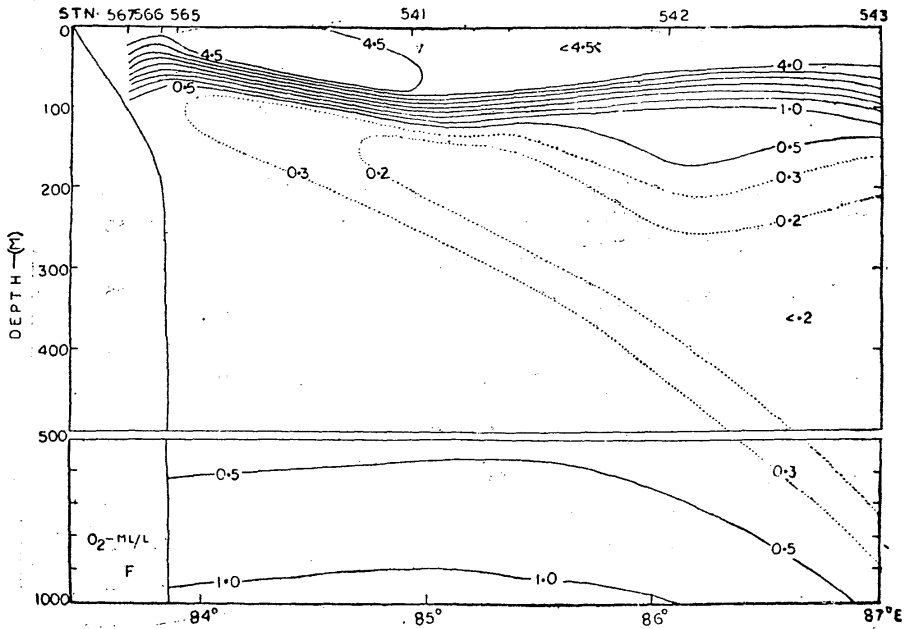


FIG. 4F.

Silicate distribution (Figs. 2B, 3B and 4B) corresponds well with that of phosphate. Surface concentrations range from 0.1 to 4 μg at/l. Higher values are found to occur in the southern section and lowest in the mid section. Within the thermocline the concentrations register a rapid increase extending down to 200 m; at deeper levels the values increase continuously with depth reaching a maximum of 21 μg at/l in the south. Similar to phosphates, silicate isolines also show a strong upslope towards the coast.

Nitrates (Figs. 2C, 3C and 4C) also follow more or less the same pattern of distribution as the other nutrients, excepting that the subsurface gradients are stronger and extending to deeper levels. Surface nitrates are low over the entire region varying between 0.1 to 2 μg at/l. An increase in the concentration towards south is noticeable. The variations towards east appear to be non-uniform with alternate bands of highs and lows with minimum concentrations around 90 E. The nitrate discontinuity layer is located within the thermocline in both the north

and south sections, but in the mid section it commences a little above the thermocline (50 m). Below 150 m the variations with depth are rather more uniform. The layer of maximum nitrate content appears to be varying between depths 300 and 800 m and in general it may be said that the nitrate maximum is at a higher level than that of phosphate over major portion of the region. From the configuration of the isolines it is apparent that significant vertical motion of the waters occur at subsurface levels.

HYDROGRAPHICAL FEATURES

Temperature profiles, (Figs. 2D, 3D and 4D) show an uniform feature along the western end of the whole region, characterised by the presence of a layer (15 m thick) of cold surface water extending to a maximum distance of 75 miles off the coast. The stretch of the cold layer decreases towards south with a simultaneous rise in temperature. In the mid section (off Gopalpur) the cold surface layer is intercepted by a significant band of warm water around 20 miles off the coast. A close examination of the thermocline layer reveals its shoaling nature towards west. The disposition of the isolines below 200 m also indicate the existence of vertical movements in deeper waters.

Salinity profiles (Figs. 2E, 3E and 4E) show that the cold surface waters near the coast off False point and Gopalpur are of low salinities whereas in the souths off Visakhapatnam are of higher salinity. In the case of former the influence of river flow is still felt. The westward upslope of the isohalines at subsurface level, is indicated with a lesser degree over the entire region. In the northern section at its eastern end (around 90°E) the ridging up of the isohalines of the upper 100 m point to an apparent divergence region. This feature is also reflected in the nutrient and temperature profiles, but to a lesser extent. Along the entire region around 90° E the salinities are low and these low salinity values appear to be associated with the prevailing gyral circulation.

Oxygen distribution is presented only for the two sections, off False point and off Visakhapatnam (Figs. 2F and 4F). The cold and low saline waters are associated with higher Oxygen content. A notable feature is that the Oxygen discontinuity layer commences at a higher level than the thermocline. However the Oxygen minimum layer (<0.5 ml/l) starts in the middle of the thermocline extending down to 800 m coinciding more or less with the depth of phosphate maximum. The sloping up of the Oxygen minimum layer towards west is well seen. This feature appears to be more pronounced in the south (off Visakhapatnam). Significant increase in the Oxygen levels could be noted only below 800 or 900 m. In general the Oxygen distribution closely follows those of salinity and phosphates.

DISCUSSION

The distributions of the hydrographical factors in the Bay of Bengal, are primarily influenced by the immense land drainage and complex current patterns

associated with the changing monsoons. The highly estuarine character of the Bay, narrows the biological influence on the nutrients. The suspended organic and inorganic particulate matters are believed to be more responsible for the observed irregular variance of nutrient distributions through the processes of adsorption, sedimentation, regeneration by chemical and bacterial agencies and finally diffusion by vertical and horizontal circulations. A cursory examination of the recent data collected on I.N.S. Kistna reveal that the effects of land drainage are evident over a wider area in the Bay, during major part of the year following the circulation patterns. The property distributions show considerable variations within narrow regional and time limits. Thus the conditions in the Bay necessitates the use of extensive small regional and temporal observations to obtain an integrated picture of the property distributions. The present report gives a descriptive account of nutrients in relation to other hydrographical features in the North-Western Bay in the month of January.

During the period of observations the general current pattern can be differentiated into (1) anticyclonic circulation at the head of the Bay extending to about 15°N and (2) the west drift in the open parts of the Bay.

A significant observation in the region under study is the beginning of coastal upwelling which is evident from all the sections, as one of the factors governing the distribution of nutrients. It is clear from the trend of the profiles (Figs. 2-4) that this feature appears to be relatively more advanced in the north and least in the mid region (off Gopalpur). LaFond (1954) while discussing upwelling off the East Coast of India, observed a marked increase in temperature and salinity at the end of January and throughout February. This is attributed largely to the reversal of the current direction during this season of the year, which brings in warm high saline water from the equatorial region. At the same time the south south-west winds cause an offshore drift of the surface water. As colder subsurface water rises to take its place, upwelling starts. Further investigations by LaFond (1954) indicate that the upwelling develops fully, off Visakhapatnam in March, extending up to April. The offshore transport of water fits with the prevailing wind direction (SW) and the northerly current along the coast. Present investigations confined to the 3rd week of January when the conditions (LaFond 1954) are favourable for the commencement of the observed upwelling. The observations show that this feature extends only up to the mid-shelf limiting the ascent up to about 20 m below the surface in the southern sections, whereas in the northern section (off False point) it extends almost to the surface towards the inner shelf. It is obvious that the resultant operative force responsible for the upwelling is weak and of variable strength over the entire region. As mentioned earlier the characteristic feature of the prevailing current system is the anticyclonic gyre at the head of the Bay extending down to about 15°N . The centre of the gyre is in proximity to the northern section (off False point). It is felt that this circulation may be playing a significant role in the upwelling processes towards the coast. The convergence at the centre of the anticyclonic gyre may be drawing the surface waters around, and therefore it is

highly probable that the magnitude of transport of the surface waters towards east could be increased tending the upwelling to be more conspicuous near the coast. This feature is well reflected in the northern section off False point. Decreasing intensity of the process towards south could be due to the increasing distances from the centre of the gyre. Local changes in the prevailing wind may also equally affect the intensities of upwelling.

The general surface nutrient levels in the upper 60 m (Figs. 2-4) reveal that the trends of variation in the east-west and north-south directions show some regional differences. These variations run parallel with those of temperature and salinity. In the north (off False point) near the coast the phosphate values are high ($0.65 \mu\text{g at/l}$) and progressively decrease towards off-shore up to 88°E and beyond this a significant rise to maximum ($1.13 \mu\text{g at/l}$) is noticeable. The higher values are associated with cold and low saline waters while the lower values with warm and high saline waters. The existence of cold and low saline surface waters near the coast may be due to the effect of discharge from the river Mahanadi. The progressive increase in salinity towards south supports this view. These waters normally extend over a thin surface layer (20 m thick) spreading to about 120 km forming a boundary with the warm high saline and low phosphate waters; these in turn form another boundary around Long. $89^\circ 30' \text{E}$ with another cold, low saline and high phosphate layer. At this end the disposition of the profiles indicate an uplift. The cold and low saline surface waters appears to be caused by a part of the surface gyres weeping from north to south-west direction, bringing in cold and dilute waters from the head of the bay. The conspicuous upslope of the same may be coinciding with a local divergence zone probably extending further east. This particular ridging feature is not found in the southern sections. But the presence of cold and low saline waters is evident, suggesting the southward extension of the gyre. The gradual rise in the temperature and salinity with a fall in phosphate level in the east indicate the weakening of the gyral circulation towards south; the sharp fall in the phosphate content perhaps suggests the influence of the westerly drift, bringing in warm high saline and phosphate poor waters from east and south-east. The phosphate concentrations over the shelf show maximum values off Visakhapatnam and minimum off Gopalpur. The intermediate concentrations off False point may be reflecting the relatively weaker upwelling trend as could be inferred from the vertical profiles. The maximum surface values in the shelf off Visakhapatnam are believed to be very local caused by regeneration processes. Ganapati and Sarma (1958) observed the phosphate peak in the surface waters off Visakhapatnam during the month of January. They attributed this to the nutrient rich Antarctic bottom water, entering the bay to compensate the loss of water due to evaporation. However, in the present case the authors consider that the high level of phosphates are due to local regeneration processes, as the present observations indicate only the beginning of upwelling which is not affecting the surface waters.

The silicate and nitrate concentrations in the upper mixed layer are low. Nevertheless they also exhibit some variations; phosphates and silicates agree fairly well while the nitrates show certain amount of inverse relation with the other

nutrients regionally. Since the concentrations and the differences are of lower order no special emphasis can be made on the factors governing the silicate and nitrate distribution excepting that the minor variations may be more of regenerative character.

At deeper levels (below 60 m) the concentration gradients of the nutrients coincide with the thermocline. The characteristic slight upslope of the gradient layers could be noticed in the east-west direction in all the profiles. The concentrations of silicates and especially nitrates show strong gradients with depth even extending down to 500-600 m. This property is obviously related to the differential rates of regeneration and some physical processes determining the accumulation. The maximum variations in the concentrations coincide with very low oxygen content. Highest accumulation of phosphates is between 600 and 800 m and the nitrate between 300 and 800 m. Silicates show a continuous increase with depth.

It is apparent from the vertical profiles that the vertical motion of the waters extend to deeper levels also. Nutrients conform well with the inference while the temperature shows wavy patterns suggesting the effect of internal waves promoting vertical eddies. It is believed that the characteristic upslope of the strong gradients of the subsurface nutrients especially that of silicates and nitrates are believed to be due to the differential rates of regeneration and disposal by eddy diffusion. Another feature of importance to be mentioned in this context is the presence of salinity maximum between 300 and 500 m. Rochford (1964) discussing the salinity maxima in the upper 1000 m of the North Indian Ocean indicated the incursion of Persian Gulf and Red Sea waters (300 to 450 m) into the Bay. The incursion of new water mass may favour the formation of internal waves at the boundary enhancing eddy diffusion, and perhaps this may explain the observed peculiar patterns of the vertical distribution of the nutrients below 200 m.

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