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HYDROGRAPHY OF THE WEST COAST OF INDIA DURING THE PRE-MONSOON PERIOD OF THE YEAR 1962

Part I. Shelf Waters of Maharashtra and South-West Sourashtra Coasts

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INTRODUCTION

A DETAILED hydrographic survey of the west coast of India from Cape Comorin in the south to Veraval in the north was undertaken during the cruises of *R. V. VARUNA* in the early part of 1962 i.e. January-May. These cruises were covered in several legs and the leg from Ratnagiri to Veraval is of importance, since it was the first time, a systematic survey of the area was made as part of the Fishery-Hydrography programme of the C.M.F.R.I. The present account is based on the results obtained during this last phase of these cruises. The area from coast to slightly beyond the continental shelf was covered with seven hydrographic sections, mostly latitudinal, (except an oblique section off Veraval) comprising in all 56 stations (Fig. 1). The spacing between the stations was fixed as 15 miles. As stable conditions were expected during the period of observation, closer spacing of stations was not considered necessary. Serial observations of temperature and salinity were made at all international depths from surface to the bottom at every station. Samples for dissolved oxygen were collected from a few stations initially, but the sampling could not be continued owing to accidental loss of the oxygen-fixing reagents.

The northern Arabian Sea region (i.e. north of 17°N.) differs in the distribution of various hydrographic parameters from the southern one. The tidal height in the region off Bombay are considerably greater than those encountered within the regions off Cochin. The influence of the bottom topography may also be markable in contrast to the southern regions.

COLLECTION OF DATA AND MODE OF TREATMENT

The collection of hydrographic data and the mode of treatment are the same as has been done in earlier published works on the subject. Data have been compiled and analysed by the standard procedures for the processing of oceanographic data and vertical profiles and horizontal distributions have been given in Figs. 2-11.

WIND OBSERVATIONS

Frequencies of wind directions and average speed of each of the various components are given as percentage distributions in Fig. 1. The frequency is shown by

the length of the arrow pointing to the place of observation from the respective direction, and average speed of that component is given in figures at the back of the

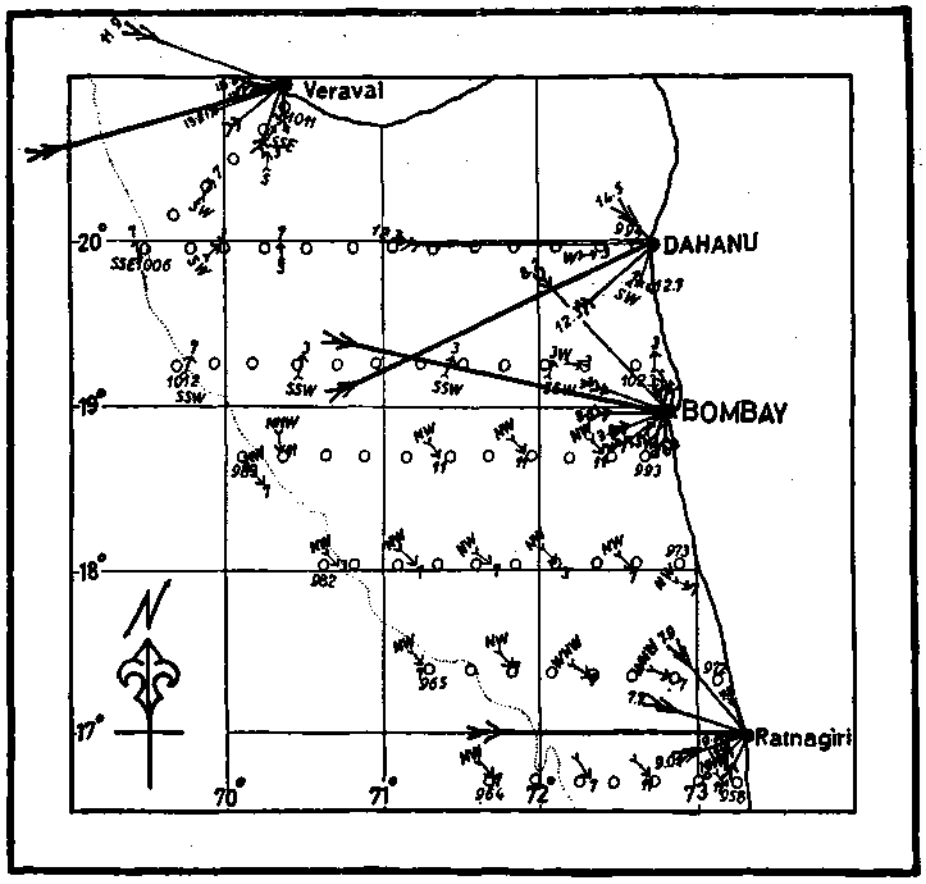

Fig. 1. Showing position of the stations occupied, percentage distribution of wind directions with average speed, and wind observations.

arrow. The wind data were compiled from the Daily Weather Reports of the India Meteorological Department at four observational centres viz. Veraval, Dahanu, Bombay and Ratnagiri. Resultant wind direction is shown by a thick arrow.

Wind data collected on board the research vessel are also indicated in fig. 1. Direction is shown by the arrow as well as by letters, and wind speed in knots per hour is mentioned in the front of the arrow.

Distribution of Properties

A three-dimensional distribution of various parameters is presented here, and these distributions are related to the water movements as well as the wind pattern during this period.

(*a*) *Temperature :*

Vertical distribution of temperature is given in Figs. 2A-8A.

Compared to the Southern Arabian Sea (area from Cape to Mangalore) the region in the northern latitudes under investigation has only a shallow mixed layer which extends from surface to an average depth of 35 m. The temp. difference within this layer is found to be only 1°C. Thus in section 1, near Ratnagiri the mixed layer is found to be mostly isothermal and the temperature discontinuity starts at about 75 m. The thermocline is quite sharp and extends upto 200 m. within the shelf as can be expected the thermocline is absent.

Proceeding further north, in section 2, the thermocline starts at a shallower depth with slightly increased temperatures in the mixed layer. The isotherms are mostly horizontal. Comparable conditions exist in sections 3 and 4 where slight wavelike nature of the isotherms are found in the mixed layer. Slightly different features are encountered within section 5 (lying off Bombay). In this section, in the inshore regions the convection layer is mostly obliterated due to upsloping isotherms. But even then, lateral drifts are highly restricted and in the offshore regions a layer of 20 m. thickness is found to be nearly isothermal.

Significant vertical gradients of temperature exist in the region further north, and thus off Dahanu within the shelf, in the inshore region, the temperature is decreased by 2°-3°C. within a depth of 30-40 m. from surface downwards. In almost all these sections the thermocline is quite stable and static. But, in the northern regions where the mixed layer is obliterated a weak southerly drift is noticed. This drift gains more strength off Veraval, where visible slopings of the isotherms are encountered with. Marked horizontal gradients also exist in the surface layers and the mixed layer is very shallow. Within the thermocline also such negative gradients towards the coast are encountered within the regions off Veraval.

The distribution of temperature at various horizontal planes is represented in Fig. 9. It is found that surface temperature varies between 27.2° and 26.9°C. thus indicating a comparatively wide range for the period of observation. The major range is between 28.8° and 29.6°C. while only a small body of water along the coast in a narrow strip of about 20-25 miles wide show lateral thermal gradients. This probably is due to the occurrence of two warm water pockets, one off Dahanu along 20°N. and the other between Bombay and Ratnagiri along 18°N. which have temperatures over 30.2°C. at the surface. A broad tongue of lower temperature is found to extend towards south at the upper layers, the width of which decreases with depth. This is noted to be the main feature of temperature distribution at the upper layers upto a depth of 20 m. Another extension with increasing temperatures towards north is found between 17° and 18°N. in the northeast direction. But one feature with the 20 m. level is that the thermal cells at 18° and 20°N. have disappeared and regular lateral thermal gradients exist. A very weak drift towards south is noticed at the 20 m. level due south of Bombay, while this develops into a distinct tongue of low temperature between 17° and 18°N. at the 30 m. level. The northeast bound extension found at the upper layers is found to be restricted to a thermal cell at 18°N. 72°E. at 30 m. level. Such a cell is found along the 70°E. meridian also. A general southeast flow is noticed from Veraval to Bombay with a branching towards southwest. Thus the 30 m. level seems to be a transitory plane between the upper and deeper layers adjacent to it.

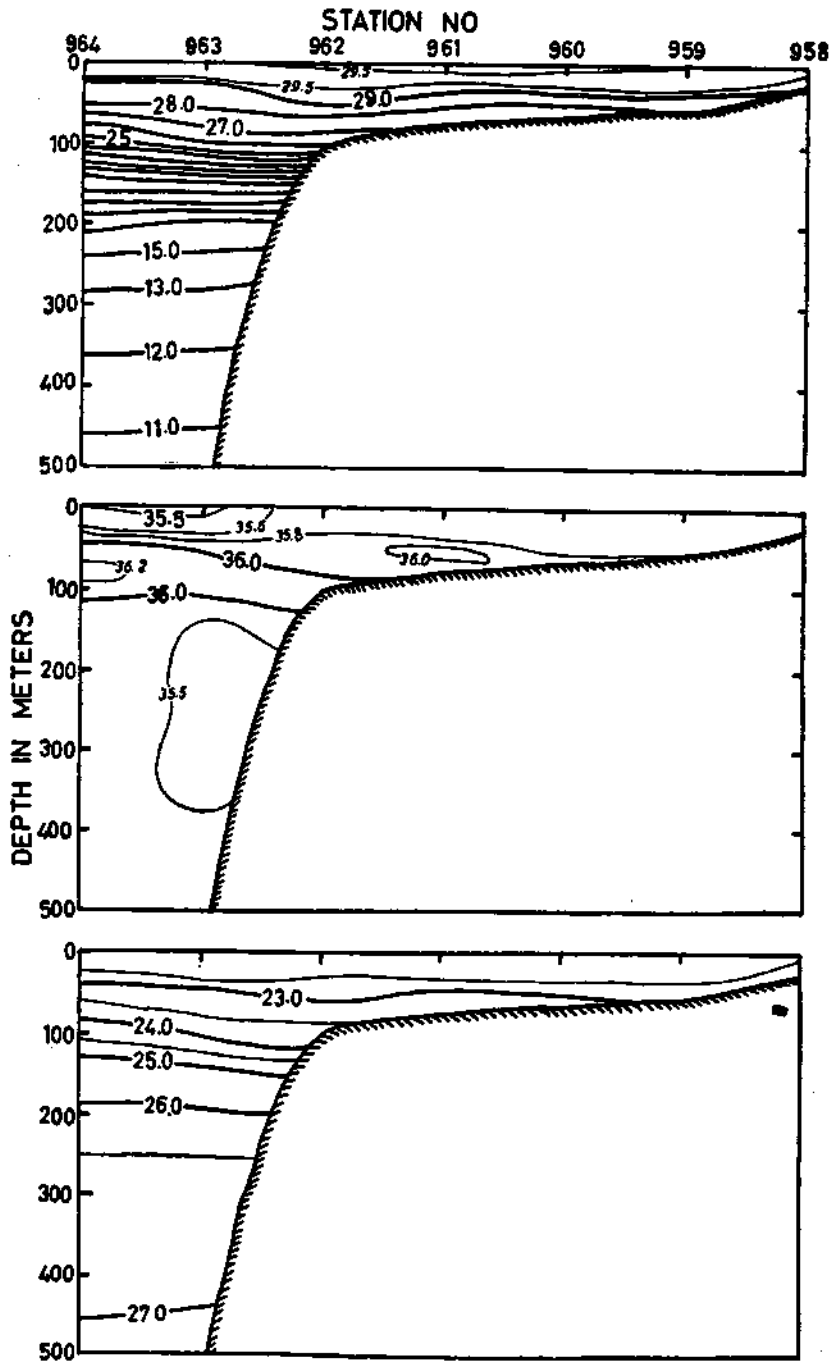

FIG. 2. Section 1, south of Ratnagiri showing vertical distribution of temperature, salinity and density.

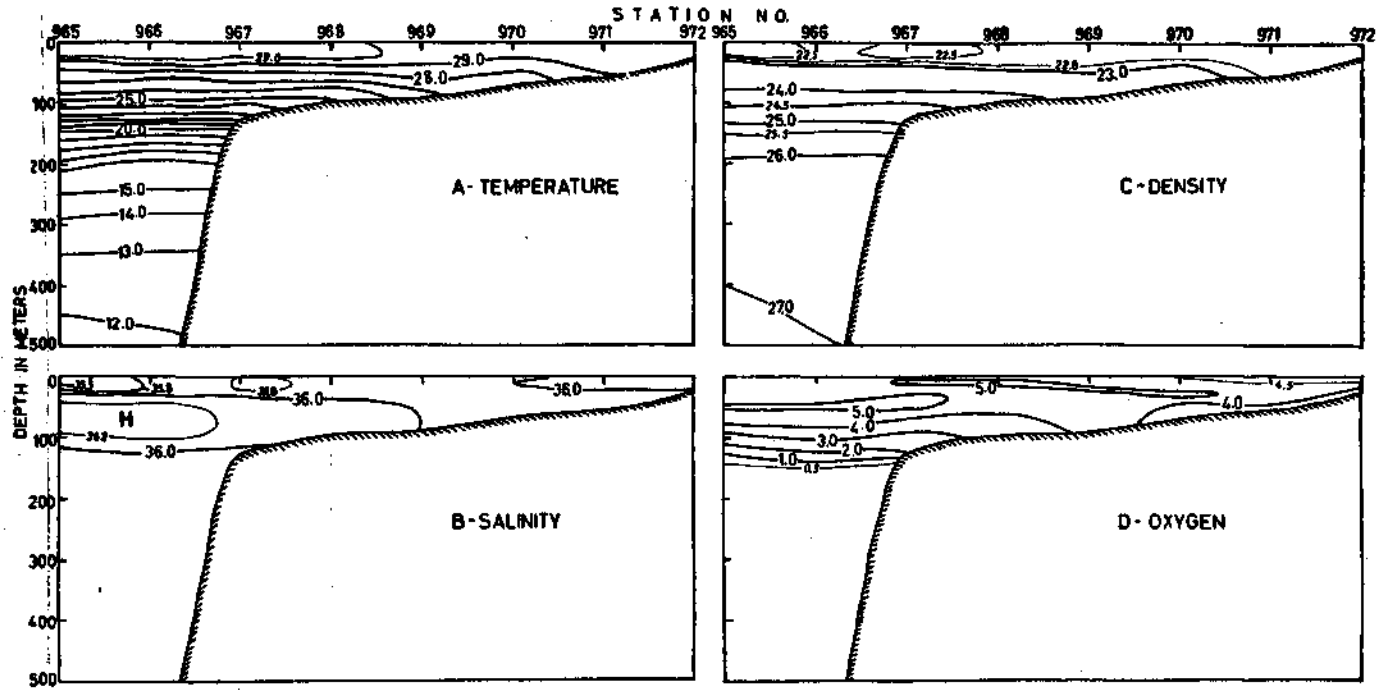

FIG. 3. Section 2, north of Ratnagiri showing vertical distribution of temperature, salinity, density and dissolved oxygen.

With stronger gradients in the lateral plane a distinct tongue of low temperature is noticed again at 50 m., extending southwards, which, has a similarity to the thermal fields at the upper levels. The cell-like structure is still evident between 19° and 20°N. and the southeast flow noticed at the upper layers is absent at the 50 m. plane. A regular decrease of temperature from south to north is visible in this plane.

Mostly eddy-like structures in the thermal field predominate at 75 m. and the regularity of decrease in temperature is still maintained. Lateral drifts are restricted and the thermal cells correspond to those found in the upper layers.

(b) Salinity :

Vertical distribution of salinity is represented in Figs. 2B-8B. In general the mixed layer which is found to be mostly isothermal is found to be more or less isohaline also. This isohaline layer extends some times even to the bottom in the inshore regions especially towards the southern area of investigation. Thus in section 1, the isohaline layer is found in the upper 30-40 m. layer. The salinity

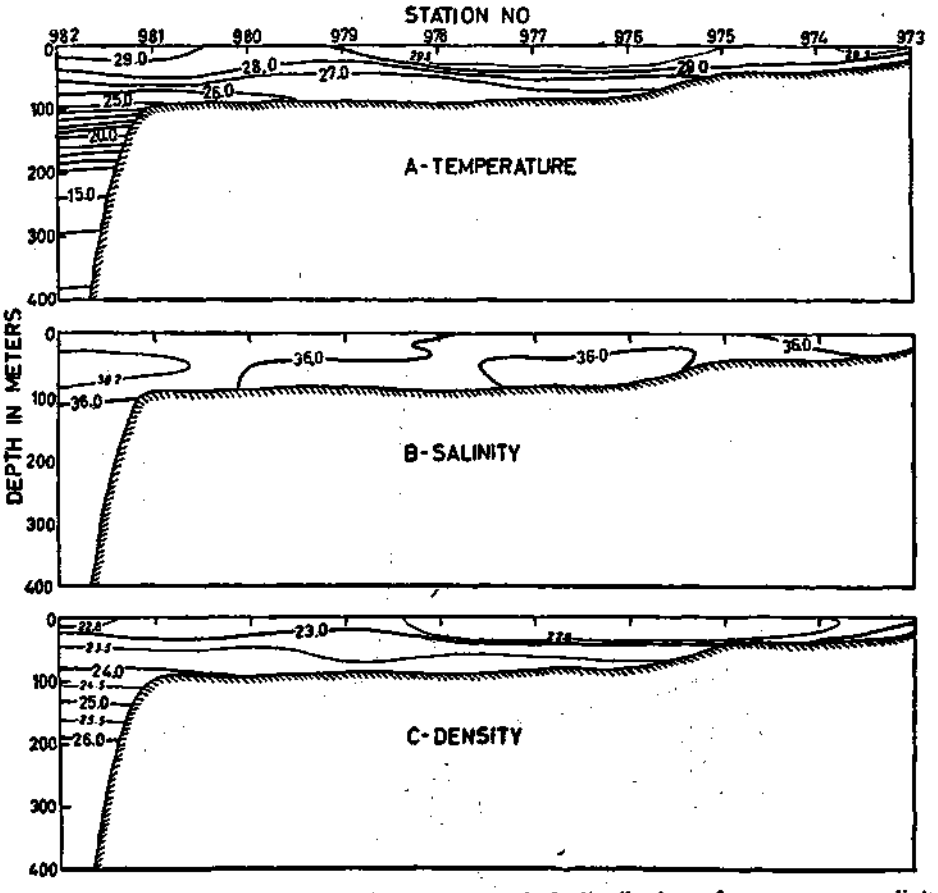

FIG. 4. Section 3, along 18°00'N., showing vertical distribution of temperature, salinity and density.

maximum is not so conspicuous as found in the southern Arabian sea. Below the thermocline the salinity is lower and is found to be around 35.5‰. Comparable features prevail in section 2 where a tongue of high saline water is found to extend towards the coast. Isolated cells of low and high salinities occur in some of the sections and the salinity maximum is not at all perceptible with notable intensity in all the sections, although the salinity values are much higher than those occurring in the southern Arabian sea region. It may be pointed out that, in regard to the

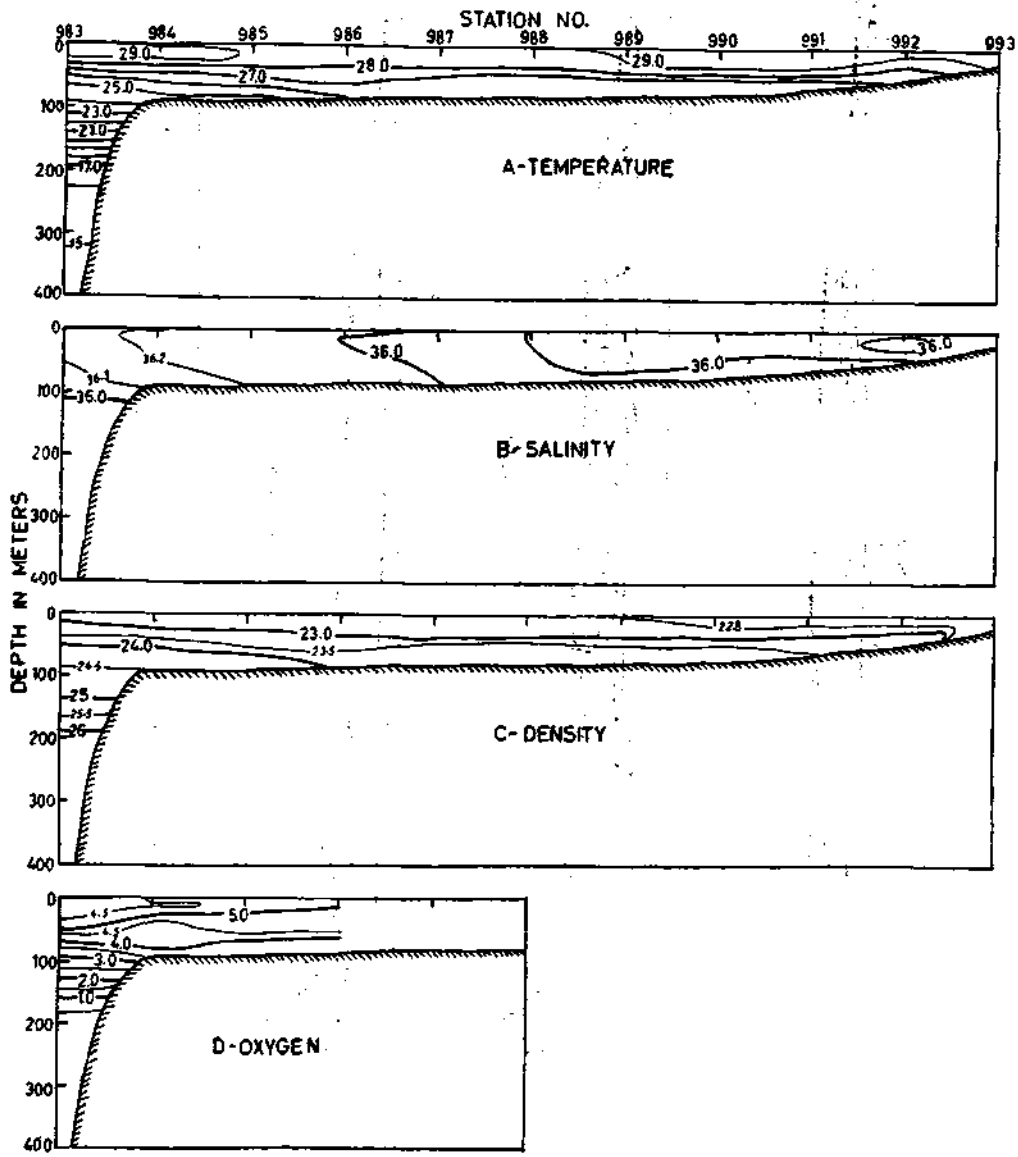

FIG. 5. Section 4, south of Bombay, showing vertical distribution of temperature, salinity, density and dissolved oxygen.

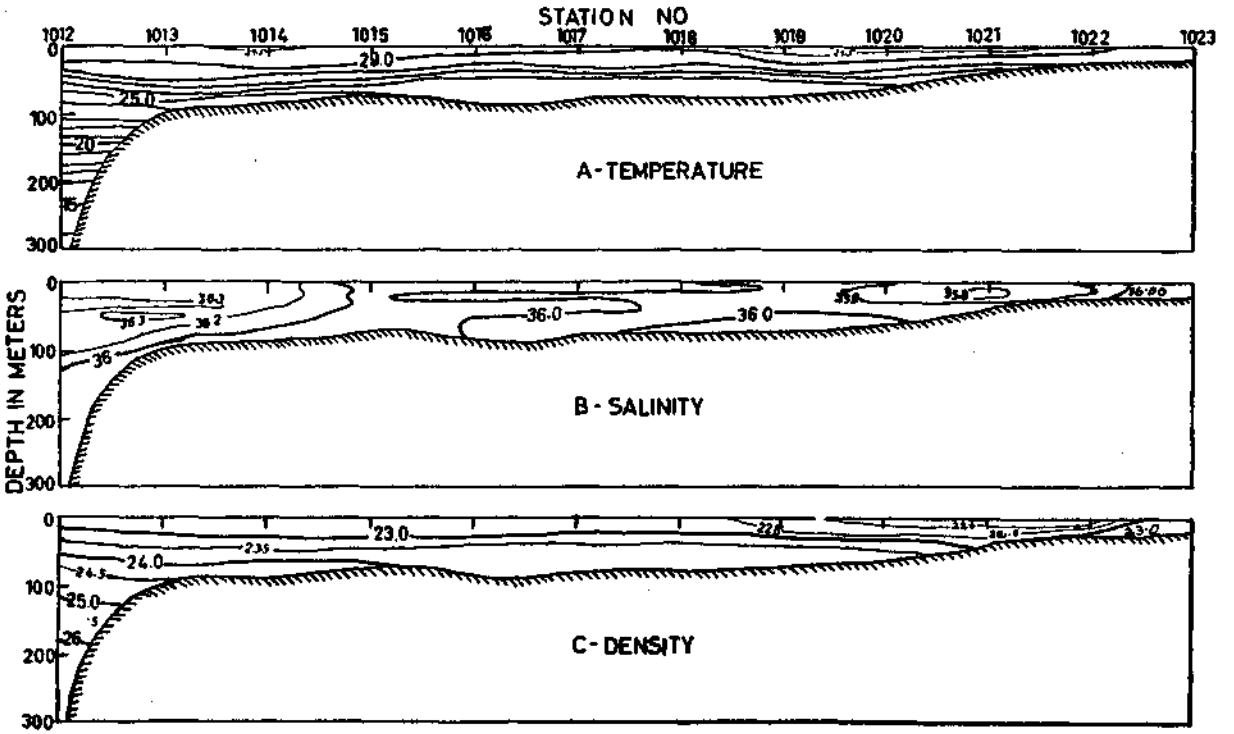

FIG. 6. Section 5, north of Bombay showing vertical distribution of temperature, salinity and density.

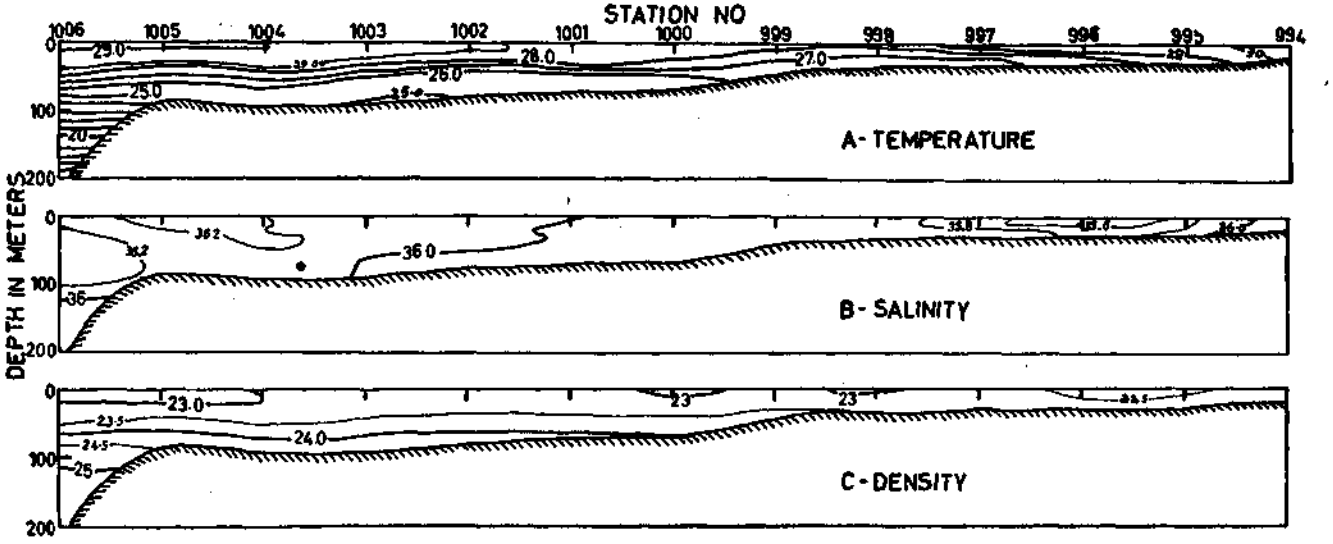

FIG. 7. Section 6, off Dahanu along 20° 00′ N., showing vertical distribution of temperature, salinity and density.

meridianal distribution of salinity, the surface value increases from Equator polewards reaching the maximum between 20° and 30°N. latitude. Hence the subsurface salinity maximum is not observed in the northern latitudes. This increase in salinity with increasing latitude is clearly brought out from a comparison of the vertical distribution of salinity in the various sections. In section 3, the 36.2‰ isohaline extends upto the surface and similar features are found in sections further north.

The distribution of salinity at various horizontal levels is given in Fig. 10. Surface salinity varied between 35.38 and 36.4‰, highest value being observed near the coast off Dahanu along 20°N. while the lowest was also recorded along the same latitude at a distance of 30-35 miles from the coast. A large body of water over the shelf show values of surface salinities between 35.8 and 36.2‰, while slightly higher values occur in two coastal pockets, one between Bombay and Dahanu, and the second around 18°N. At surface slightly lower values below 35.6‰ occur in the low saline tongue observed in the offshore region due south of 18°N., with an axis in the northeast direction, and in another one of similarly low values between 19° and 20°N. about 30 miles away from the coast with an axis in the southwest direction. The influence of these two tongues is found only in

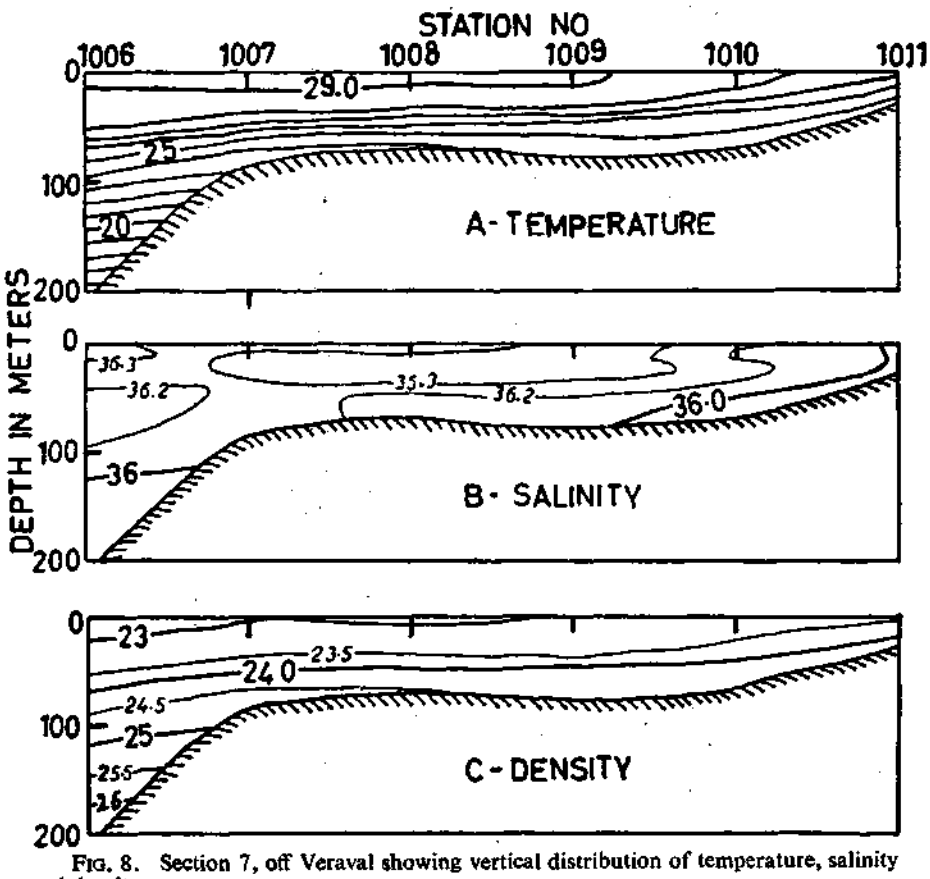

FIG. 8. Section 7, off Veraval showing vertical distribution of temperature, salinity and density.

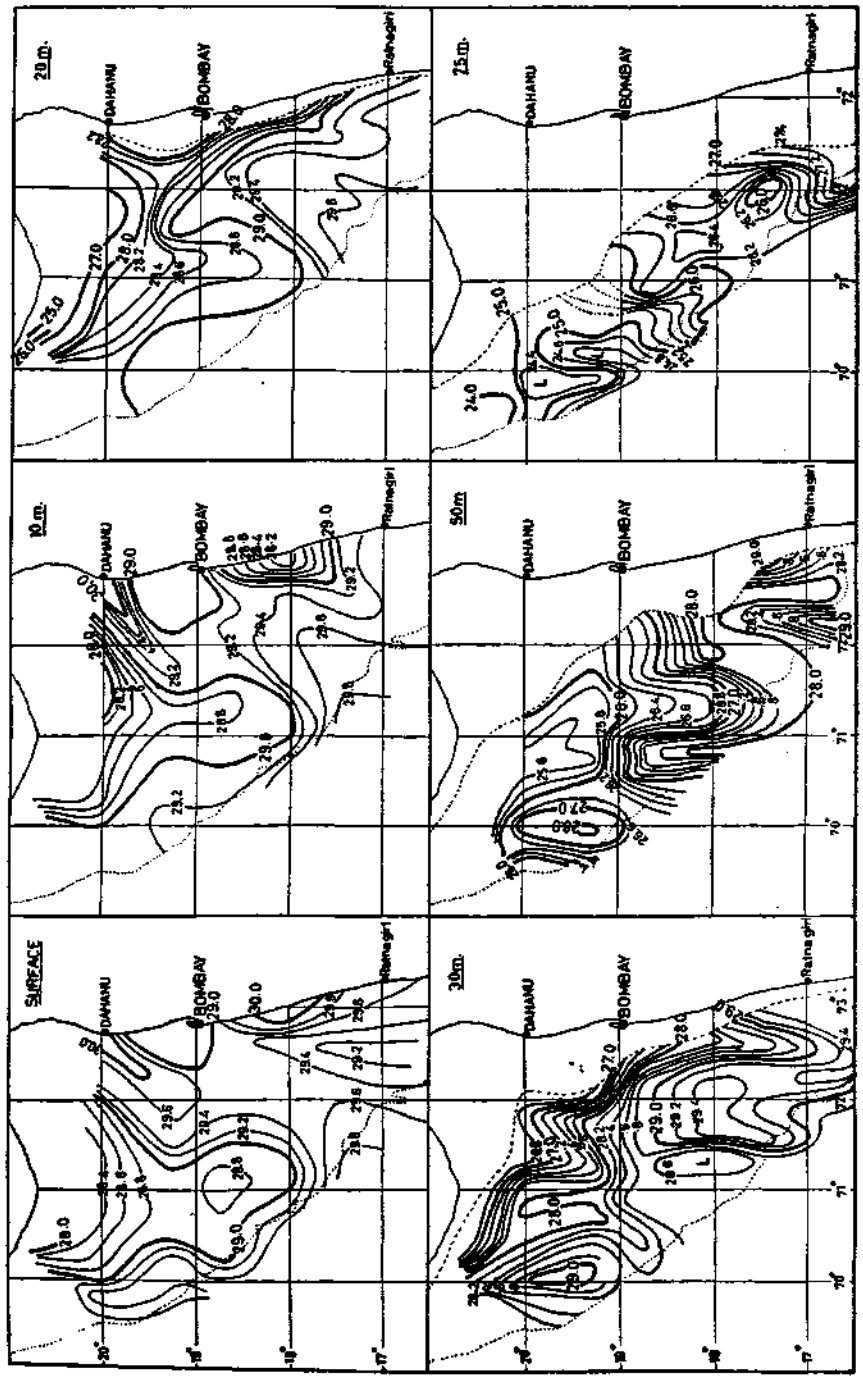

FIG. 9. Horizontal distribution of temperature at 0, 10, 20, 30, 50 and 75 m. levels.

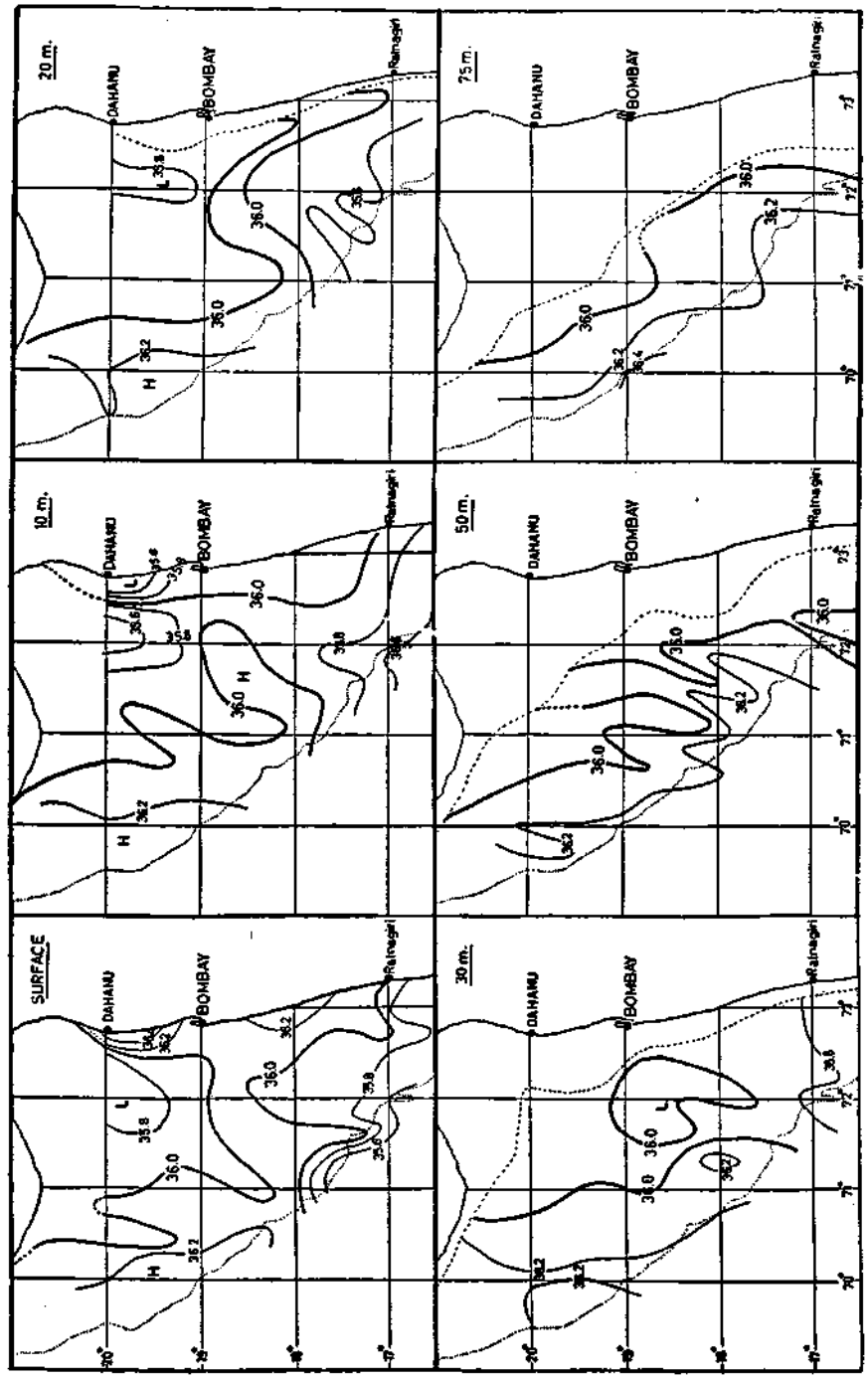

FIG. 10. Distribution of salinity over specified lateral planes.

the upper 20 m. layer. The distribution of salinity becomes more uniform below this depth upto which isohaline water occurs, though the distribution at 30 m. level shows a transition between the upper and lower layers. Complete obliteration of the pocket characteristics is noted at and below 30 m. In layers below 30 m. in the northern region (north of 18° 30'N.) lateral decrease from west to east, and in the southern region lateral decrease from north to south is also noticed.

(*c*) *Density* (*Sigma-T*) :

Vertical distribution of density is represented in Figs. 2C-8C. Density distribution is very similar to the distribution of temperature. The layer of no density-gradient has a thickness of 20-30 m. indicating a well mixed layer on the shelf, but this layer becomes slightly thin over north of 18° 30'N. A well defined pycnocline identical with the thermocline is seen to occur beyond the shelf. The gradual upslope of the isopycnals towards the coast off Veraval indicate a weak southerly drift as shown by the isotherms.

Horizontal distribution of density is represented in Fig. 11. The surface values of sigma-T varies between 22.06 and 23.43, again showing a comparatively large range similar to that of surface temperature. The surface water having highest density is located along the southwest Sourashtra coast, while the water of least density is found along 19°N. latitude beyond the shelf. Similar to temperature and salinity distribution a large body of water having a small density range occurs between 18° and 20°N. At surface a lighter water tongue appears along 20°N. with an axis in the southwest direction while another one appears to the south of 18° 30'N. with an axis in the northeast direction. These tongues are limited to the upper 20 m. layer. Numerous eddies are noted at 30 m. in the shelf region, while below this depth a gradual decrease from off to onshore area especially in the southern region is observed.

(*d*) *Oxygen* :

The vertical distribution of oxygen in section 2 and a part of section 4 is represented in Figs. 2D and 4D. Along these sections surface values of dissolved oxygen vary between 3.95 and 4.8 ml./L.Down below the surface oxygen values are greater than 4.0 ml./L. upto a depth of 75 m., maximum values being observed at varying depths from 10 to 50 m. depth at individual stations. Below 75 m. depth a sharp gradient in oxygen content occurs and this extends down to 150 m. depth. Very low oxygen values (0.5-0.8 ml./L.) persist down to 700 m., after which a rising trend is noticed.

Discussions

From the distribution of the various properties as described in the previous paragraphs it may be seen that during the period of observation in the entire region, water movements have not been quite appreciable. The weak drifts present are especially in the surface mixed layer upto 30 m. depth. In the layers below, water movements are practically absent and a good deal of stability is found as can be expected during the period of observation. Ramamirtham *et al.* (1960) while describing the seasonal behaviour of the waters off Cochin, have pointed out that stable summer conditions are observed from the month of March to middle of May, while the second half of May represents a transition towards the unstable conditions observed during the period of southwest monsoon, which starts generally by the

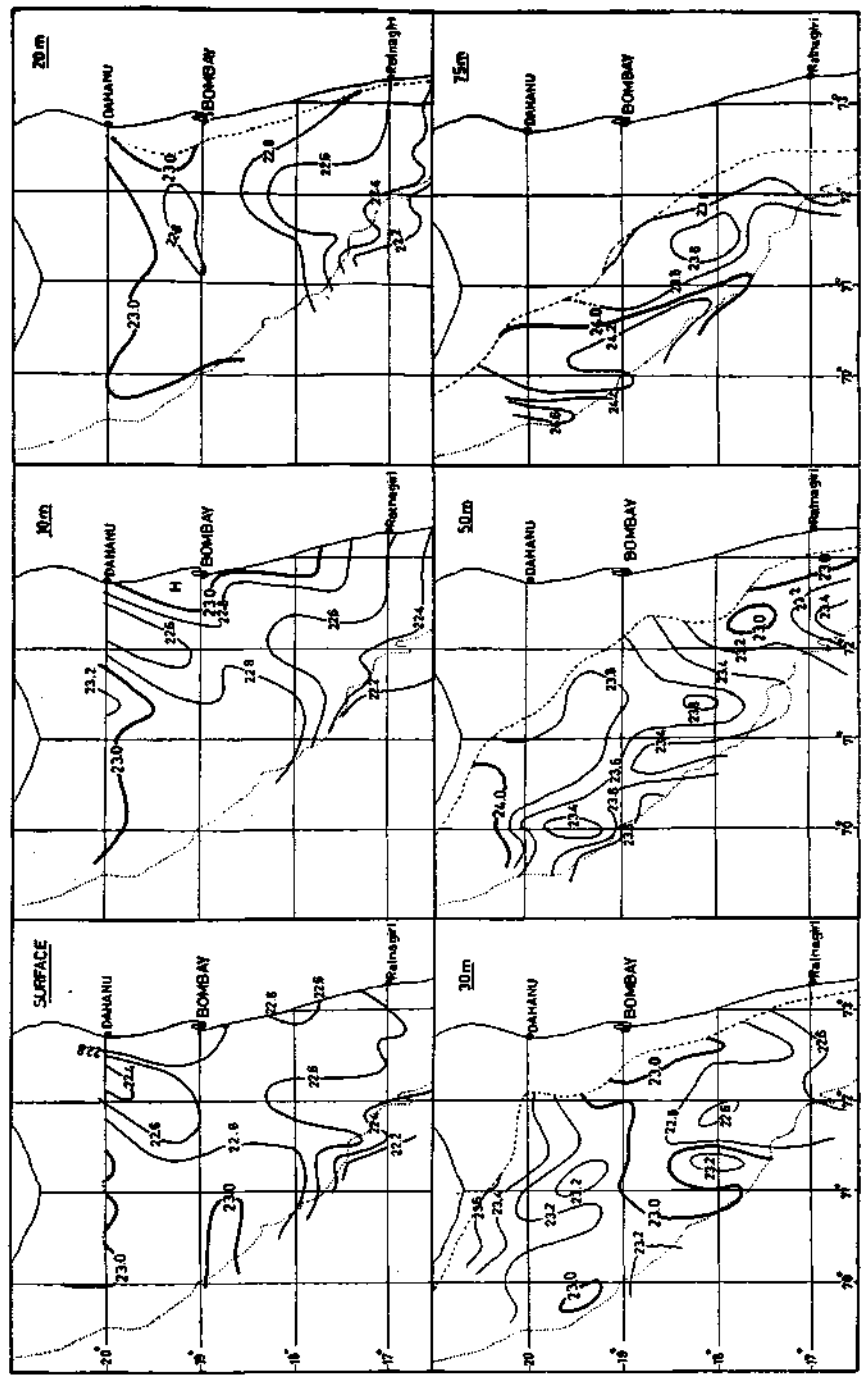

FIG. 11. Distribution of density (Sigma-T) over specified lateral planes.

end of May. This is quite clear from the wind observations on board the Research Vessel *VARUNA*, during the cruise period. The first half of May represents winds mostly from northwest direction and with more or less constant speed, while the second half shows varying winds suggesting from the direction frequency. The small time-lag in the occupation of stations in the southern and northern regions may account for the small differences which exist in the distribution of the various properties in these two regions, especially of the waters which occur over the shelf region. Thus in the southern region (south of 18° 30′N.) the mixed layer generally extends downward to 30 m. or more, sometimes reaching the bottom. This layer is represented more or less by a homogeneous mass of water, while in the northern region (north of 18° 30′N.) the mixed layer rarely extends below 30 m. depth, and due to the upsloping of the isolines as in case of section 7, is reduced to practically zero thickness. Below this narrow mixed layer in the northern region, the waters over the shelf further show the presence of another narrow layer bounded by 23 and 23.5 sigma-T surfaces, characterised by a comparatively high thermal gradient. (2-3°C for 20-30 m.). The occurrence of this mid-layer thus separates the upper mixed layer from another homogeneous water mass which rests upon the bottom. It may further be pointed out that warmer low saline water is observed in the south-east region of the area of observation. This water is shown in the upper layer of 20 m. thickness and seems to be of offshore origin, moving over the shelf in a north-easterly direction as a tongue. Another tongue of lower salinity and slightly higher temperature is observed 30-35 miles off Dahanu along 20°N. moving in a south-westerly direction in the upper 20 m. layer. This tongue seems to be formed due to mixing of river run off from the various rivers (Sabarmati, Tapti, Narbada etc.) which pour their water in the gulf of Cambay. However, the effect of this tongue is limited to the upper 20 m. layer and this can be traced further south upto 19° 30′N. During the period of observation comparatively more saline and warmer water can be expected along the coast, especially in the upper 10 m. layer, as this water will receive extra heat radiation from the adjacent land. As has been mentioned in the introduction the tidal influence in the northern Arabian Sea is high and the cold waters found off Veraval and neighbouring regions may be attributed to the above effect. The drifts produced due to the above phenomenon are transient and short lived. However, more data is necessary regarding tides and temperature distribution to interpret the above phenomenon in a detailed manner.

An examination of the temperature-salinity relationships shows the existence of 3 main water masses whose temperature and salinity ranges are as follows :

(1)	Temp. range	—26°-30°C ;	S‰ range	—35.5-36.3‰
(2)	,,	—19°-26°C ;	,,	—35.5-36.3‰
(3)	,,	— 6°-19°C ;	,,	—35.1-35.6‰

Although there is resemblance for the above water masses with these in the southern Arabian Sea, the temperature and salinity ranges are distinctly modified as can be seen from the table given. When proceeding north the salinity maximum gets dissipated due to the increase in salinity with latitude, and the distinction between the particular water masses becomes more vague. At any rate, more data is necessary to define the water masses in this region in a satisfactory manner.

Summary

Systematic hydrographic observations are made during the month of May off the Maharashtra and Southwest Sourashtra Coasts. The properties investi-

gated in detail are temperature, salinity and density, while oxygen determinations were limited to the initial stage of the cruise. The distribution of these properties in vertical as well as horizontal planes is presented and the various factors associated with these distributions are discussed. From the distribution it is clearly seen that the stable summer conditions gradually progress towards unstable conditions with the approach of southwest monsoon, say, by about middle of May. In the upper layers upto 20 m. a tonguelike drift of the waters towards south is observed while in the southern region a northeast bound weak drift is noticed. Lateral drifts are, in any case, very weak. Below 30 m. depth which forms a transition layer, eddy formations are conspicuous. A general increasing trend in salinity is observed with increase in latitude. The water masses found have different characteristics from those found in the southern Arabian Sea. The tidal influences in the coastal regions may be quite appreciable in modifying the oceanographic characteristics ; so too the effect of bottom topography.

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