

DISTRIBUTION OF PHOSPHATES AND SILICATES IN THE CENTRAL WESTERN NORTH INDIAN OCEAN, IN RELATION TO SOME HYDROGRAPHICAL FACTORS

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The paper presents a descriptive account of the distribution of phosphates and silicates of the Central region of the Western North Indian Ocean in the upper 200 m during the south west monsoon period. The relationship of the nutrients with temperature, salinity, oxygen and also zooplankton is shown. Vertical distribution of the nutrients indicates low concentrations at the surface layers up to 50 or 75 m. This is followed by higher concentration layers down to 200 m. Considerable meridional and zonal variations in the concentrations and the thickness of these layers have been noticed. The distributional features of the oceanographic properties indicate the distinctness of the North Equatorial Indian Ocean from the geographically similar regions of the Pacific and Atlantic Oceans. The disposition of the isopleths shows an equatorial upslope of the waters which is associated with the equatorial divergences. However, the ascent appears to be weaker near and along the equator as compared to the equatorial regions of the Pacific and Atlantic. The spreading of the isolines near and along the equator is probably due to the equatorial undercurrent. Three regions of convergence (i) between Lat. $15^{\circ}30'$ and $16^{\circ}30'$ along $68^{\circ}E$, (ii) around $8^{\circ}N$ and $71^{\circ}30'E$, and (iii) around $5^{\circ}N$ and $75^{\circ}E$ have been noticed. The variations in zooplankton volumes seem related to the changes in hydrographical features.

INTRODUCTION

Before the International Indian Ocean Expedition began, our knowledge about the Oceanographic Conditions of the Indian Ocean was mainly based on reports of the Dana Expedition (1928—1930), the John Murray Expedition (1933—1934), the Discovery Expedition (1934), the Swedish Deep Sea Expedition (1947—1948) and the Galathea Expedition (1950—1952) and more recently from the data collected by the Russian Ship "Ob" (1956) and Vityaz (1958).

As part of the Indian Programme of the International Indian Ocean Expedition, the vessel, I.N.S. KISTNA carried out many cruises in the Arabian Sea and the Bay of Bengal. The present paper which deals mainly with distribution of nutrients (phosphates and silicates) in the Central Western North Indian Ocean, is based on the observations made during the XII and XIII monsoon cruises of the I.N.S. KISTNA undertaken in August 1963. Until recently most of the investigations on nutrients were made in the Arabian Sea, along the West Coast of India and these were limited to shelf waters only (Reddy and Sankaranarayanan 1966). The present data from the open ocean may give a better understanding to the problem of possible influence of the oceanic waters on the inshore waters.

METHODS

Cruise tracks with the station locations are given in Fig. 1. The cruise XII

covers 68°E meridian from Lat. 19° to 14°N in August 1963. Cruise XIII covers a composite section of the following three legs: (1) A meridional section along 71° 30'E

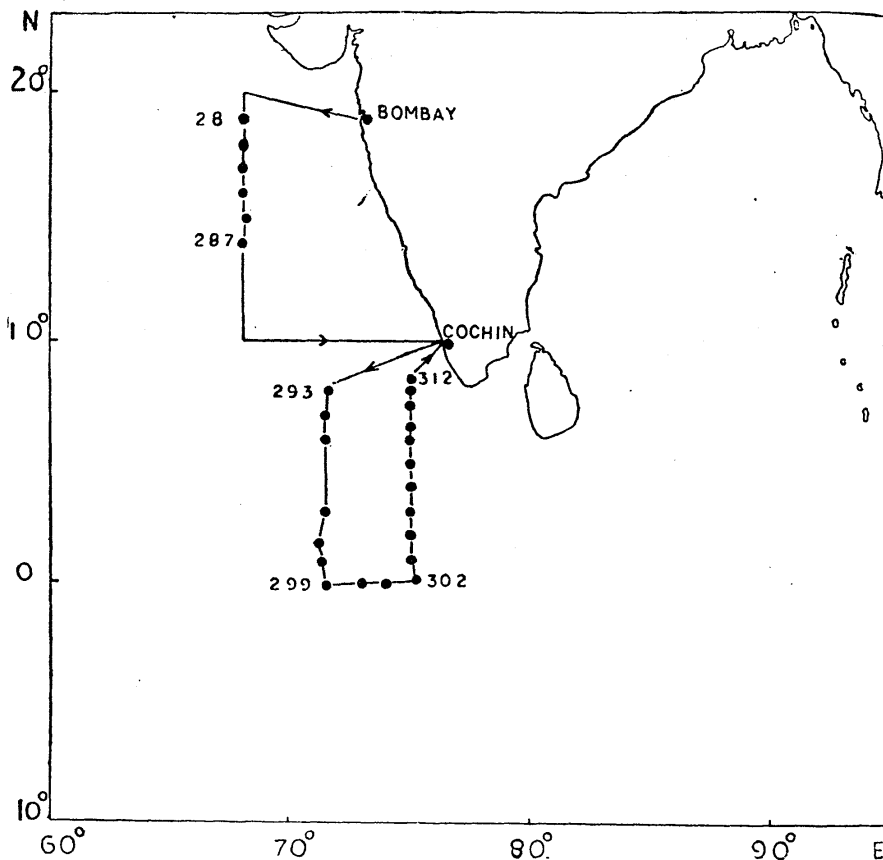


FIG. 1. Map showing the cruise tracks and station locations.

from Lat. 8°N to Equator, (2) Zonal section along the equator through 71°30' to 75°E, and (3) Meridional section along 75° across Lat. 0° to 8°24.5' N.

Sea water samples were collected at all standard depths up to 200 m. Samples were preserved at -10°C . on board the ship and analysed in the Indian Ocean Biological Centre, Cochin soon after the cruises.

Inorganic phosphates were estimated by the method given by Wooster and Rakestraw (1951). The values are not corrected for salt error. Silicates were estimated by the method outlined by Robinson and Thompson (1948). Absorbance was measured at $404\text{ m}\mu$ as suggested by Barnes (1960) and comparisons were made with potassium chromate standard solutions, buffered with borax.

RESULTS

1. Section along 68°E meridian, between Lat. 19° and 14°N

Figure 2A shows the phosphate distribution in surface layers. It can be seen from the figure that phosphate in surface layers down to 50 m is more or less uniformly distributed (Fig. 2A). The values are generally low (0.4 $\mu\text{g at/l.}$).

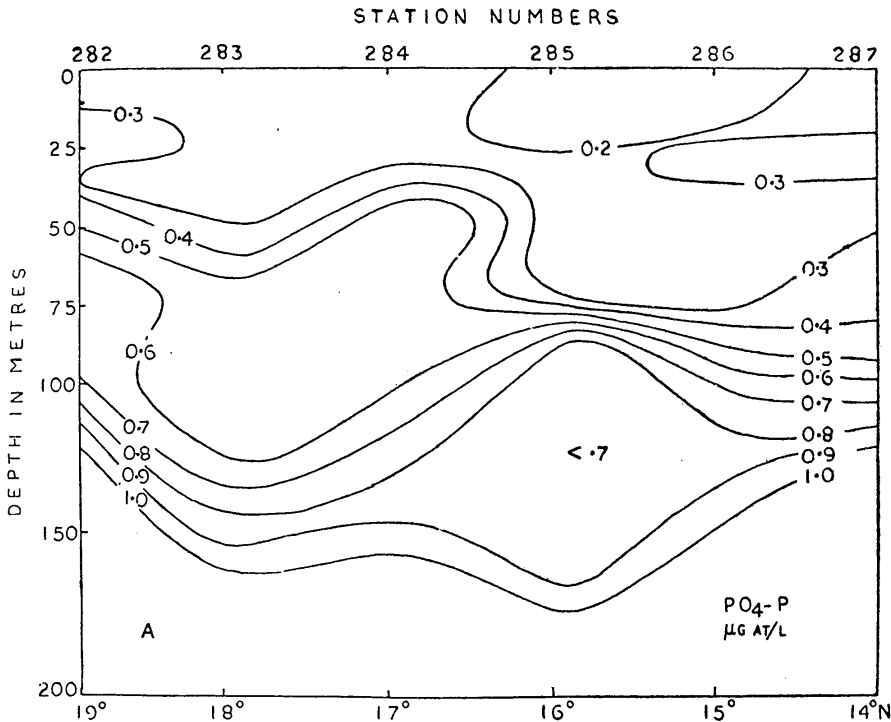


FIG. 2A.

FIG. 2(A-E). Vertical distribution of properties along 68° E meridian between Lat. 19° and 14° N

Vertical profiles indicate that the values tend to increase slightly depthwise up to 100 m. This is followed by a sharp increase at deeper levels reaching maximum concentrations of 1 to 1.5 $\mu\text{g at/l.}$ at about 200 m. Phosphate gradient is not well defined in the first half of the section. The gradient which is weak in the northern part, tends to become strong towards the mid section and further south the gradient again weakens. The phosphate values are relatively high in the northern end of the section. Between Lat. 16° and 15°N the concentrations are remarkably low at all depths.

Silicate values (Fig. 2B) down to 75 m are also low. They show more or less the same pattern of distribution as that of phosphates. The surface values ranged from 0.2 to 4 $\mu\text{g at/l.}$ Relatively higher values are found at deeper layers, reaching maximum values up to 14 $\mu\text{g at/l.}$ A strong gradient of silicate is noticeable in the northern most part between Lat. 19° and 17°N at 100 and 200 m. The

presence of the strong silicate gradient in the northern end is in contrast to that of phosphates which is noticeable only in the mid section, running at a higher level.

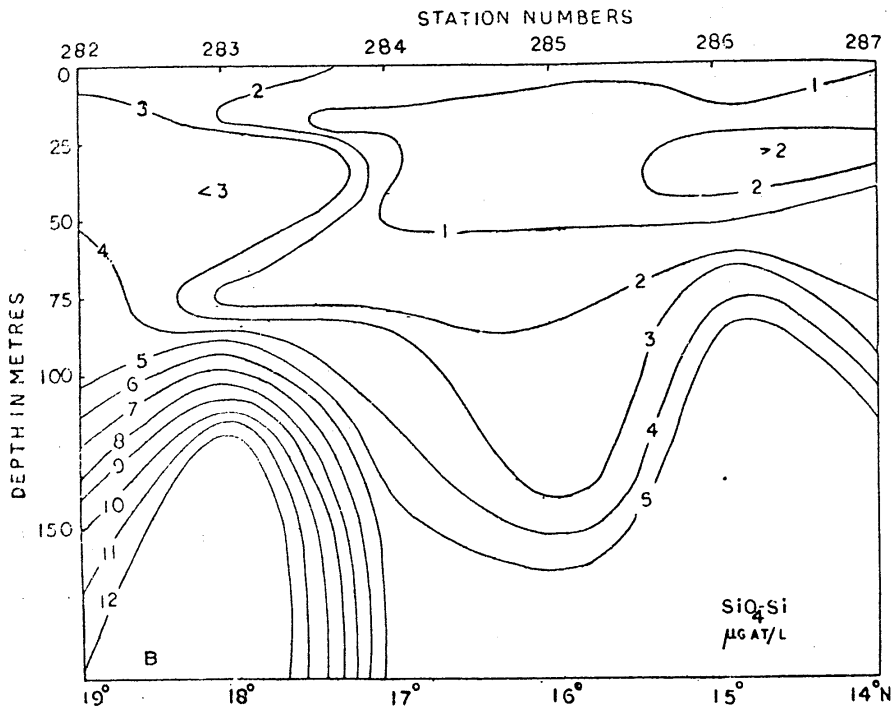


FIG. 2B

Temperature distribution (Fig. 2C) shows that the depth of mixed layer increases towards the South (from about 40 to 50 m in northern section to about 60 to 90 m towards South). The down slope of the isotherms towards south is significant enough to indicate the presence of an easterly current which is in accordance with the general current pattern described in the Admiralty (1950). Thermocline (gradient $2^{\circ}/25$ m) layer found between 45 and 75 m in the northern part up to 17° N Lat. penetrates gradually to deeper levels further south, setting between 75 and 130 m.

Salinity distribution shows more uniform variation with depth showing a decreasing trend down to 200 m (Fig. 2D). Distinct gradients are absent. Salinities decrease slightly towards south. The isohalines show a general reverse pattern to that of isotherms.

Oxygen distribution (Fig. 2E) within the upper 50 m shows little variation. Oxygen discontinuity is noticeable within the thermocline extending down to 200 m. The gradients are rather strong in the southern half. Minimum values of 0.5 ml/l. or less are normally found below 150 m. Along the north-south direction, values were found to be more or less constant, but the southern end of the section is marked by a decrease in Oxygen. Oxygen isopleths follow more or less the same trend as those of salinity and silicates.

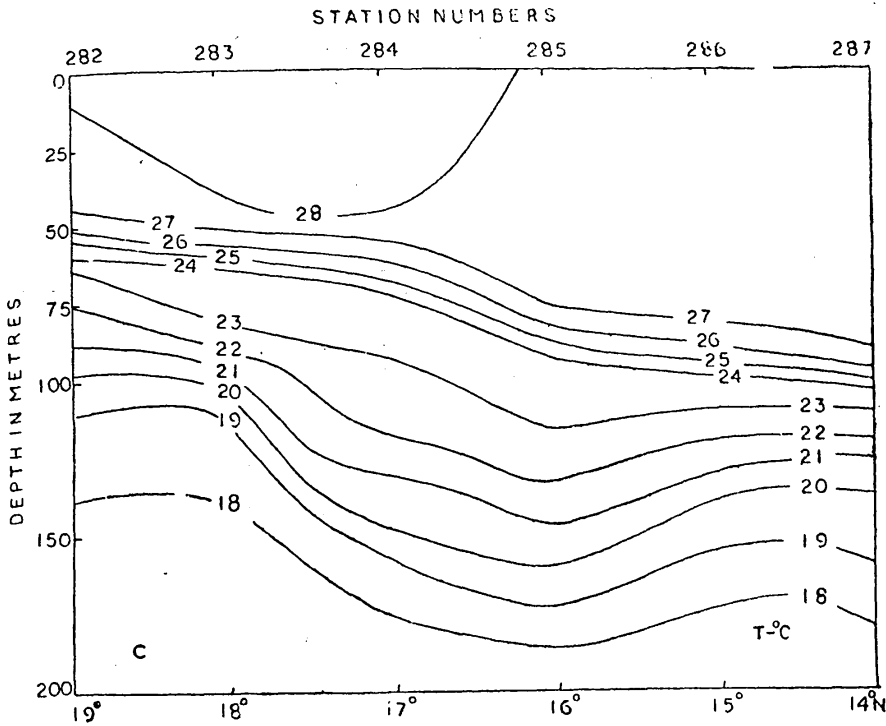


FIG. 2C.

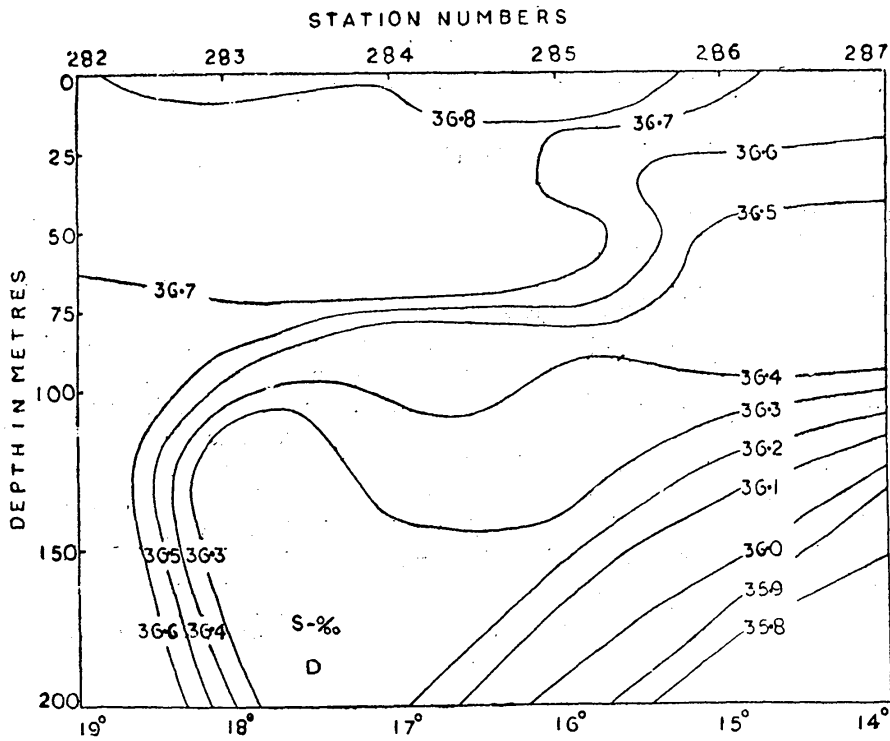


FIG. 2D.

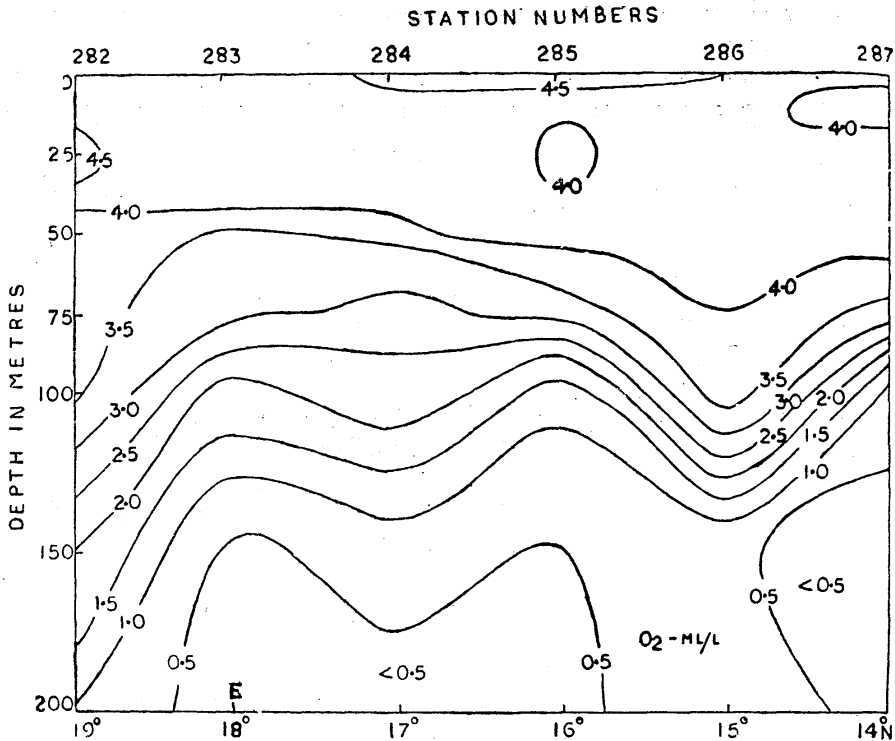


FIG. 2E.

Section along 71°30' E meridian between Lat. 8°N and 0°:

Phosphate levels in the upper 75 m are generally low ($0.3 \mu\text{g at/l.}$) and further south the low phosphate zone is limited to upper 50 m only (Fig. 3A). The isopleths at deeper levels (below 120 m) in the northern end of the section (Station 293), show a significant upslope towards south (up to station 294). Beyond that, the isolines converge and constitute a steep gradient delimited between 75 and 100 m. This gradient is maintained at the same level between 75 and 100 m up to Lat. $0^{\circ}58'N$ (Station 298). Near the equator the gradient weakens. A core of high phosphate (2 to $2.5 \mu\text{g at/l.}$) water is present between Lat. 6° and $1^{\circ}42.5'N$, just below the phosphate discontinuity layer (below 100 m) extending down to 200 m.

Silicates in the upper 75 m in the northern part up to about $6^{\circ}N$ Lat., in general, are low, the values ranging between 0.9 and $2 \mu\text{g at/l.}$ (Fig. 3B). Like phosphates, the silicates also exhibit a weak gradient (varying from 2 to $7 \mu\text{g at/l.}$) in the northern most station below 75 m and the isolines slope upwards towards south with simultaneous steepening of the gradient, setting between 80 and 130 m. Towards the equator the gradient tends to be weak and loses its identity near about the equator. Low silicate concentrations are observed just below the gradient

layer, in contrast to the higher phosphate values found in the same region (between Lat. 6° and 2°N).

Temperature profiles (Fig. 3C) indicate that the mixed zone is maintained down to 50 m along the entire section excepting in the northern end where it reaches

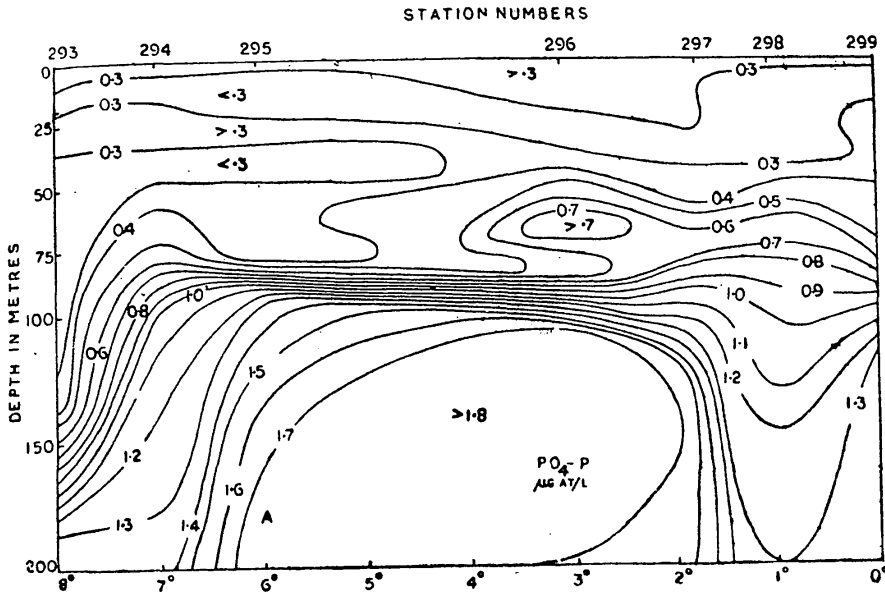


FIG. 3A.

FIG. 3(A-E). Vertical distribution of properties along 71° 30'E meridian between 8° N and 0°.

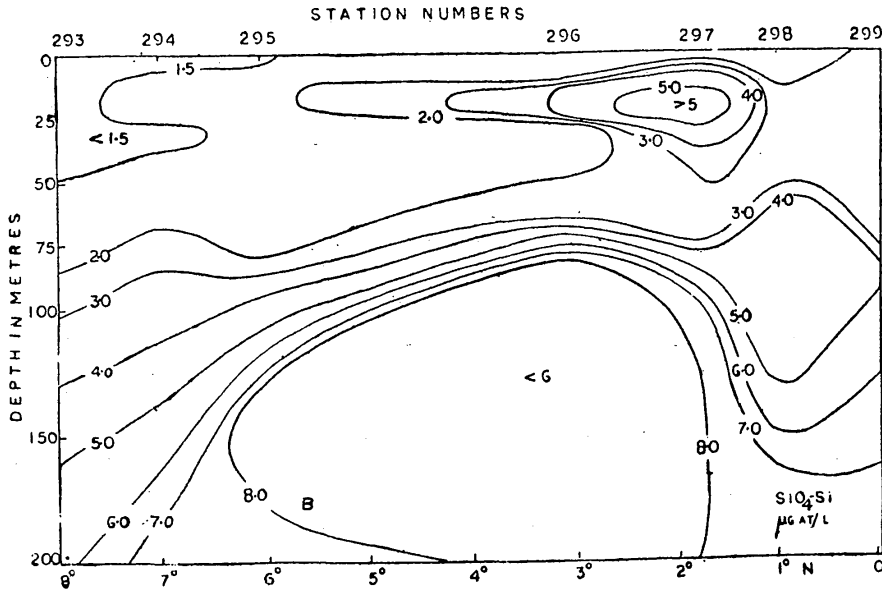


FIG. 3B.

down to 75 m. Isotherms slope upwards in the north-south direction up to 3°N. Lat. similar to those of phosphates and silicates. Thermocline layer varies between 100 and 150 m in the northern end. It migrates to upper levels between 50 and 100 m towards south and at the equator the thermocline tends to spread.

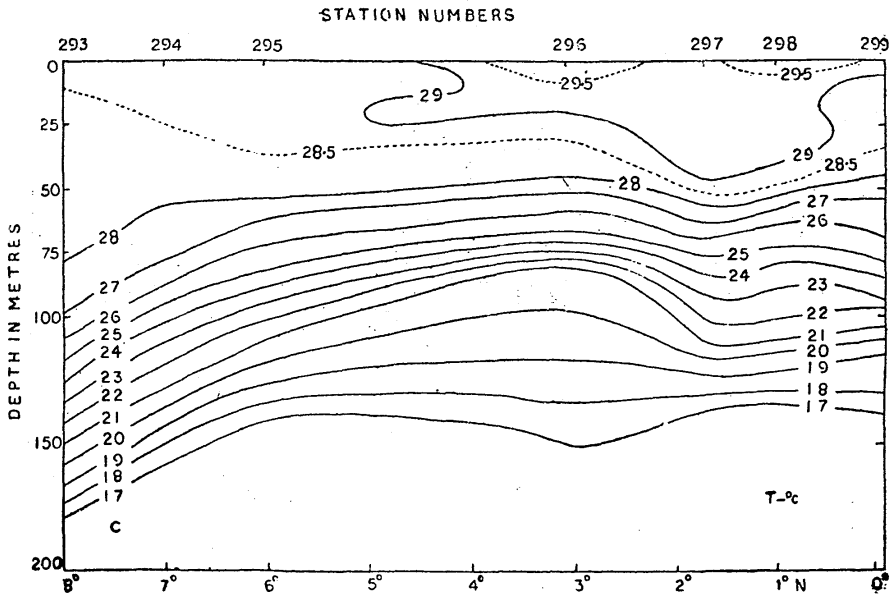


FIG. 3C.

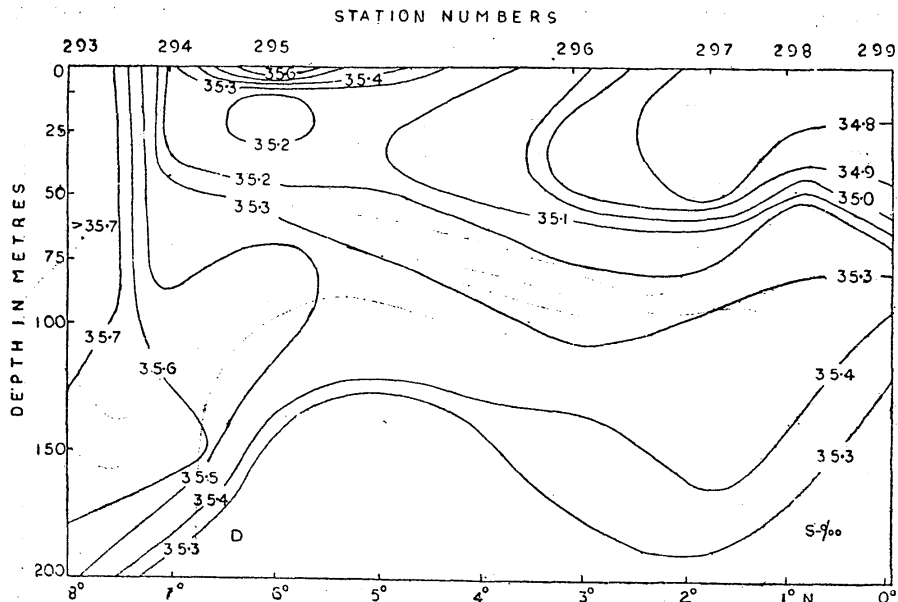


FIG. 3D.

Salinity profiles (Fig. 3D) do not bear any relationship with those of temperature. There is no marked variation with depth, except for a slight decrease from surface to 50 or 75 m. Below this depth a thin layer of relatively high salinity zone exists which is followed again by a gradual decrease in salinity down to 200 m. Northern part of the section is generally associated with higher salinities.

Oxygen values in the upper mixed zone show uniform distribution (Fig. 3E). Along the section towards the south, the surface values remain more or less uniform

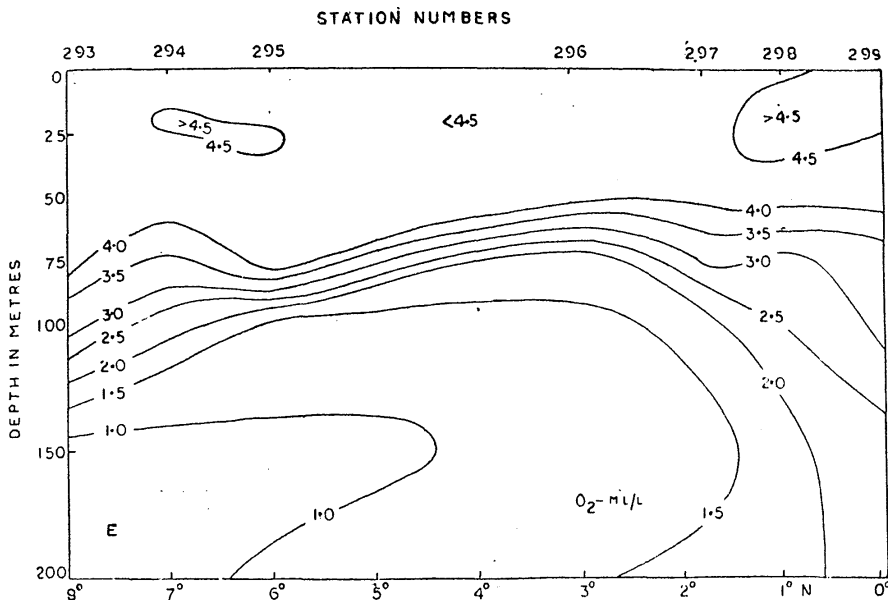


FIG. 3E.

up to 3°N Lat. and beyond that, the values tend to increase reaching maximum at the equator. Oxygen discontinuity layer coincides with the thermocline depth. Isolines show an upward extension towards south, tending to spread near the equator. Lowest values of less than 1 ml/l. are found below 150 m in the northern end of the section. But near the equator at almost the same levels, relatively more oxygenated waters occur (2-3 ml/l.).

Section along the Equator between 71°30' and 75°E:

Phosphate values of the surface layers (about 75 m) are particularly low and more or less uniformly distributed (ranging from 0.19 to 0.56 μg at/l.) (Fig. 4A). Little variations have been found along the west to east direction. Below 75 m the layer of phosphate gradient (varying from 0.6 to 1.5 μg at/l.) extending down to 150 m is present along the entire section. Below that the values tend to increase slightly and remain more or less constant (1.5 μg at/l.) to about 200 m.

Silicate concentrations (Fig. 4B) also are in general of lower magnitude in the surface, excepting that they are more variable than phosphates in the west to

east direction and slightly higher concentrations are found in the mid section. Progressive increase towards deeper levels becomes apparent. Surface values vary from 2 to 5 $\mu\text{g at/l.}$ and higher values of about 9 $\mu\text{g at/l.}$ are recorded at about 200 m,

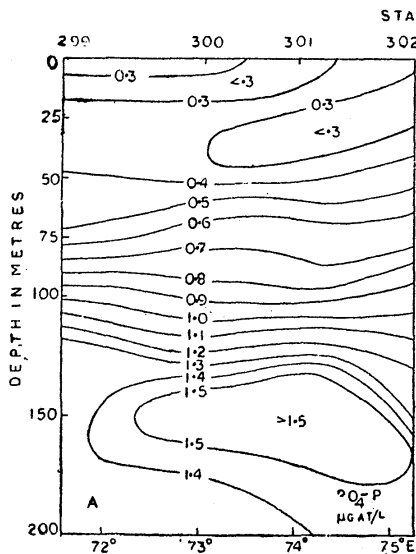


FIG. 4A.

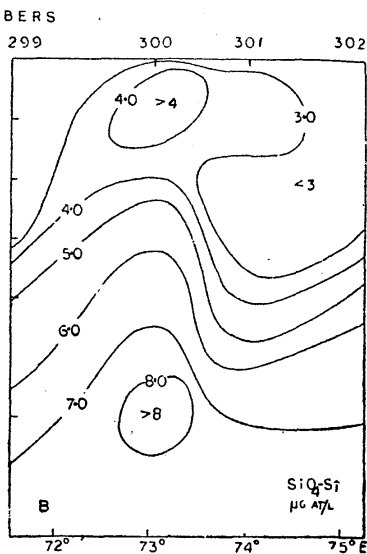


FIG. 4B.

FIG. 4(A-E). Vertical distribution of properties along the equator between 71° 30' and 75° E.

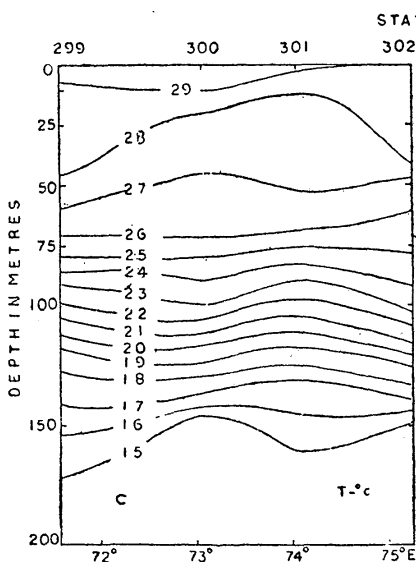


FIG. 4C.

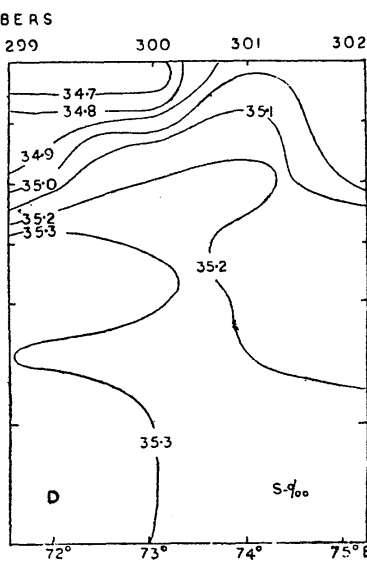


FIG. 4D.

Temperature distribution is uniform in the upper 75 m (Fig. 4C). The thermocline is present just below 75 m, spreading down to 150 m. Surface temperatures are slightly low towards east indicating an uplift of the subsurface layers within 50 m.

Salinity profiles also indicate a uniform vertical distribution (Fig. 4D). Progressive increase up to 75 m is noticeable, which is followed by isohaline conditions down to 200 m. Isohalines within 50 m show an upward tilt towards east resulting in the formation of relatively higher salinities as compared to the western part.

Distribution of oxygen (Fig. 4E) is relatively more uniform vertically and

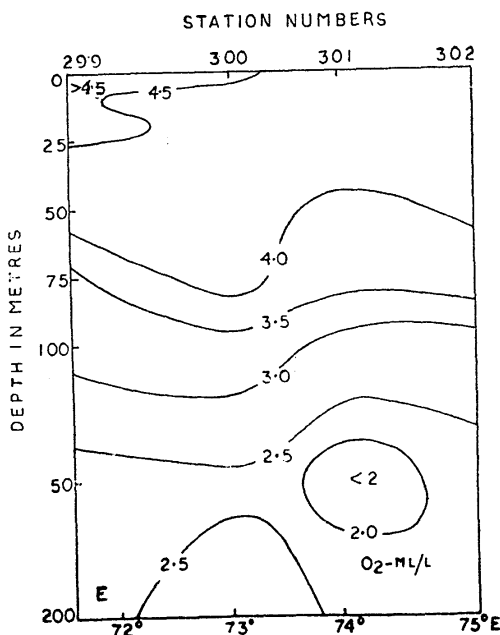


FIG. 4E.

horizontally as compared to the previous sections. Oxygen discontinuity is noticeable below 50 m and the gradient is weak. Lowest oxygen values of the order 2 ml/l. are found below 150 m. The oxygen isopleths tend to slope upwards in eastern part, similar to salinity and silicate profiles.

Section along 75°E meridian from 0° to 8°24.5' N:

Uniformly low phosphate levels are present down to 75 m along the entire section (Fig. 5A). The values being generally less than 0.5 $\mu\text{g at/l}$. Values of

phosphate varying between 0.5 and 1.1 μg at/l. are found between 75 and 120 m near the equator which are continued up to 3°N Lat. wherein there is a slight increase

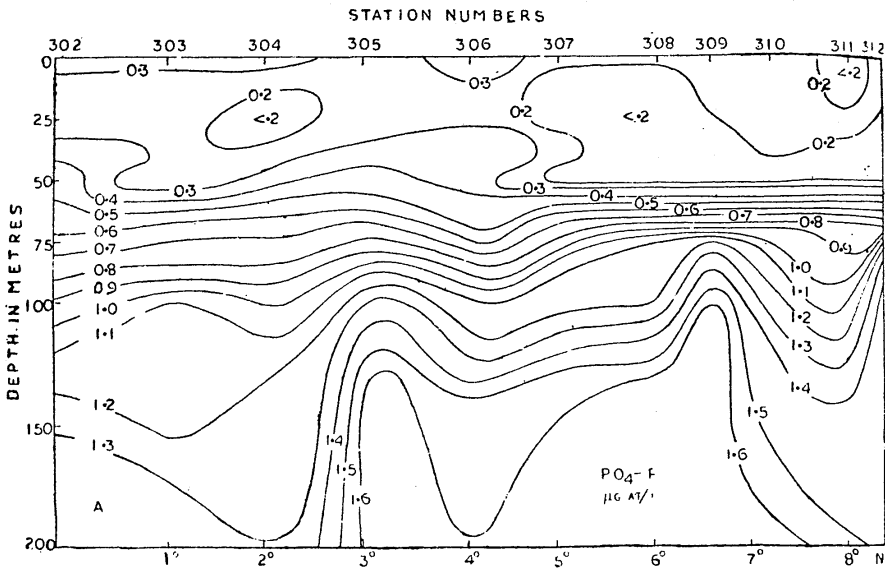


FIG. 5A.

FIG. 5(A-E). Vertical distribution of properties along 75° E meridian between 0° and 8° 24.5'N.

in the range (from 0.5 to 1.5 μg at/l.) with corresponding increase in the lower depth limit to 130 m. The general disposition of the profiles indicate a certain amount of instability below 75 m.

Surface silicates down to 75 m at both ends of the section are low varying between 1.2 and 3 μg at/l. (Fig. 5B). In the mid section between Lat. 4° and 5°N a slight increase in the values (3-5 μg at/l.) is noticeable due to upslope of the layers between 75 and 100 m. Values greater than 9 μg at/l. are present below 150 m. However, it may be mentioned that the profiles present an irregular pattern, suggesting the existence of eddies.

Temperature variations in the upper 10 m along the section are interesting (Fig. 5C). Near the equator the values are lower and northwards up to 5°N Lat., the temperature increases, and beyond a fall in temperature is again noticeable. The same trend is reflected down to about 40 m excepting that the intensity of variation is less marked between Lat. 3° and 6°N; there appears to be an upslope of waters from 30-40 m towards the surface thus causing the transition from higher to lower temperatures towards higher latitudes. Thermocline begins just below 75 m extending down to 150 m near the equator and breaks up towards 1°N Lat. limiting between 40 and 68 m only, and further north it extends down to 80 m. It

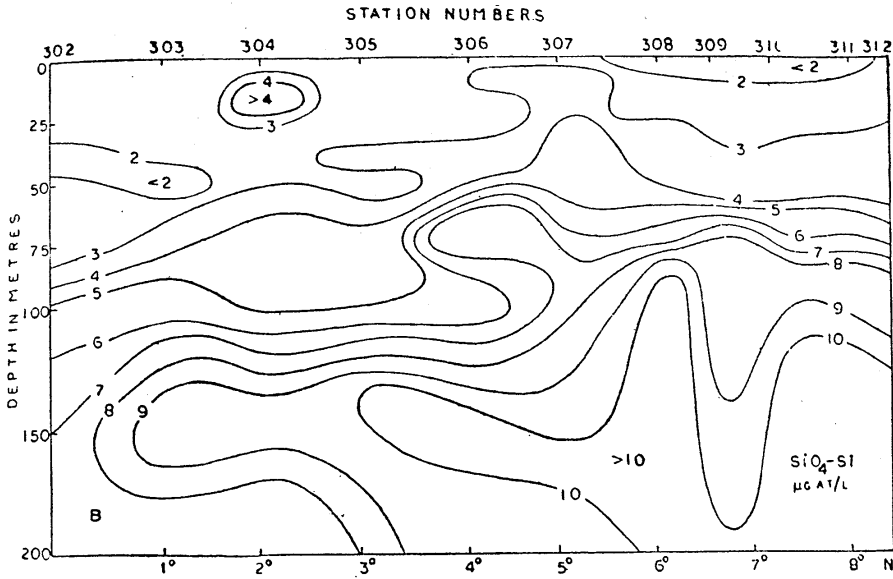


FIG. 5B.

may be mentioned here that meridionally the thermocline is tending to be weak from west to east direction. At deeper levels the vertical temperatures show relatively a uniform distribution; the general pattern of the isotherms suggest considerable movement of waters.

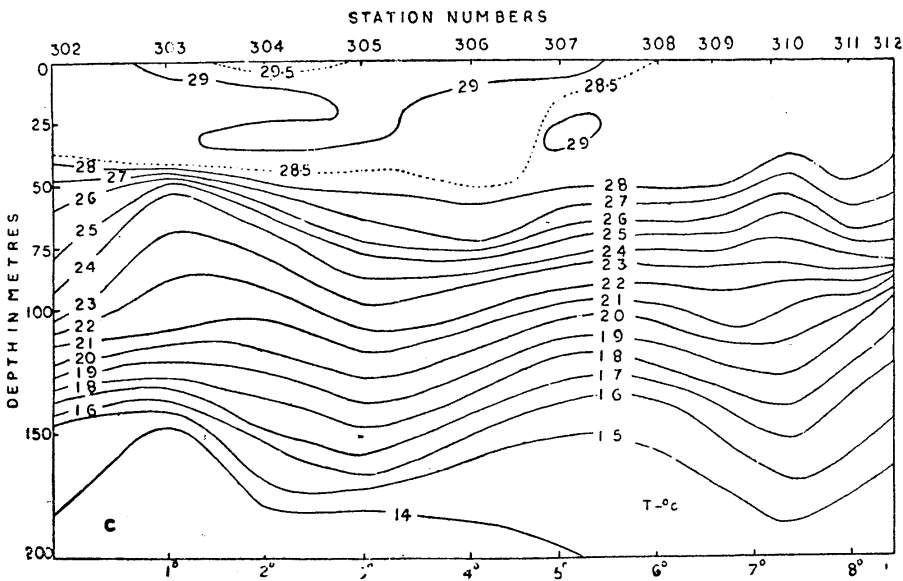


FIG. 5C.

Salinity distribution of the upper 75 m (Fig. 5D) presents an irregular pattern which might be the result of eddies as is also indicated while examining the distribution of the other parameters. There appears to be a general increasing trend from

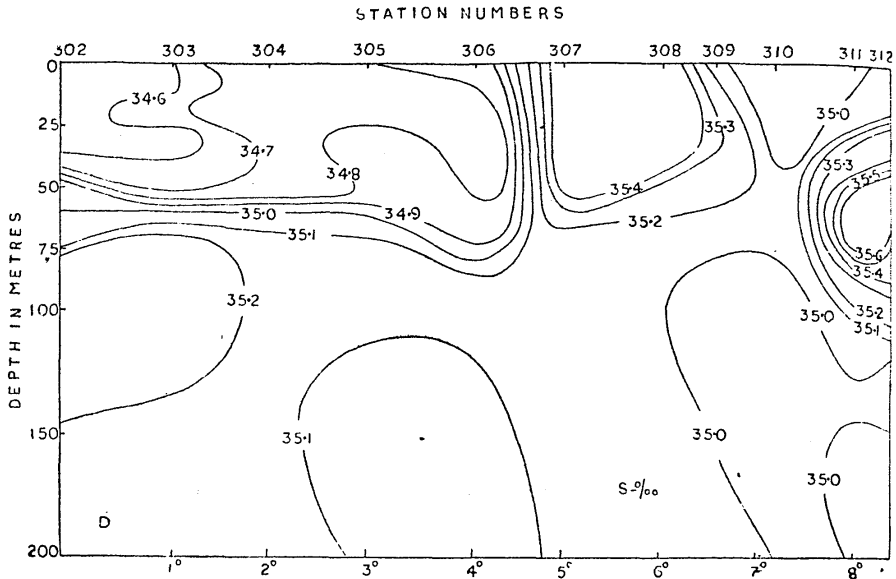


FIG. 5D.

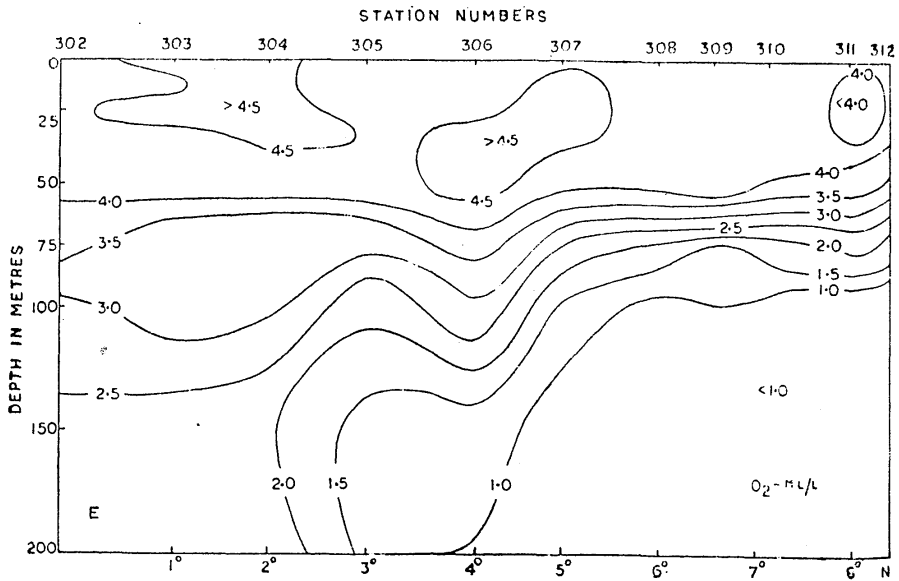


FIG. 5E.

south to north direction up to 2° Lat. followed by a fall up to 4° Lat.; rather a sharp increase is again noticeable up to about 7°N. Lat. and beyond a general lowering of the values are observed. Below 75 m the vertical variations are very little and remained more or less constant. In the northern end of the section a tongue of high saline water between 20 and 100 m appear to be moving northwards (the axis points slightly downwards). A layer of salinity maximum at about 100 m level extends all along the section excepting that the level shoals up towards north coinciding with the tongue of high saline water.

Vertical variations of the oxygen in the upper 50 m are little (Fig. 5E) and a general decrease in the values towards north is noticeable. Oxygen discontinuity begins below 50 m and the gradient which is weak near the equator tends to become stronger towards north. Oxygen poor layer (<1 ml/l.) is present at 4° N at 200 m level and towards further north it extends to shallow depths, reaching up to about 80 m.

DISCUSSION

Distribution of nutrients and other parameters like temperature and salinity in the open oceanic waters seems to be more uniform and regular than those in the inshore waters where the proximity of land introduces complexity in the nature of distribution of these parameters. Nutrients of the oceanic waters appear to be more dependent on the general current pattern and sources of origin of distinct moving water masses. Greater accumulation of nutrients at deeper levels and their consistency, irrespective of seasons and places may have far reaching significance in determining the fertility of surface waters. The deep nutrient rich waters seem to act as inexhaustible reservoirs and these may replenish the losses of nutrients of the surface layers caused by physical or biological factors. A knowledge of the spatial and temporal distributions of the nutrients in the oceanic regions is valuable in understanding their influence on the shelf waters which are more productive.

Present investigations are mainly related to the distributional aspects of nutrient salts in relation to some hydrographical factors of the upper 200 m waters in the Central Western North Indian Ocean during the south-west monsoon season in the month of August. The great impact of the south-west monsoon on the North Indian Ocean, resulting in the extensive movements and exchange of water masses in determining the biological productivity of the shelf waters of the Arabian and West Indian coasts are well established and as such the information on spatial variations of these important factors in the oceanic waters during this period may also aid in understanding the fertility of different regions.

Monsoon winds over the north Indian Ocean change the current pattern into two distinct types of circulations. During the south-west monsoon period the coastal circulation is clockwise and in the open ocean the current is easterly. But during the north-east monsoon period the entire pattern reverses. The current system becomes strong and stable during the south-east monsoon period in contrast

to that during the north-east monsoon. The effect of north-west monsoon is relatively weak over the North Indian Ocean. Towards the equator the general west going North Equatorial Current is replaced by stronger east going monsoon current during south-west monsoon season.

Water masses of the North Indian Ocean have the general characteristics of mid-latitudes and equatorial region and the main surface water mass extending to moderate depths is demarcated as North Indian Equatorial Water mass (Sverdrup *et al.* 1942). Present observations on the hydrographic characteristics are limited to the upper 200 m of this water mass.

Examination of the vertical profiles of nutrients reveal broadly two distinct features; a surface layer of low nutrient content extending down to 50 or 75 m followed by a region of higher and fairly steep gradient of nutrient concentrations down to 200 m. Considerable meridional and zonal variations in the thickness of these layers are apparent which may be mainly due to variable intensities of the current velocities and consequent vertical movements of the waters. These broad features in general, correspond to those observed in Pacific and Atlantic Oceans. Present investigations indicate that the nutrient levels in the regions of the North Indian Ocean under review, generally fall between those in the similar regions of Pacific (highest) and Atlantic (lowest). The major exception being the region north of 10° N in the Indian Ocean where in the surface values are observed to be higher than in Pacific. Temperature, salinity and oxygen profiles are consistent with the variations in the nutrient profiles. A scrutiny of the nutrient profiles with those of temperature, salinity and oxygen indicates a closer relationship of phosphates with temperature, while silicates with salinity and oxygen. This feature, perhaps is characteristic of the upper layers of the Oceanic waters of this region, in view of the relatively more labile nature of phosphates and temperature in the surface layers than the silicates, salinity and oxygen which are rather more stable, and which may often characterise the distinctness of a surface water body.

Phosphate distribution along the North-South direction presents some striking features; along 68° E meridian, even though the surface values are of low order along the entire section, concentrations tend to decrease further towards south up to 14°N Lat. This feature is in contrast to the conditions prevailing in the shelf waters along the West Coast of India wherein the phosphate levels tend to increase towards south (Reddy and Sankaranarayanan 1965). At deeper levels also, the increase in phosphate is not marked; the maximum of about 1 μg at/l. is found only at about 200 m. The probability of the existence of low phosphate levels in this region, might be due to the easterly transport of nutrient depleted surface layers off the Arabian Coast caused by the prevailing southerly component of south-west monsoon winds and these waters are continuously transported across the sea by the large eastward current. The general high salinity of the region is also in agreement with the above explanation. The secondary effect of these impoverished waters in lowering the phosphate content towards deeper levels (down to 200 m) might have been thus indicated as a result of progressive mixing. The

general disposition of the isopleths also indicate considerable amount of water movements along the entire section.

Silicate distribution also corroborates the inferences drawn from those of phosphate data. It is significant to note that in the northern region between 19° and 17° N Lat., below 100 m, the formation of silicate isolines of relatively higher concentrations suggest an apparent streaming up of silicate rich waters. While salinity and oxygen profiles are in agreement with the above observation, those of phosphate and temperature do not indicate this feature. Possibly this might be due to relatively small vertical variations of phosphate or temperature as compared with the silicate or salinity.

Remarkably low nutrients between stations 284 and 285 (Lat. $16^{\circ}30'$ to $15^{\circ}30'$ N) with corresponding increase in depth of mixed zone is noticeable indicating marked convergence which may possibly be due to the influence of horizontal eddies.

The southern section along $71^{\circ}30'$ E from Lat. 8° N extending to the equator, is characterised by deeper mixed zone extending down to 75 m. Generally phosphates and silicates, even though continued to be low show slightly increasing trend towards the south and this feature is more distinct near the equatorial region. A core of high phosphate layer containing relatively lower silicate and oxygen concentrations, is found below 100 m, in the region extending approximately between 2° and 6° N along 71° E meridian. The indications suggest a distinct water body with longer residence time and thus perhaps accounts for higher phosphate and lower oxygen contents due to biochemical oxidation. The strong discontinuity layer in the area might be impeding vertical mixing and thus promoting regenerative processes. Around 8° N along 71° E a rather abrupt variation in all the parameters, particularly in salinity and temperature is noticeable towards south. Temperature and nutrients show an increase while salinity and oxygen show a decrease. The salinity and temperature magnitudes at either sides of the transition region are suggestive of sinking process. Towards the equator, nutrients, temperature, salinity and Oxygen profiles show a slight and gradual uplift of the waters from about 75 m to the upper levels. This phenomenon may be attributed to the natural sequences associated with the equatorial divergences. Varadachari and Sharma (1964) presenting the seasonal distribution of divergence field of the surface waters in the north Indian Ocean, showed the occurrence of several centres of divergence and convergence in the open ocean regions throughout the year, more intense field being in the south-west monsoon period, particularly in equatorial regions. The general pattern of equatorial divergences and centres of convergences in regions north of equator in the south-west monsoon period as could be inferred from the present observations, are in broad agreement with their findings. However it may be mentioned that the nutrient levels at the surface layers near the equator are continued to be of low order in spite of the divergences and consequent upwelling. From the vertical profiles of nutrients, it is seen that the uplift of waters is restricted to within the shallow depths wherein the nutrient concentrations are not high and thus indicating that intensities of divergences in the equatorial Indian Ocean may be of lower

magnitude than in the counterparts of the other Oceans. Possibly this difference between the equatorial Indian and the equatorial Pacific and Atlantic Oceans, appears to be somewhat related to the absence of the regular west going North Equatorial Current in the Indian Ocean during this period and instead the presence of east going monsoon current. In the Pacific and Atlantic the general equatorial current systems remain unchanged throughout.

However, the situation in the North of equator (beyond 10°N) presents a different picture in the Indian Ocean, wherein higher surface nutrient concentrations are found to exist, compared with the same regions of other Oceans. Armstrong (1965) while discussing the phosphate distribution in the oceans, mentions that in the Central Pacific region between 40° and 10°N and away from the coast, lower surface concentrations of less than $0.16 \mu\text{g at/l.}$ were encountered. Present investigations in Central North Indian Ocean show relatively high surface concentrations ($0.3 \mu\text{g at/l.}$) of phosphate between 20° and 10°N as compared with the same region of the Pacific.

Another notable feature in the Central North Indian Ocean is the presence of relatively shallow zone of phosphate low layer extending from surface to only 75 m as compared with the similar zones which are generally thicker, extending down to 100 m or more in North Pacific and Atlantic. This featural difference may have an important bearing in rapid exchange of nutrients to the surface layers from the nutrient rich sub-surface layers, and thus may explain the existence of relatively higher surface concentrations in the Central North Indian Ocean than in the same regions of the Pacific and Atlantic.

Nutrient concentrations along the equator between 71° and 75°E do not show the expected higher levels. Phosphates and temperature profiles (Fig. 4 A & C) exhibit more or less a normal pattern while the silicates, salinity and oxygen profiles (Fig. 4 B, D & E) indicate fairly a marked divergence pattern in the upper 70 m between 72° and 73°E meridians. Phosphate and temperature profiles also do agree to some extent with the above feature, though not strongly indicative and this is obviously due to more uniform vertical characteristics of both the parameters within that layer. Thermocline is present at deeper level (70 m) spreading down to 150 m and is maintained throughout at the same level. Phosphate gradient coincide with the thermocline. Salinity gradients are limited to upper 70 m only while the silicate and oxygen profiles do not exhibit strong gradients. The characteristic spreading of the thermocline, nutrient and oxygen isolines at the equator was also reported by Knauss (1964) and Gangadhara Rao and Jayaraman (in press) and related to the presence of an undercurrent. However the discussion relating to the presence of this current is beyond the scope of the present paper.

The section running south to north along 75°E gives some idea in the meridional variation in the distribution of nutrients, running parallel to the North-South section along 71°E . However, the observed meridional and zonal differences appear to be more influenced by the Maldiv Islands positioned between these two sections (at 73°E). The nutrients register an increasing trend towards south along both the sections. In the northern half, the concentrations are in general, slightly

higher on the western side, while along the southern half, only the surface waters show slightly higher concentrations towards east. The nutrient values in the eastern equatorial region and the distribution might be associated with the monsoon current augmented by the island effect. In the northern half, the observed low values on the eastern section could possibly be related to the diffusion of the southerly current, contributing the nutrient depleted waters. Another notable feature is the relatively low stability of the waters towards east, as could be seen from the thermocline structures and the disposition of nutrient isopleths (Fig. 5 A-E). Around 5°N Lat. along 75°E a marked transition in the water properties could be noticed (Fig. 5 A-E). The indications point to boundary conditions. Investigations by Varadachari and Sharma (paper under publication) on the circulation of surface waters in the north Indian Ocean, showing some point similarities and line similarities in the streamline pattern of the circulation, documented a line convergence around the same region. It may be mentioned here that this region may be limiting the extent of the spread of southerly flow and thus forming a boundary with the easterly monsoon drift current.

A brief comment on the abundance of zooplankton in some parts of the ocean during the cruise may reveal some interesting features related to nutrients and other oceanographic features. Zooplankton samples were collected from some regions covered during the 13th cruise. Several earlier workers have reported a correlation between zooplankton and $\text{Po}_4\text{-P}$, and other oceanic features such as thermocline, and pycnocline topographies in the Pacific and Atlantic Oceans (King and Hida 1957; Holmes *et al.* 1957; Brondhorst 1958; Reid 1962).

Zooplankton organisms (in terms of displacement volumes collected from the upper 200 m using IOSN) between Lat. 8° and 0° N along 71°E show a general increase towards the equator and along the equator between 71° and 75°E. Along 75°E there was a sharp decrease towards north of equator up to 3°N and beyond this position a short increase in zooplankton organisms (3 to 6 fold, became noticeable). The increase of zooplankton toward the equator along 71°E coincided with the general upslope of the isopleths. Higher zooplankton content along the equator also seem to be associated with divergences. However the sharp decline in zooplankton along 75°E towards north of equator up to 3°N presents a complex situation. Since the nutrient concentrations in this region are more or less same as those along the equator and relatively higher than further north (between 3°N and 8°N), the sharp reduction in zooplankton might be associated with hydrographical conditions or may be related to natural sequences of the food cycle. It is also possible that in this region a greater intensity of easterly current and the presence of large eddies might be responsible for the low plankton content. The very high incidence of zooplankton between 3° and 8°N along 75°E is in close correspondence with the boundary conditions observed (*loc. cit.*) between eastward monsoon current and the spread of the southerly flow. The waters of the southerly flow along the West Coast of India might be contributing to the extremely high plankton concentration of this region. Synchronously the low nutrient content of the same region suggests that the waters brought in by the southerly current were stripped off their nutrients

during their sojourn along the West Coast of India due to high biological productivity and thus contributing to the observed increase in the biomass of the region.

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