HYDROLOGICAL FEATURES OF THE ARABIAN SEA OFF THE NORTHERN AND CENTRAL WEST COAST OF INDIA DURING 1964 WINTER

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Abstract

The hydrographic features prevailing along the northern and central west coast of India during the early part of winter 1964 are discussed. A weak northward gradient in temperature north of 17°N and an eastward gradient south of it is noticed. The thermocline is found at shallower depths in the northern regions. A steady increase in the salinity is observed northward, the maximum being off Bombay. North of 17°N the flow is mainly eastwards which deflects towards south with increase in depth. At 50 m a continuous weak southward drift is noticed. More or less uniform distribution is found in the dissolved oxygen content at surface and 20 m depth, but at 50 m depth eastward gradients are noticed. Sharp decrease in dissolved oxygen values occur from the top of the thermocline and the oxygen minimum layer is conspicuous in all the sections. The nature of the isotherms and the isolines of oxygen indicate the presence of upwelling in the region off Bombay.

The total phosphorus content is much less in the region between 15°N and 18°N with higher values further south and north of these latitudes. The patterns of distribution of dissolved oxygen and total phosphorus contents show an inverse relationship. A westward gradient in the phosphorus values is seen at 50 m depth.

Introduction

A detailed hydrographic study of the waters along the north-west coast of India from Bombay to Honavar was undertaken in one of the cruises of R. V. *Varuna* during the first half of December 1964. The investigations were carried out during a period of six days, and this account is based on the results of this cruise. The area covered extended from the coast to slightly beyond the continental shelf with five latitudinal sections, viz., off Bombay, Bankot, Ratnagiri, Goa and Honavar, comprising in all 38 stations (Fig. 1). Observations on temperature and salinity were made at every station at all international depths from surface to bottom, whereas those for dissolved oxygen and total phosphorus content were carried out at alternate stations only.

Data and Methods

The water samples were collected by means of Nansen reversing bottles fitted with deep-sea reversing thermometers. Salinity determinations were done

by conductivity measurements using an inductively coupled salinometer (Model No. 33, C.S.I.R.O., Australia), and dissolved oxygen by the modified Winkler method. The samples for total phosphorus were stored in polyethylene bottles in deep freeze. The method of Strickland and Parsons (1960) was followed for the determination of total phosphorus. The colorimetric estimation was done by visual comparison using Nessler tubes.

The hydrographic data have been analysed by the standard methods for processing of oceanographic data (La Fond, 1957). The vertical profiles and horizontal distribution are given in Figs. 2 to 10. The wind directions observed on board the research vessel at the various stations are also indicated in Fig. 1.

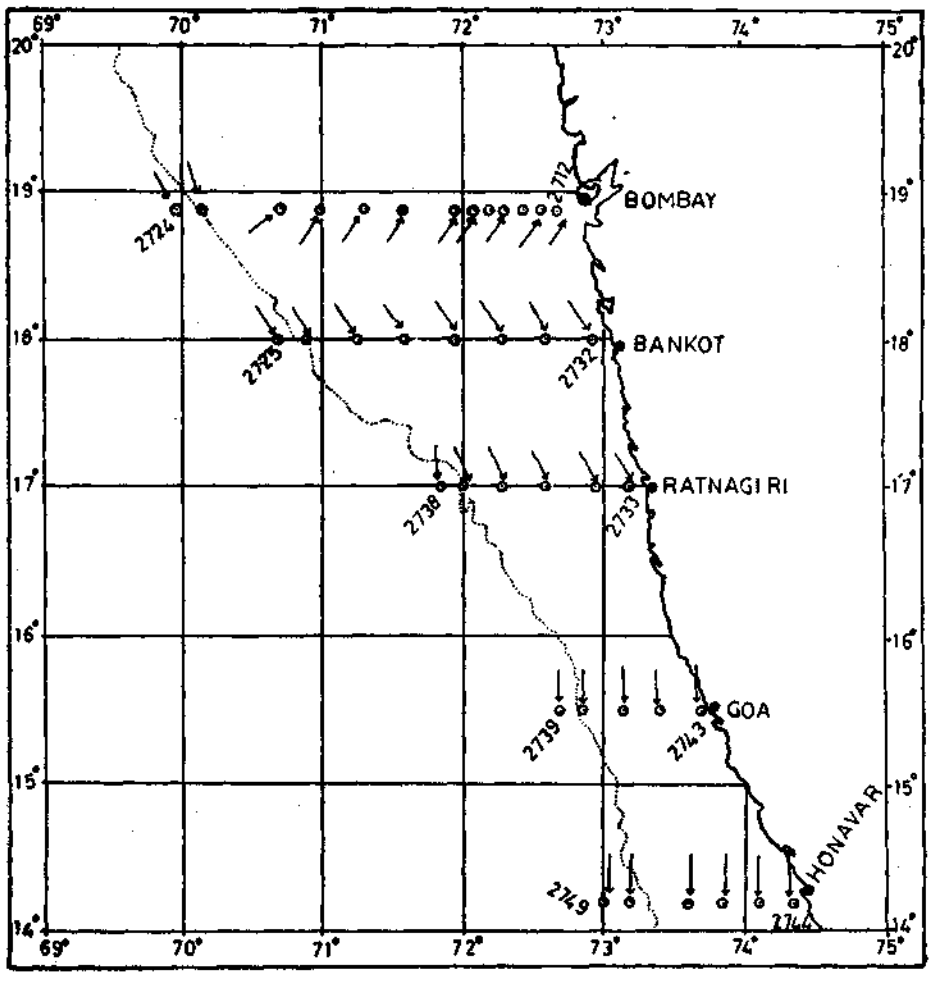

FIG. 1. Position of stations occupied with wind directions.

VERTICAL DISTRIBUTION OF PROPERTIES

Honavar Section (Fig. 2)

In this section the thermocline is well defined from 70 to 150 m, and the extent of the mixed layer is found to be decreased near the coast. Over the shelf the rising trend of the isotherms towards the coast is noticed and this feature is exhibited by the salinity and density isopleths as well. The salinity maximum is observed at the top of the thermocline within a high saline vertical column. Off the shelf the salinity values are lower than in the coastal region in the upper layers. Such contrasts between the offshore and inshore conditions are not so evident in the dissolved oxygen values where uniformly high values are found in the mixed layer. Steep decrease in dissolved oxygen values occur from the top of the thermocline.

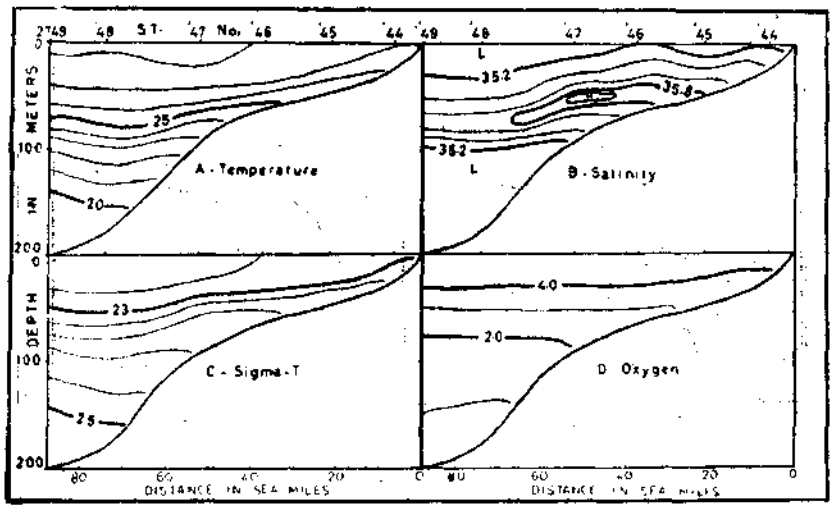

FIG. 2. Vertical distribution of temperature, salinity, sigma-T and oxygen in the section off Honavar.

Goa Section (Fig. 3)

The shoreward rising trend of the isotherms is observed in this section also, but the thickness of the mixed layer is considerably reduced compared to the previous section. Thus the thermocline is found at much shallower depths (10 to 20 m) over the shelf. The overall temperature range is more or less the same as in the previous section. The salinity maximum now is within the thermocline. The tilting of the isotherms over the shelf is not reflected in the density section so clearly. But off the slope, the distribution of density is comparable to that of temperature. As regards the dissolved oxygen distribution, a layer of low oxygen (below 1 ml/l) is found over the bottom of the continental shelf although the distribution in the upper layers is comparable to that off Honavar.

Ratnagiri Section (Fig. 4)

More or less same features are exhibited in the section off Ratnagiri except for a stronger gradient of temperature in the vertical, within the thermocline. The salinity maximum is found within a coastward extending tongue of high salinity and very near the coast the salinity values are comparatively low. The influence of the high saline tongue is observed in the distribution of density. Oxygen distribution is comparable with those of the previous sections.

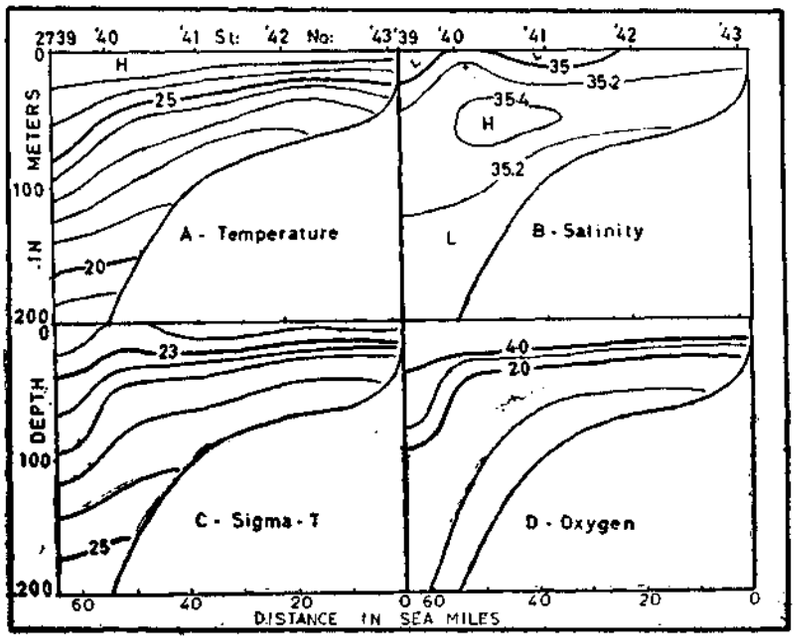

FIG. 3. Vertical distribution of temperature, salinity, sigma-T and oxygen in the section off Goa.

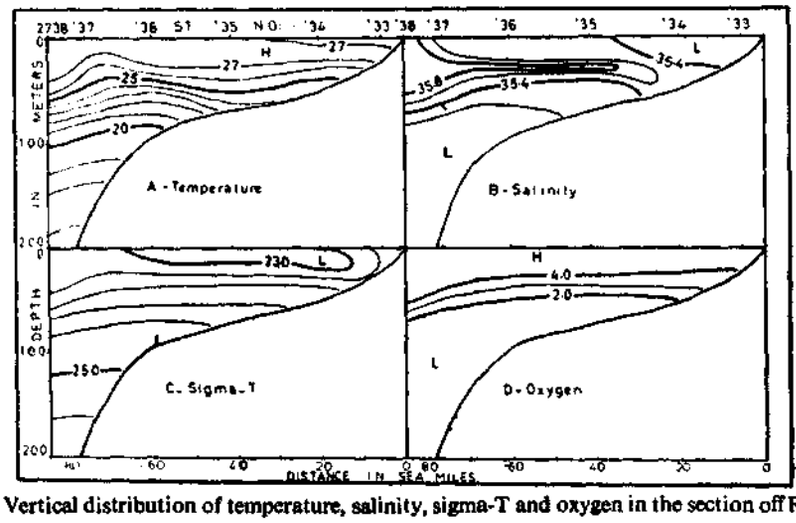

FIG. 4. Vertical distribution of temperature, salinity, sigma-T and oxygen in the section off Ratnagiri.

Bankot Section (Fig. 5)

With an intensification of the vertical stratification of the thermocline over the shelf the distribution of temperature off Bankot is more or less the same as that off Ratnagiri. Wave-like nature of the isotherms within the thermocline is observed. The mixed layer is much thinner than the southern sections. In this section the salinity maximum is found within the mixed layer in the offshore regions. The low saline zone is evident over the bottom of the shelf. The density distribution exhibits mostly stable stratification and the distribution of dissolved oxygen is comparable with that of the previous section.

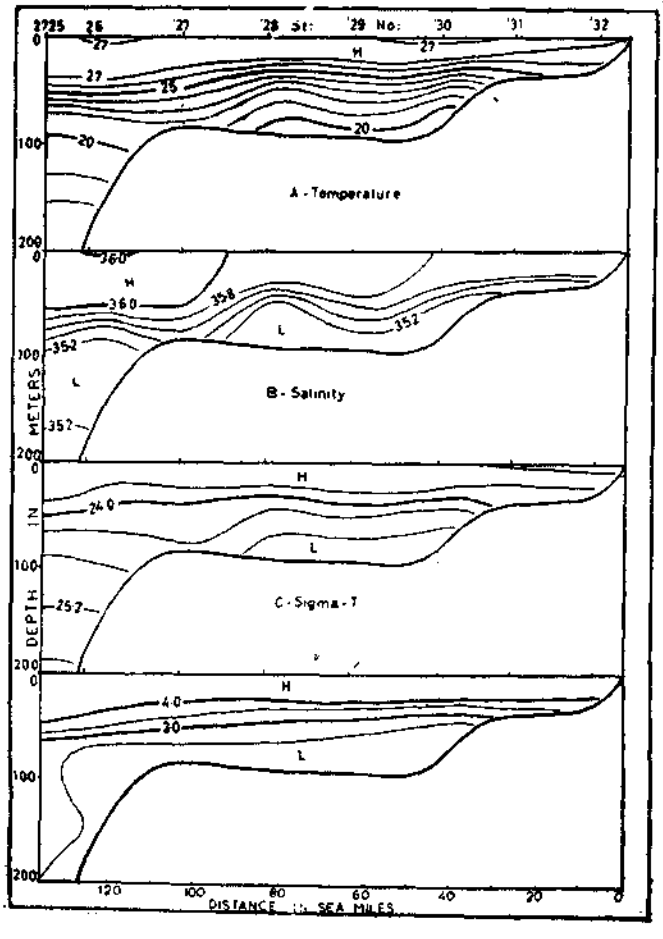

FIG. 5. Vertical distribution of temperature, salinity, sigma-T and oxygen in the section off Bankot.

Bombay Section (Fig. 6)

A dome-like structure in the temperature distribution at station 2716 seems to produce a sort of thermal boundary at the surface at the said station off Bombay. The vertical temperature gradient within the thermocline is much stronger and the mixed layer is, on an average, not more than 25 m thick. The overall temperature range is wider than the southern sections. The distribution of salinity presents, again, a maximum within the mixed layer in the offshore region. Uniformly high oxygen values are encountered within the mixed layer and the steep decrease within the thermocline is also observed.

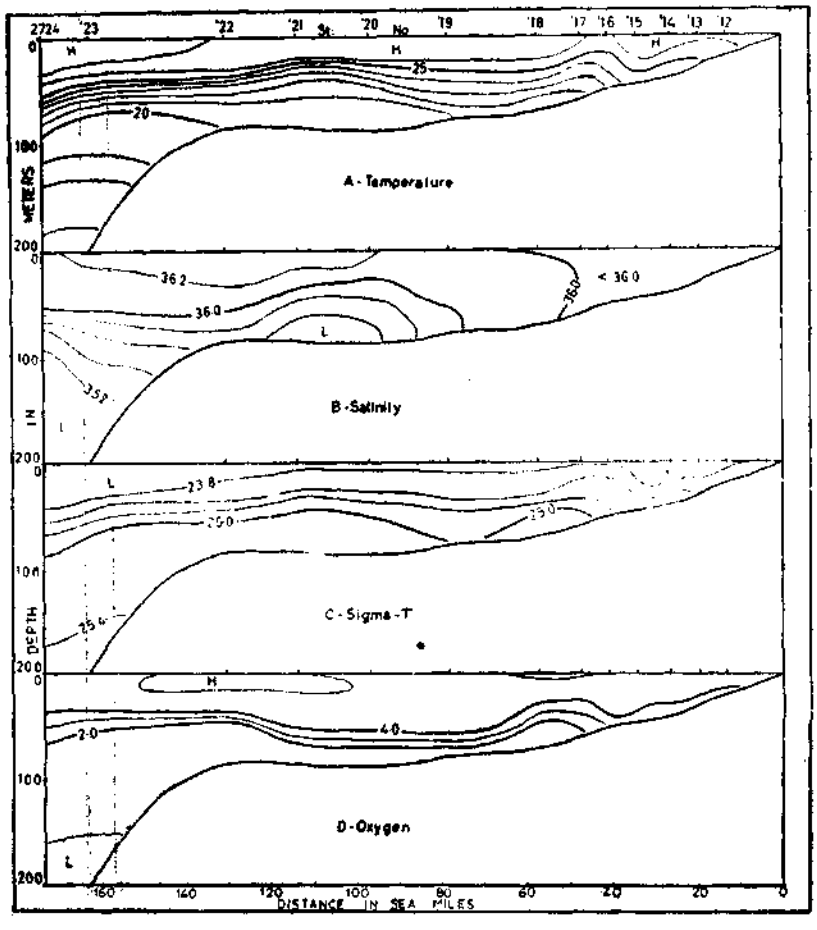

FIG. 6. Vertical distribution of temperature, salinity, sigma-T and oxygen in the section off Bombay.

Horizontal Distribution of Properties

The distribution of properties in the horizontal plane at 0, 20 and 50 m are shown in Figs. 7 and 8.

Temperature

The surface temperature varies from 26.2° to 28.2° C throughout the whole investigational area, and a weak northward gradient is observed north of 17° N.

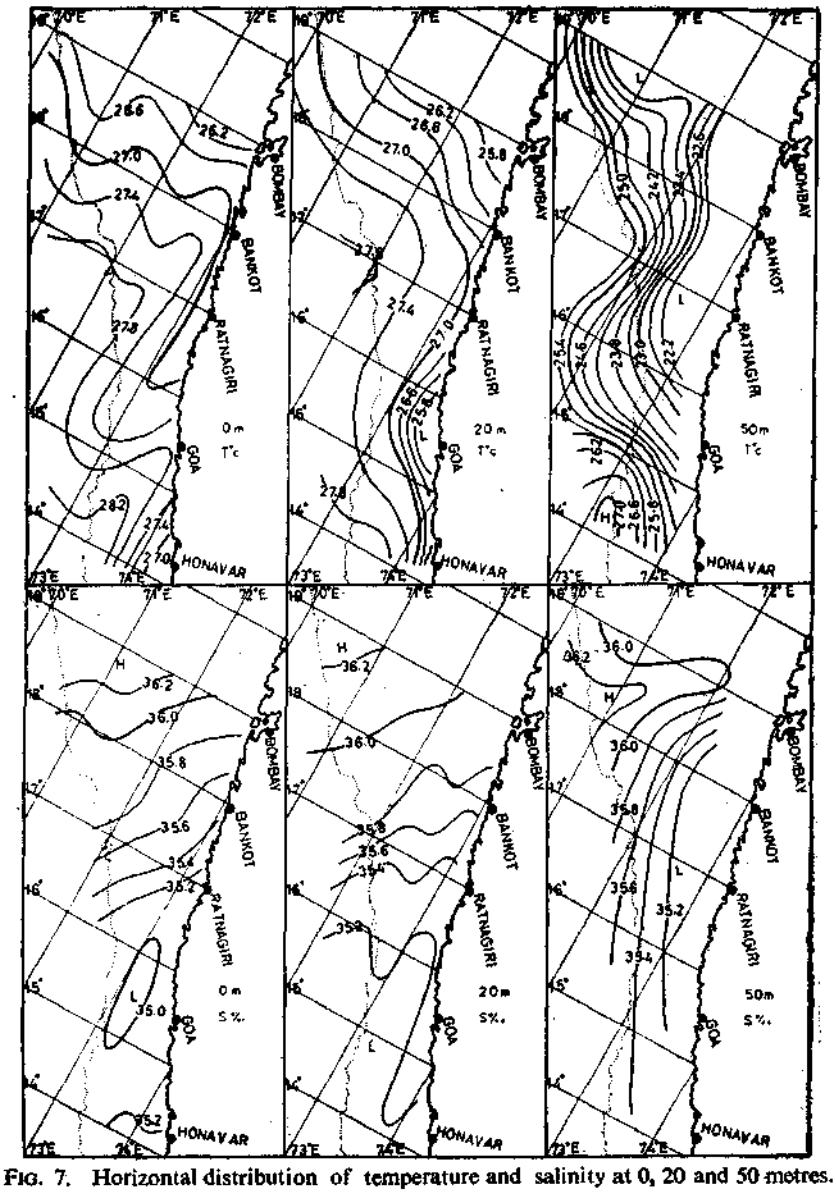

FIG. 7. Horizontal distribution of temperature and salinity at 0, 20 and 50 metres.

At 20 meters these temperature gradients are stronger and oriented in the west-to-east direction and have spread into the regions off Goa also, these being strongest in the region south of Ratnagiri. Two cold water zones are observed one off Goa and another off Bombay. With more or less the same trend of distribution, the temperature values are much lower and west-to-east gradients are much stronger at 50 m depth. The temperature discontinuities are reduced very much, compared to the upper levels and a high temperature cell is observed off Honavar.

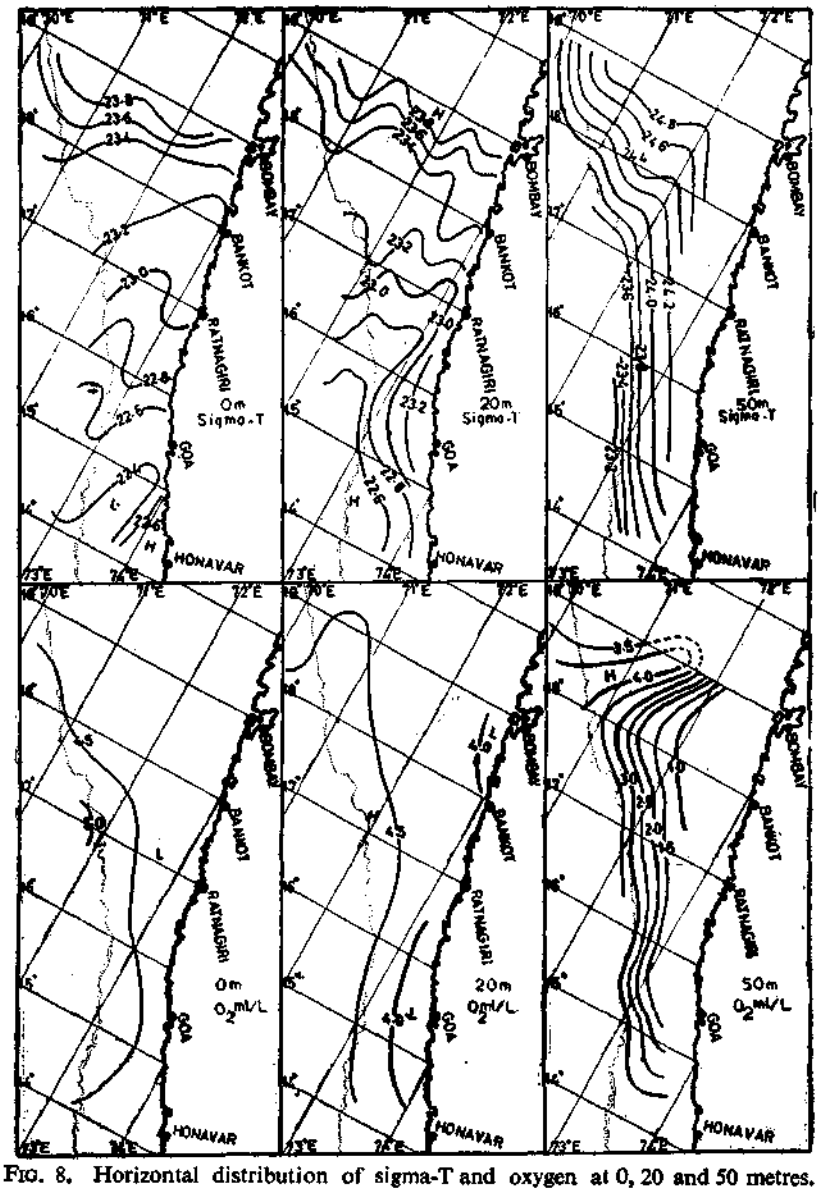

FIG. 8. Horizontal distribution of sigma-T and oxygen at 0, 20 and 50 metres.

Salinity

A more or less isohaline zone between Honavar and Ratnagiri, is a noticeable feature of the surface salinity distribution. From the region off Ratnagiri a steady increase in salinity is observed northward, the maximum being off Bombay. Comparable features prevail at 20 m, but at 50 m depth an eastward gradient in salinity is observed. The salinity maximum off Bombay is now observed within a high saline tongue extending eastwards.

Sigma-T (Density)

The temperature gradients noted at the different levels constitute east-west density gradients in the regions south off Ratnagiri. At surface a weak eastward flow is noticed in the region between Ratnagiri and Bombay and south of 17°N the drifts are still weaker. At 20 m depth, the weak southward drift within the shelf is more regular than the surface, and at 50 m depth this drift is stronger as can be observed from the density distribution.

Dissolved Oxygen

The distribution of dissolved oxygen content at surface and 20 m depth is more or less uniform, values ranging from 4 to 5 ml/l. At 50 m depth eastward gradients in the oxygen distribution are found. The presence of high saline tongue is reflected in the form of a high oxygenated tongue off Bombay. In accordance with the southward flow, the values towards east are uniformly lower in the whole of the investigational area due south off Bankot.

Distribution of Total Phosphorus

Vertical Distribution (Fig. 9)

In the section off Honavar, the total phosphorus content is higher than that in the offshore stations and a sharp increase in the values is found depthwise in the thermocline. Off Goa, very near the coast, there appears to be a high phosphorus cell at the bottom and in the region off Ratnagiri the values are uniformly higher than in the previous sections. But over the bottom of the shelf the values are comparable in all the three sections. Off Ratnagiri, a shoreward rising trend of the isolines is observed which is a consequence of the higher values near the coast. Off Bankot the values are still higher near the coast and the sharp discontinuity in the phosphorus content in the vertical is restricted to the near-coastal regions. Similar to the temperature discontinuity noted at the surface at station 2716 in the Bombay section, a sharp discontinuity in the phosphorus values is also observed. Maximum values of total phosphorus are encountered in this section over the bottom of the shelf. In this respect, the vertical distribution of phosphorus in the offshore regions off Bombay and off Honavar are similar.

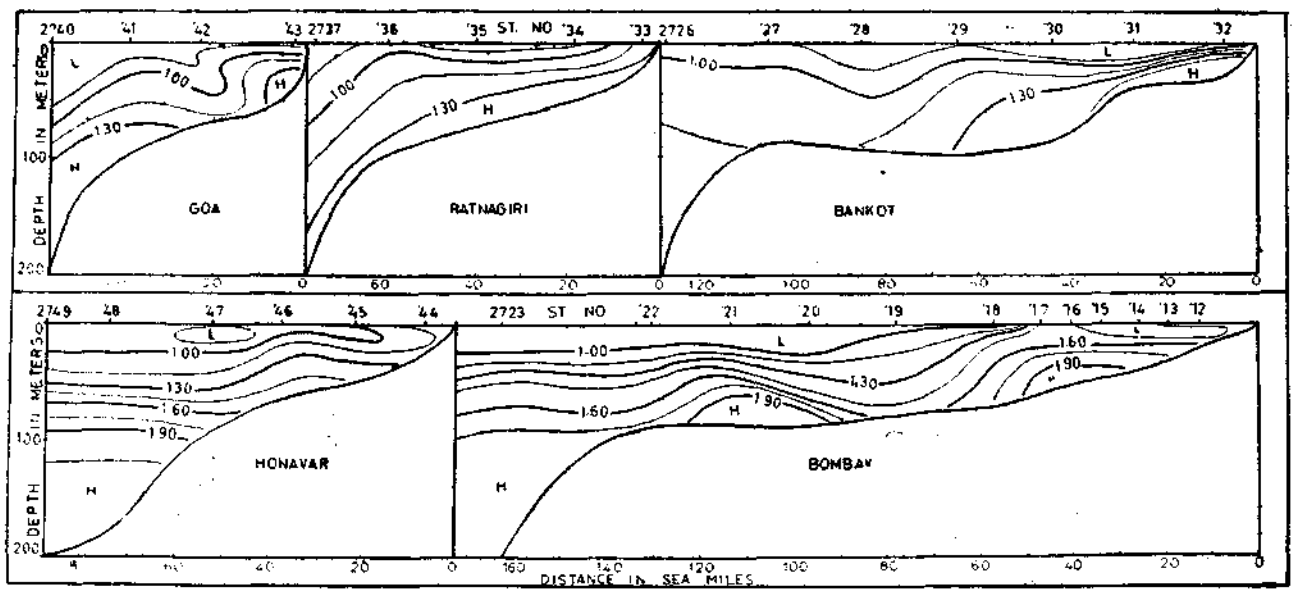

FIG. 9. Vertical distribution of total phosphorus in the sections off Honavar, Goa, Ratnagiri, Bankot and Bombay.

Horizontal Distribution (Fig. 10)

Considering the horizontal distribution of total phosphorus at surface, the region between Goa and Bankot appears to have less phosphorus content than the regions further south and north of this. Again, the maximum is found off Bombay. With similar trends of distribution, the values are higher at 20 m depth with a high phosphorus zone in the region between Bombay and Bankot. The high saline tongue noticed off Bombay is reflected in the form of one with low phosphorus content. Another high phosphorus cell is found in the region off Honavar.

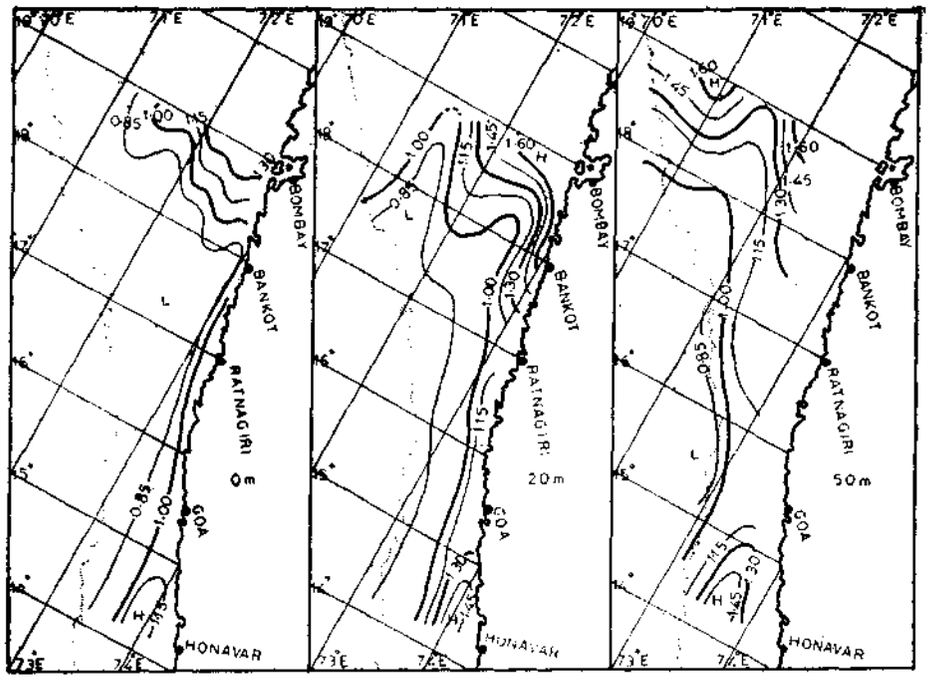

FIG. 10. Horizontal distribution of total phosphorus at 0, 20 and 50 metres.

Thus, in general, phosphorus content is much less in the region between 15°N and 18°N but higher values are seen further south and north of these latitudes. An inverse relationship is observed in the patterns of distribution of dissolved oxygen and total phosphorus.

DISCUSSION

It may be seen from a study of the distribution of the various parameters in different sections that the thermocline becomes shallower shoreward during this period, particularly off Bombay. The isotherms are seen to have a rising trend

towards the coast and the mixed layer is nearly isothermal. Carruthers *et al.* (1959) and Vijayakrishnan Nair *et al.* (1966) have also noticed the shoreward upslope of the isotherms off Bombay during the period October to December. Jayaraman and Gogate (1957) have indicated the possibility of upwelling in this region during November-December period. Although, as they had mentioned, there was paucity of data in this region, the data presented here appear to lend confirmation to the occurrence of upwelling. Elizarov (1968) who had carried out studies along the west coast of India gives evidence for the presence of upwelling off the Bombay coast. However, south of Bombay, upwelling is not much in evidence. Goa region seems to be the boundary between northern and southern upwelling regions. The two cold water pockets noticed around 15°N and 19°N at 0 and 20 m indicate the possibility of incursion of colder waters inshore. The effect of cooling of the waters in the inshore region is maximum conspicuous at 50 m depth. Wave-like nature of the isotherms noticed in the section off Bankot may be due to the influence of internal waves, but the influence of the topography of the bottom cannot be ignored.

The nature of the isohalines resembles that of the isotherms, the high saline region off Bombay corresponding to the low temperature region. Further, a general latitudinal increase of salinity towards north may contribute to this feature (Ramamirtham and Patil, 1965 and Patil *et al.*, 1964). The subsurface conditions, however, reflect to some extent the characteristics of Red Sea and Persian Gulf waters (Panakala Rao and Jayaraman, 1970). These authors further suggest that sinking and spreading of oxygen-rich waters from the Gulf of Aden and Persian Gulf is more likely to enrich the subsurface layers rather than deplete them of oxygen. This feature can be observed from the high saline and high oxygen tongues off Bombay at 50 m depth (Figs. 7 and 8). This may be similar to the sinking reported by Clowes and Deacon (1935) from the Red Sea to the Indian Ocean.

The drifts in the investigated area are mainly eastwards in the region north of 17° N which deflects towards south with increase in depth and thus at 50 m depth a continuous weak southward drift is noticed. The effect of this drift is further noticeable in the distribution pattern of dissolved oxygen content at 50 m (Fig. 8). The corresponding increase of total phosphorus is noticed in the phosphorus distribution.

Acknowledgements

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