VERTICAL DISTRIBUTION OF TEMPERATURE, SALINITY AND DISSOLVED OXYGEN IN THE MALDIVE REGION OF THE INDIAN OCEAN

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ABSTRACT

The hydrographical features existing in the region from 1° S to 8° N between the meridians of 71° E and 80° E during September—October 1962 are presented and discussed. A well-developed thermocline is observed in the investigational area and an upslope towards north is noticed in the eastern regions. Below 500 m depth the distribution of temperature in all the sections are similar. A salinity maximum is observed in the northern part of all the sections at the top of the thermocline and towards the equator this maximum is not at all conspicuous, and the water masses have more or less uniform salinity throughout the vertical. Dissolved oxygen distribution in the vertical showed good comparison to the observations already made in the Laccadive region. Occurrence of oxygen deficit layer between 300 and 1250 m is observed with increase in oxygen content from 1250 m downwards, and values as high as 3.5 ml/l were observed at 3000 m depth.

INTRODUCTION

Hydrographic investigations along the west coast of India have been conducted by the Central Marine Fisheries Research Institute since the year 1957, and various publications have been issued based on the data collected during the cruises on board the research vessels *Varuna* and *Kalava* (Sastry and Myrland, 1960; Ramamirtham and Jayaraman, 1960; Jayaraman *et al.*, 1959; Patil and Ramamirtham, 1963). Patil and Ramamirtham (1963) discussed the hydrographic features in the Laccadive region during winter and a preliminary discussion of the dissolved oxygen content at deeper layers was made. Anand *et al.* (1968) discussed the temperature and oxygen distribution in the north Indian Ocean during monsoon period of 1963 and 1964. In the present paper the vertical distribution of temperature, salinity and dissolved oxygen content in an area covering the meridional region 71° - 80° E within the latitudes of 1° S and 8° N is discussed.

DATA AND METHODS

The data were collected during the cruises of R. V. *Varuna* conducted in connection with the International Indian Ocean Expedition during September-

October 1962. Forty two hydrographic stations were occupied (Fig. 1) in four meridional sections. The observations were extended to depths of 3000 - 4000 m in deeper waters. The vertical distribution patterns of temperature, salinity and dissolved oxygen content were plotted for each section. An enlargement of the upper 200 m layer is also given along with each chart to have a clearer idea of the distribution pattern in the upper layers.

Vertical Distribution of Parameters

Section I

This section lies in a meridional direction (average longitude being 71° 30' E) extending from equator to 6° N. The distribution of temperature (Fig. 2) reveals the presence of a clearly formed mixed layer, the average thickness of

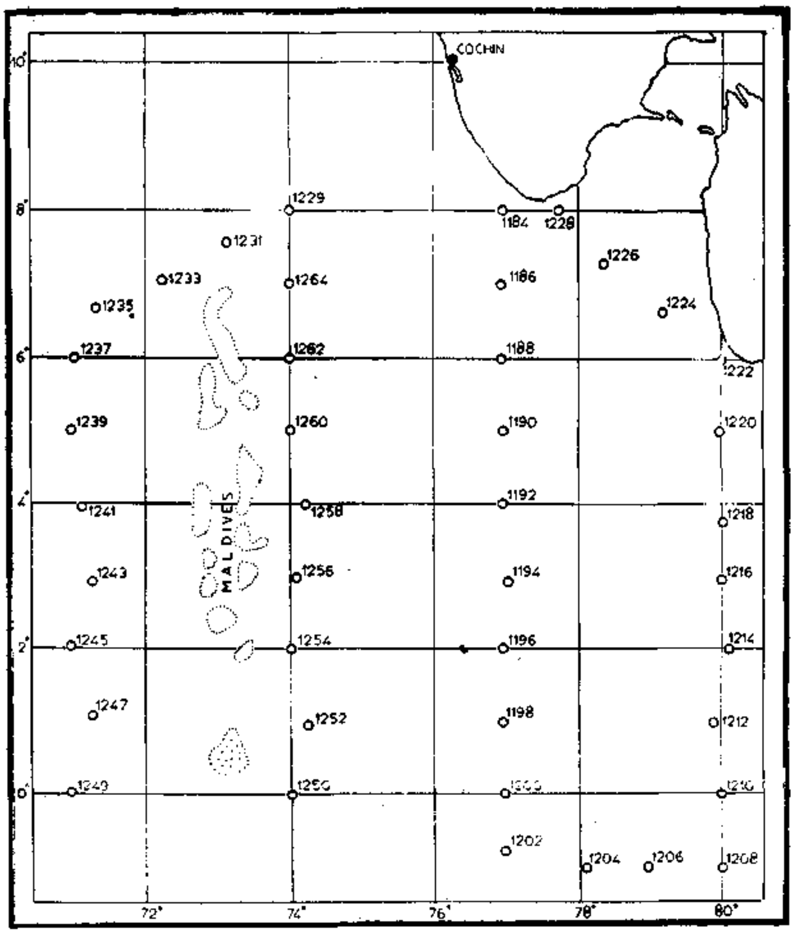

Fig. 1. Geographical positions of the hydrographic stations investigated.

which is 70 m. The thermocline starts at about 70-75 m and the vertical stratification is stronger in the northern regions. Spreading of the thermocline is conspicuous in the region close to the equator. Except for a depression at station 1243, the upper part of the thermocline is mostly level, but in the lower portion there is found an upslope towards north. In the deeper layers (below 500 m) the temperature distribution is mostly uniform and the isotherms are mostly level indicating static conditions.

The distribution of salinity shows the presence of a salinity maximum zone in the northern part of the section. This region coincides with the top of the thermocline. Towards south the salinity is found to decrease (Fig. 3) and the minimum salinity value is observed near the equator within the mixed layer. This agrees with the general concept that minimum salinity in the ocean surface is found at equator, and maximum at 20°N and 20°S. Below 100 m depth the salinity values decrease and below 1000 m more or less uniform values are observed.

As regards the distribution of dissolved oxygen content, the distribution in the whole mixed layer appears to be uniform, values ranging from 4 to 4.5 ml/l. Rapid decrease depthwise is noticed within the thermocline and the nature of the isolines of dissolved oxygen resembles that of the isotherms. A layer of low oxygen content (values less than 2 ml/l) is noticed between 500 and 1500 m and the oxygen minimum layer is centred in the northern regions around 1000 m, the value within the layer being less than 1.5 ml/l. Below 1500 m the values of dissolved oxygen content increase and values as high as 3.45 ml/l are observed at a depth of 3500 m (Fig. 4).

Section 2

This section lies to the east of the Maldives Archipelago and is oriented in a north-south direction along the 74°E meridian. Unlike the previous section the thermocline starts at a shallower depth in the southern regions (Fig. 5). But the northward upslope is not so conspicuous as in the previous section. The spreading of the thermocline is of a lesser extent. In the deeper part of the thermocline the northward upslope is more, indicating lower temperatures in the northern regions. In the deeper layers (below 1000 m) the meridional distribution is quite uniform (Fig. 5).

The extension of a high saline tongue southwards is again noticeable in section 2 (Fig. 6). The core of this high saline tongue lies at about 50-60 m and the core values lie between 36.2 and 36.4‰. Towards south, the salinity value decreases and minimum values are noticed near the equator. Below 150 m depth, the salinity values are found to decrease and below 1750 m the values are less than 34.8‰.

The vertical distribution of dissolved oxygen content is very similar to that in section 1, especially in the upper layers (Fig. 7). The high values in the mixed

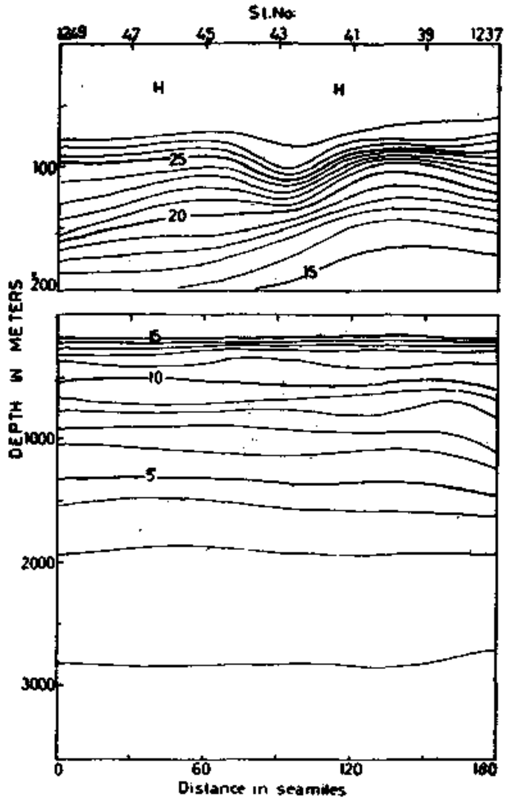

FIG. 2

Vertical distribution of temperature in section 1; Vertical exaggeration for the overall section is 160 and is constant for all sections except the enlargements given in each.

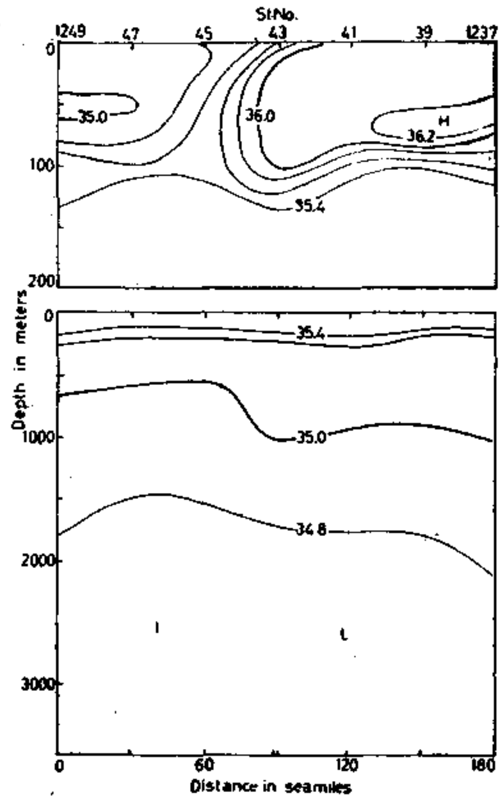

FIG. 3

Vertical distribution of salinity in section 1.

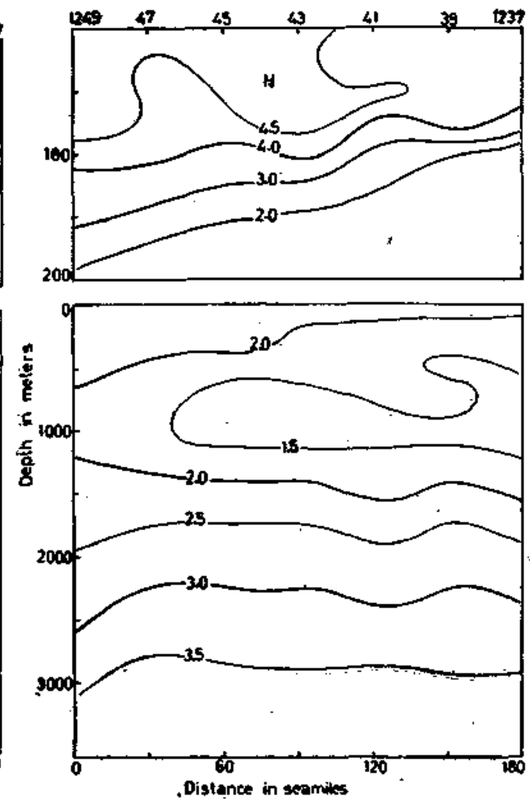

FIG. 4.

Vertical distribution of dissolved oxygen content in section 1.

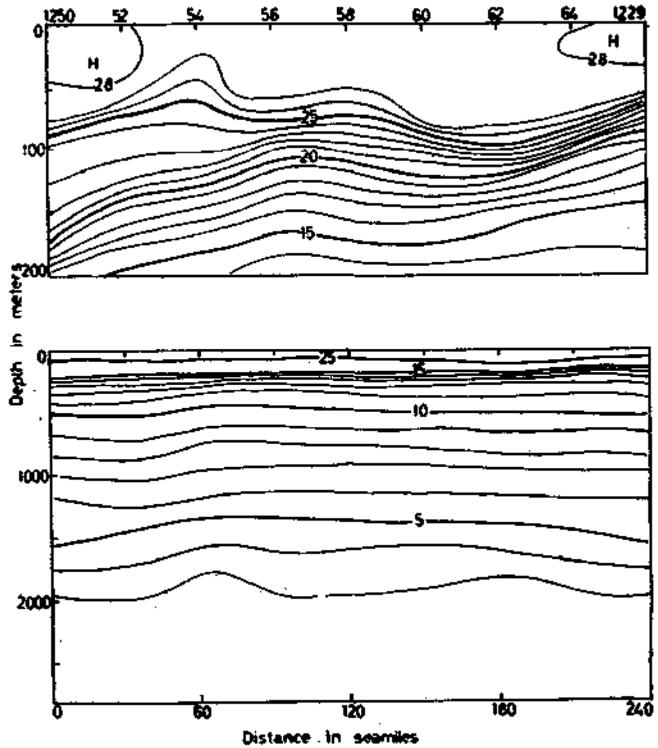

FIG. 5
Vertical distribution of temperature in section 2.

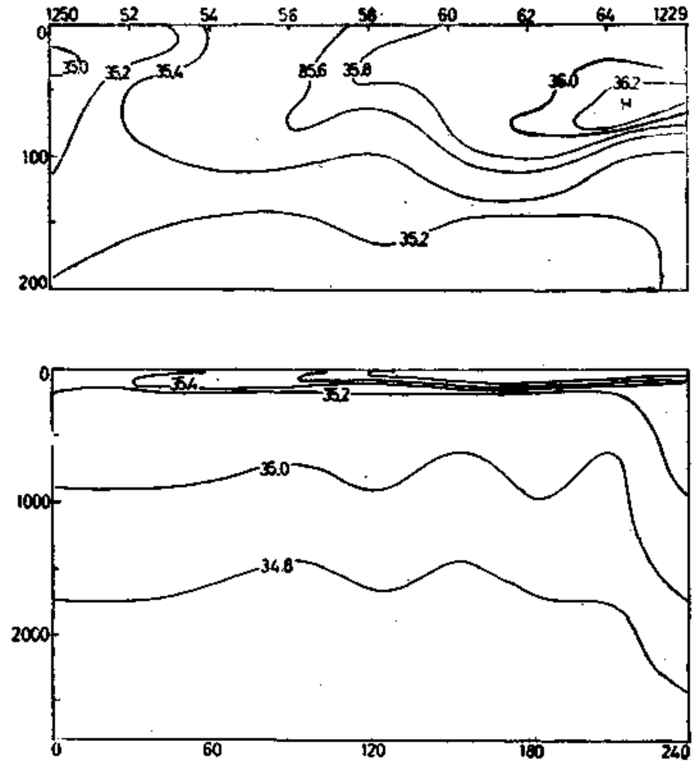

FIG. 6
Vertical distribution of salinity in section 2.

layer and the minimum zone around 1000 m depth are all again evident, and values as high as 3.5 ml/l are conspicuous at about 3000 m depth.

Section 3

Distribution of temperature in section 3 (Fig. 8) indicates the presence of a shallower thermocline in the northern regions compared to the previous sections. The mixed layer in the southern regions is developed as a warm isothermal zone unlike the northern regions. Wavy nature of isotherms is noticed with a clear depression at station 1196. The vertical stratification of the thermocline is more

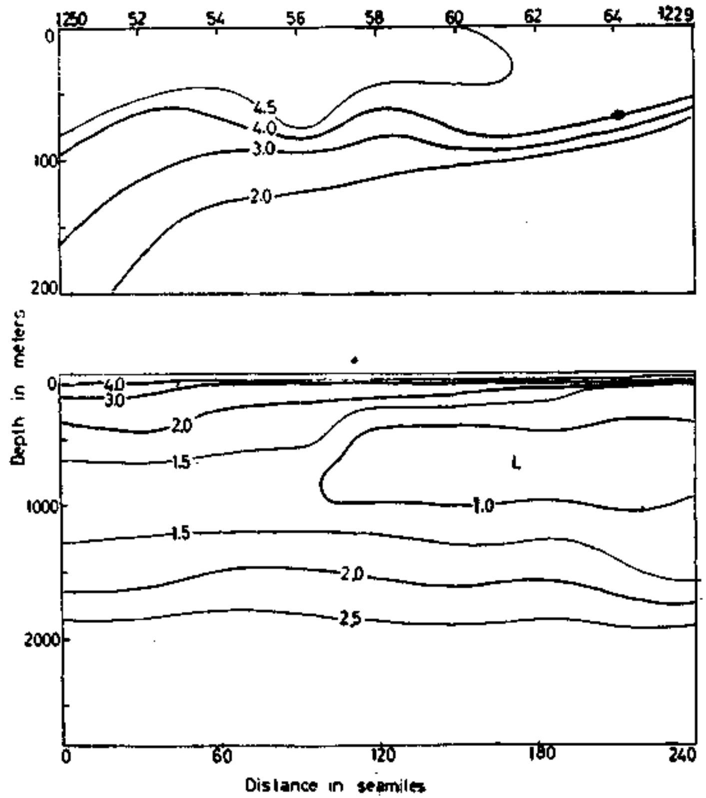

FIG. 7. Vertical distribution of dissolved oxygen content in section 2.

intense than the previous sections and spreading of the thermocline is much less. Although the temperature discontinuity layer is mostly level due south of station 1196, there is a conspicuous northward upslope in the region north of station 1196. In the deeper layers the temperature distribution is comparable to those in previous sections.

With a well-defined gradient of salinity in the surface layer between stations 1194 and 1190 the distribution of salinity indicates the presence of one high saline

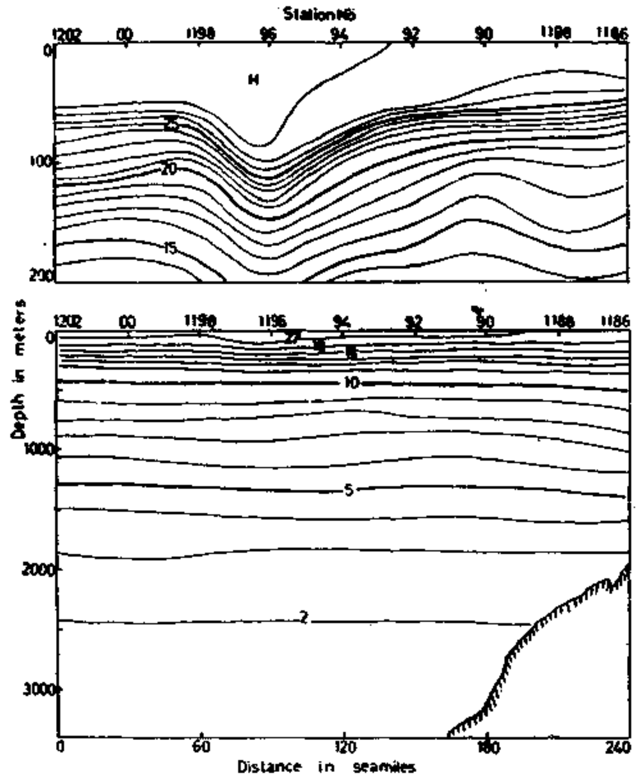

FIG. 8
Vertical distribution of temperature in section 3.

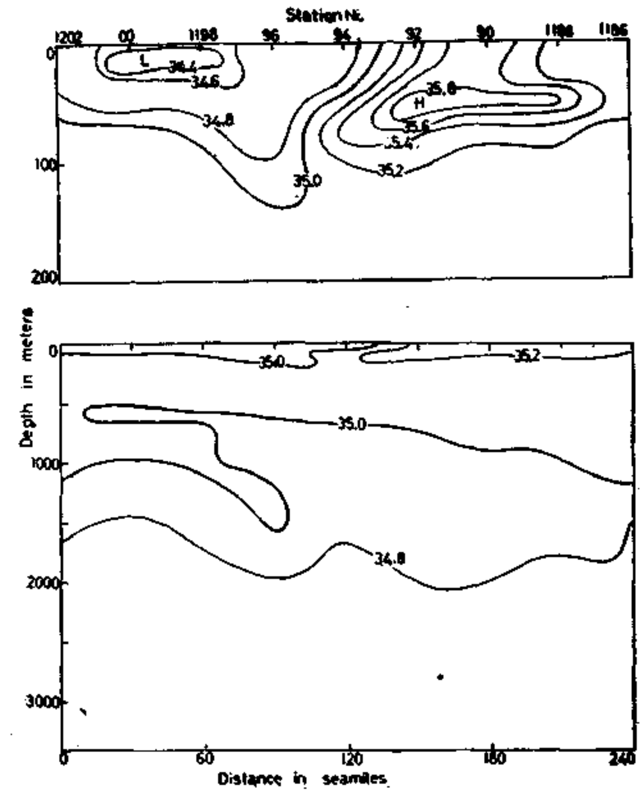

FIG. 9
Vertical distribution of salinity in section 3.

cell in the north and one low saline cell in the south (Fig. 9). The core of the high saline cell coincides with the top of the thermocline in the northern regions and the low saline core lies at very shallow depths near the equator. It is noticed that the low saline region lies mostly in the high temperature zone discussed earlier. As noticed in the previous sections the salinity values below 1000 m depth are low (Fig. 9).

The distribution of dissolved oxygen content in section 3 reveals the presence of a high oxygen zone in the surface layers, in the northern regions. Within the thermocline the oxygen values are higher in the southern regions. The oxygen

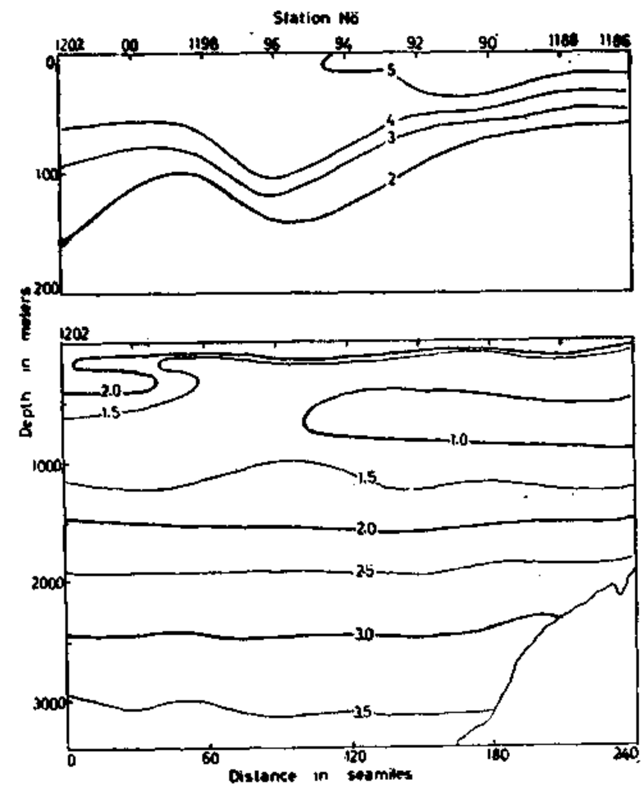

FIG. 10. Vertical distribution of dissolved oxygen content in section 3.

deficit zone is similarly placed and the distribution in the deeper layers is comparable to the previous section, high values occurring at about 2500-3000 m (Fig. 10).

Section 4

It is observed from the temperature distribution in section 4, that the temperature discontinuity layer is well stratified compared to all other sections

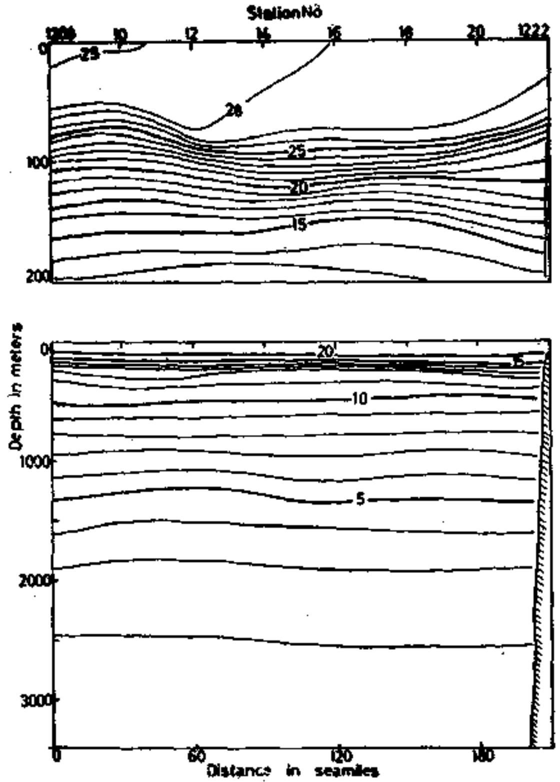

FIG. 11
Vertical distribution of temperature in section 4.

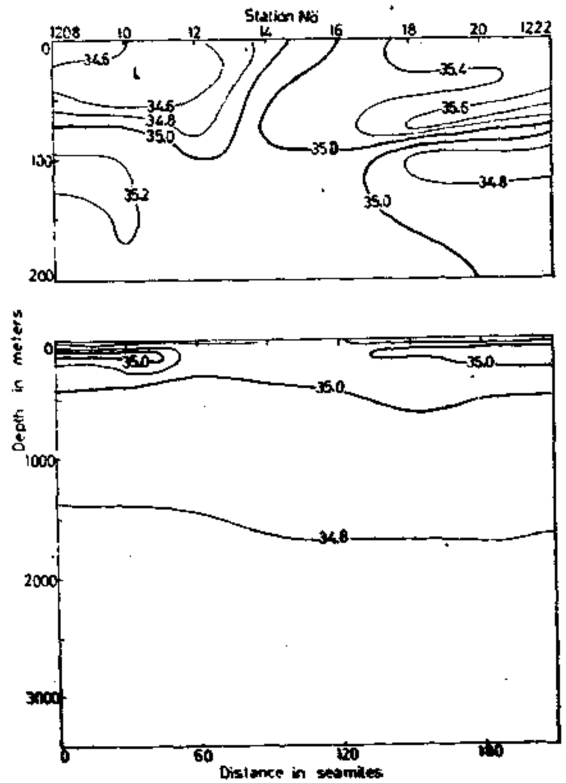

FIG. 12
Vertical distribution of salinity in section 4.

(Fig. 11). In the mixed layer high temperatures are found in the southern regions and a high temperature zone is developed. Considering a single level surface within the thermocline, the temperature values are minimum, compared to the previous sections. Another feature noticed is that the thermocline is mostly level unlike the other sections, where slope of thermocline was noticed. In the deeper layers distribution is mostly uniform in the whole section, as observed earlier.

The distribution of salinity in section 4 reveals the presence of one low saline zone in the mixed layer in the southern regions, and a salinity maximum

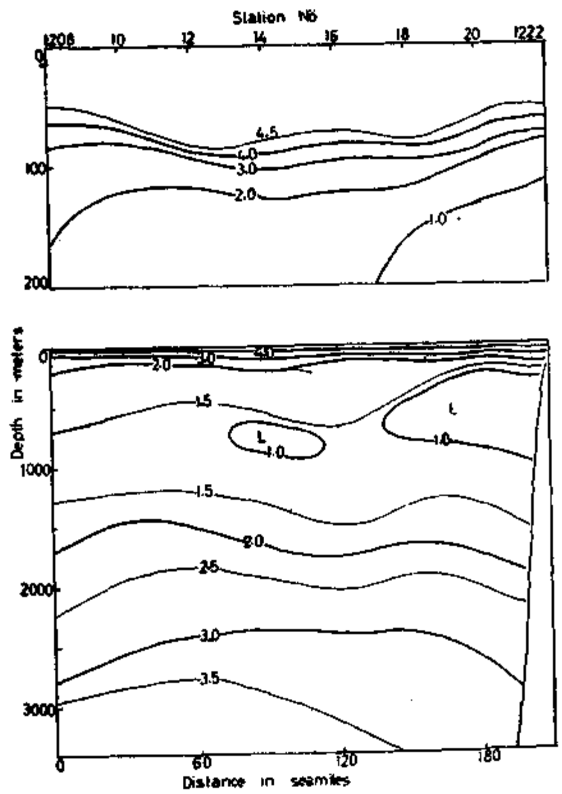

FIG. 13. Vertical distribution of dissolved oxygen content in section 4.

zone in the northern regions, situated at the top of the thermocline, as noticed in the earlier seetion (Fig. 12). Below the salinity maximum zone a low saline zone is also evident within the thermocline, a feature not observed in the earlier sections. Below 1000 m depth the distribution is mostly uniform.

The distribution of dissolved oxygen content in the mixed layer is quite uniform and the values are between 4.5 and 5.0 ml/l (Fig. 13). An abrupt decrease within the thermocline is observed and the oxygen minimum zone is again conspicuous, as in the previous sections, around 1000 m. The depthwise increase from 1250 m is again observed and values as high as 3.5 ml/l are found around 3000 m depth.

Discussion

The results presented show that there is a gradual increase of temperature of the mixed layer towards the south, and maximum of 29° C and above is found in section 4 near the equator. Anand *et al.* (1968) have observed comparable features in the equatorial region during monsoon. Thermocline is well stratified in all the sections, but towards east the depth of thermocline is shallower and the northward upslope is more conspicuous. This observation is in accordance with those made by Gangadhara Rao and Jayaraman (1968). Except in the easternmost section, wavy pattern of isotherms is noticed at the top of the thermocline which can be attributed to the presence of internal waves. Similar features are reported elsewhere too (Gangadhara Rao and Jayaraman, 1968). These authors, while investigating a meridional section across the equator, have also observed that the thickness of the mixed layer is less in the southern regions than in north, and that the thermocline at equator is shallower than in the regions north of it. The above features were not so conspicuous in the present investigations except in section 4, as the meridional extent of the sections were comparably smaller.

From the vertical sections of temperature (Figs. 2,5,8 and 11) a conspicuous feature may be observed. Treating the isotherms of 25°C and 20°C as the top and bottom of the thermocline, the vertical spreading of the thermocline is found from the above figures within about 2 degrees from the equator. It can be said that the trend of the isotherms indicates divergence at subsurface levels with the possible indication of the setting in of the equatorial undercurrent.

Salinity maximum is well defined in all the sections and that too in the northern part in each section. The maximum zone is invariably located at the top of the thermocline in all the sections. Towards south the salinity values decrease. This decrease is mostly associated with a sharp southward gradient around 3° N in almost all the sections. The low salinity values towards the equator are in accordance with the general observation that the salinity of the oceans is minimum near the equator and maximum at 20° N and 20° S (Defant, 1961). As can be observed the halocline is not so conspicuous near the equator, as it is in the northern parts. In all the sections the distribution below 1000 m is quite uniform. The watermass structure studied at random stations, revealed the presence of three different ones in the northern regions along the 6° N latitude. But the structures at stations along the equator showed the presence of more or less uniform salinity from top to bottom, thereby exhibiting the absence of the upper two watermasses. This change occurs at about 3°N latitude which can be considered as a sharp salinity boundary region. This provides additional confirmation for the absence of salinity maximum along the equator. Patil and Ramamirtham (1963), while discussing the watermasses in the Laccadive region, have observed the presence of three water masses, the most prominent being the one below 150 m depth and characterised by a steep temperature range. The latter is observed in the present case also, and is found to extend up to the surface with increased temperature range. The upper and lower subsurface waters observed by the above authors are not, as mentioned earlier, found in the equatorial region.

As far as the distribution of dissolved oxygen is concerned it can be observed that the waters up to about 100 m depth are nearly 80-90% saturated and a steep gradient occurs down to a depth of about 800 m. Another increase from a depth of about 1250 m reserves the layer between 800 and 1250 m as an oxygen deficit layer which is more or less similarly stratified in all the sections. This layer has a wider range towards north in all the sections. Jayaraman *et al.* (1959), when discussing the oxygen distribution in the Laccadive region during summer, observed the oxygen poor layer between 150 and 500 m, with an increase from 700 m downwards, and a value double that of the oxygen minimum occurred at 1000 m. Patil and Ramamirtham (1963) found this layer to be between 200 and 800 m in the Laccadive region and observed values as high as 2.45 ml/l at about 2000 m. But in the present case (in the near-equatorial region) the deficit layer is far wider and the observations were extended to 3000-3500 m, where still higher values were recorded (3.5 ml/l at 3000 m).

This oxygen-poor intermediate layer mentioned above is the most prominent feature of the oxygen distribution in middle and low latitudes. Below the minimum layer the waters are richer in oxygen content and are nearly 70% saturated at 3000 m or so. This oxygen content of the deep sea circulation of the oceans originates from the major convection areas of the subpolar and polar regions of the ocean where the water masses in the surface layers can sink to great depths and from there also fill the depths at middle and low latitudes. In spite of the long path travelled by these water masses there is little depletion of oxygen content because of the low temperature and the small amount of organic material present, and the oxygen content shows only slight decrease (Defant, 1961).

ACKNOWLEDGEMENTS

The author wishes to express his thanks to Dr. S. Jones for his keen interest in these investigations. Thanks are also due to Dr. R. Subrahmanyan for his encouragement and valuable suggestions offered during the course of the work, and to Dr. A. V. S. Murty for going through the manuscript and suggestions for its improvement. The help rendered by Shri D. S. Rao in processing and analysis of the data is gratefully acknowledged.

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