

HYDROGRAPHIC FEATURES OF THE LAKSHADWEEP (LACCADIVES) SEA DURING WINTER

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ABSTRACT

Hydrographic features of the Lakshadweep Sea during winter have been studied using the data collected in December during the 13th cruise of R.V. *Gaveshani*. The mixed layer depth in this region varies between 30 and 70 m. The thickness of the thermocline varies between 150 and 200 m. A northward flow in the surface and a counterflow in the subsurface layer in the slope regions of the southwest coast of India could be inferred from the distribution of temperature and thermosteric anomaly. The geostrophic currents along the deep sea section indicate the presence of eddies in this region. Various water masses have been found in the region as distinct salinity maxima and minima. Incursion of the Bay of Bengal water along the southwest coast is a noticeable feature.

INTRODUCTION

The waters of the Lakshadweep Sea exhibit complex thermohaline features and undergo seasonal changes. A variety of watermasses intrude into this region and their movements are largely influenced by the Lakshadweep Archipelago. Lakshadweep Sea has the presence of several islands and shallow banks which affect the topography of the region. The present study is based on the data collected during the 13th cruise of R.V. *Gaveshani* mainly covering the area beyond the continental shelf off the southwest coast of India.

DATA AND METHODS

Temperature and salinity data were collected at 23 stations (Fig. 1) along 4 sections, two parallel and two perpendicular to the coasts using the standard hydrographic casts. Salinity was measured using a precision laboratory salinometer (0.003‰ accuracy). Distribution of temperature, salinity and thermosteric anomaly were studied with the help of the four vertical sections drawn for different transects (Fig. 1). The depth of occurrence of thermocline was taken as the depth where the temperature fall by 1°C from the surface and 15°C isotherm was considered as the bottom of thermocline. Geostrophic currents along section II were computed taking 1000 m as reference level.

RESULTS AND DISCUSSION

Temperature:

Surface temperature in section I (Fig. 2a) varies between 28 and 29.1°C. Mixed layer thickness varies between 30 and 60 m. Small scale inversions noticed in the

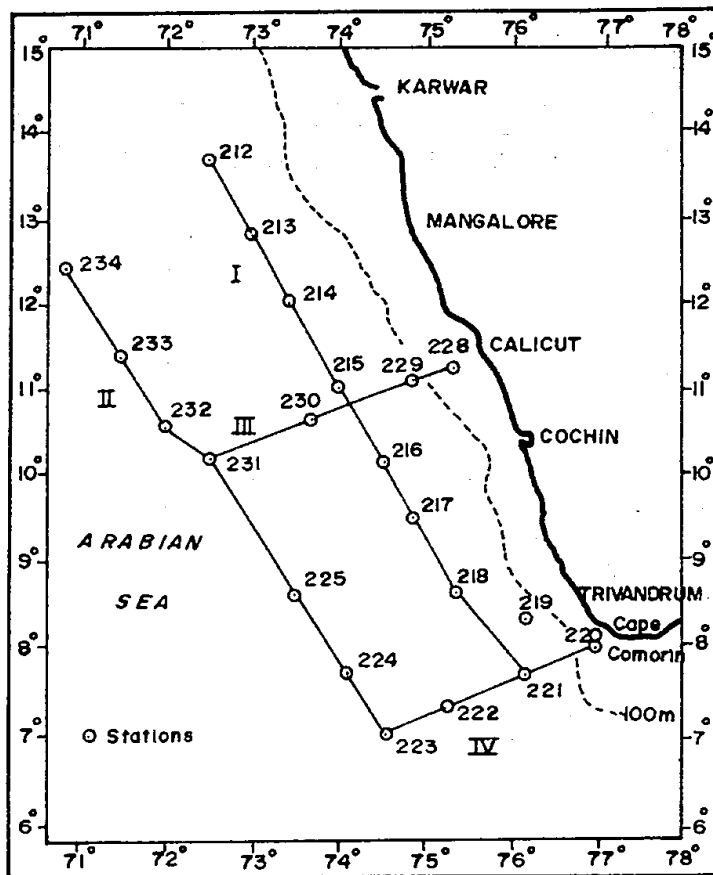


Fig. 1. Station location map.

mixed layer in this section at the northernmost stations were smoothed out while contouring. This may be the effect of winter cooling and subsequent sinking of surface water. Darbyshire (1967) also earlier reported temperature inversions in this season off the west coast of India. Below the mixed layer a strong thermocline exists and its thickness varies between 150 and 200 m. Bottom of the thermocline is found to be between 195 and 225 m. Surface temperature in section II varies between 26.2 and 23.2°C (Fig. 3 a) and thickness of mixed layer varies between 30 and 70 m. Thermocline exhibits strong gradients and extends down to 150 to 250 m. In both the sections, an upsloping of isotherms towards south has been noticed below 300 m. Also, the isotherms below the thermocline shows a wavy pattern. This may perhaps be indicating considerable movement of water at these intermediate depths. Such a pattern can be seen in the distribution of thermocline anomaly also (Fig. 2c). Similar features were observed by Jayaraman *et al* (1960) during March-April in the Laccadive areas.

Surface temperature varies between 28 and 28.8°C in section III (Fig. 4a) and the mixed layer varies between 40 and 60 m. Thermocline thickness varies between 120 and 150 m. In section IV, the surface temperature varies between 28.6 and

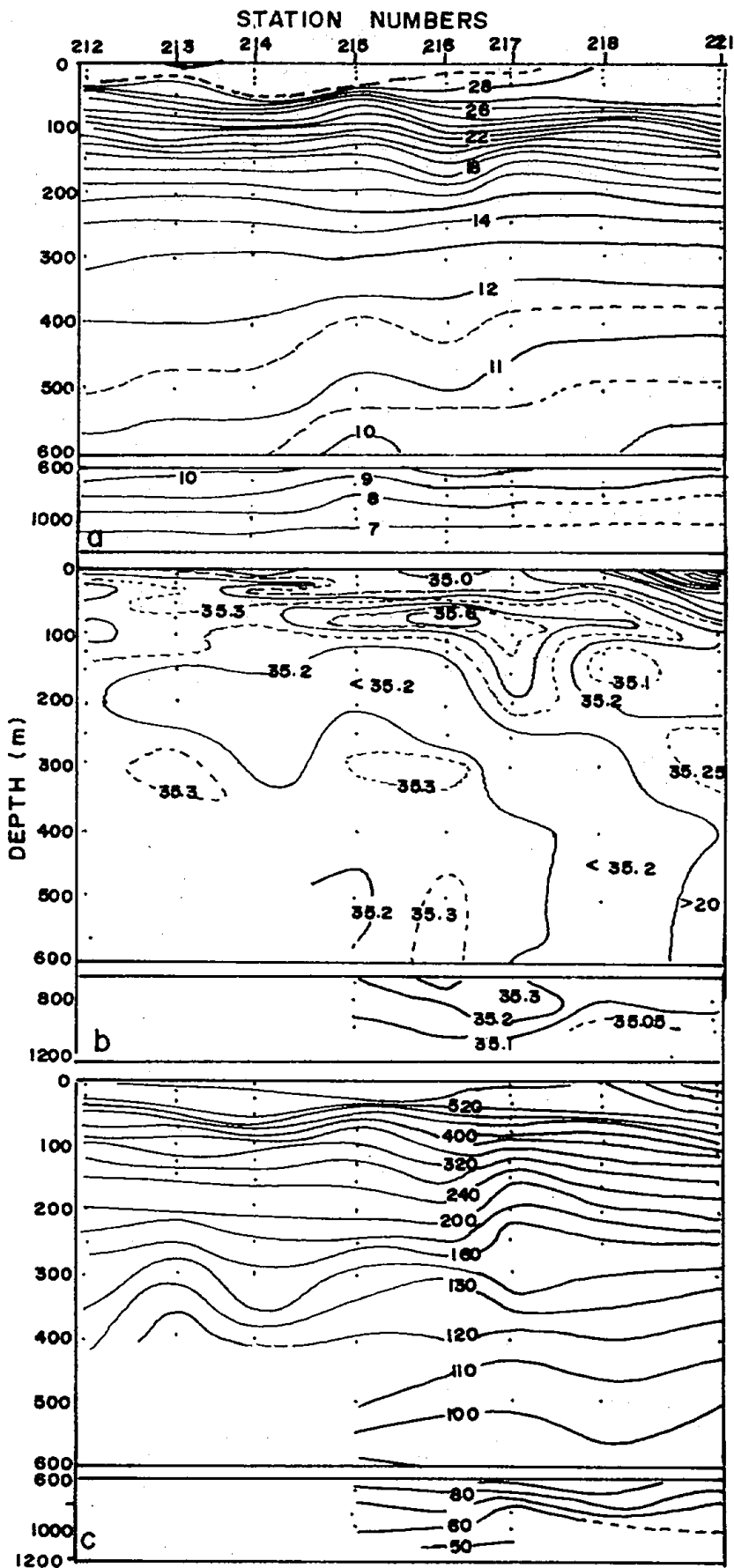


Fig. 2. Temperature (a), salinity (b), and thermocline depth (c) along section I.

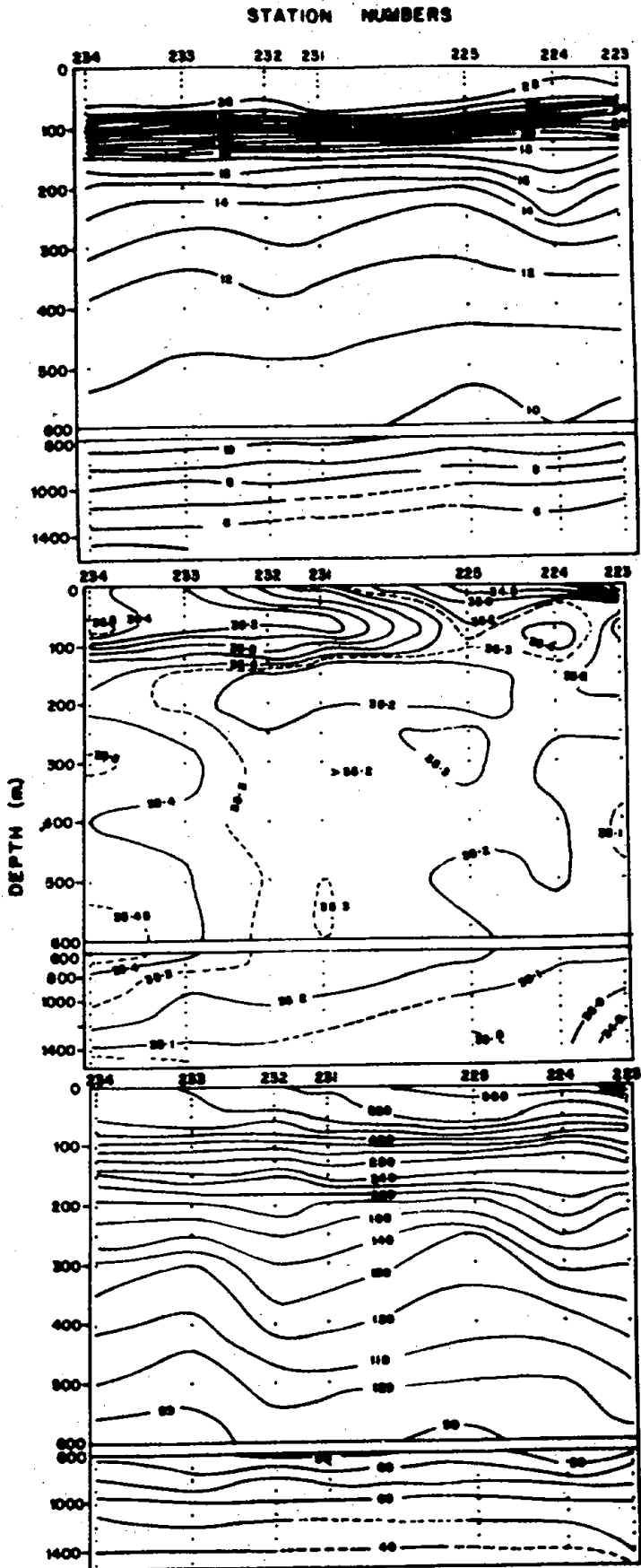


Fig. 3. Temperature (a), salinity (b), and thermosteric anomaly (c) along section II.

29.0°C and the thickness of mixed layer varies between 50 and 60 m. Thickness of the thermocline is about 150 m throughout the section and the bottom of thermocline occurs at depths around 200 m. In the upper 200 m, especially in the thermocline, the isotherms slope downward towards the coast in both sections. Below 200 m upto 500 m the trend reverses. The down-sloping of isotherms towards the coast in the upper layer may be indicating sinking in the surface layers and the reversal of trend in the intermediate layers may be indicating a reverse flow compensating for the sinking in the upper layers. The sinking process appears to be typical of this season along the west coast of India as indicated by earlier studies (Varadachari *et al*, 1974; Banse, 1959). A few bathythermograms obtained during the cruise in the shelf area show that the shelf waters are almost isothermal.

Salinity:

Surface salinity decreases from north to south as seen in sections I & II (Fig. 2b and 3b). The range of variations is more in section II (34.13 to 36.47‰) than in section I (33.1 to 35.1‰). In general, salinity distribution in the upper 100 m layer exhibits strong horizontal and vertical gradients. In general, there is a decrease in salinity from north to south throughout the water column except for the sparse maxima found at intermediate depths.

In the surface, a low saline water appears to spread towards north. This could be the Bay of Bengal water intruding into the Arabian Sea during north-east monsoon due to the northerly coastal current. Intrusion of low saline water from south filling the southwest coast and Lakshadweep area was reported earlier by other investigators also (Wyrcki, 1971; Banse, 1959; Ramasastry, 1959; Darbyshire, 1967; Varkey *et al*, 1979). Banse (1959) observed that during the period of north-setting currents, waters of relatively low salinity (34‰) appears off Cochin. He reported further lowering of salinity (33‰) in the month of January. Ramasastry (1959) named it the Arabian Sea Surface Water and Darbyshire (1967) argued that it was the Equatorial Surface Water. Banse (1959) preferred the latter's view. But it is, more likely, the Bay of Bengal water which enters the Arabian Sea as also can be inferred from Wyrcki (1971, plate No. 55).

A salinity maximum is found between 50 and 100 m in all the sections. Its presence is more conspicuous in section II than in section I indicating that the core of this salinity maximum lies in the offshore region. This salinity maximum is obviously due to the spreading of the Arabian Sea high salinity water as the core value of this salinity maximum decreases from north to south. The variation in the core value is more in section II (35.22 - 36.58‰) than in section I (35.3 to 35.6‰). The core value also decreases from offshore towards the coast as can be seen in Figs. 4b and 5b. It is interesting to note that this maximum extends down to about 200 m at station 217 in section I (Fig. 2b).

Below this salinity maximum, a salinity minimum is encountered around 200 m (Figs. 2b & 3b). This can be either due to the sandwiching effect of the salinity maximum of the Arabian Sea high salinity water above and the salinity maximum of Persian Gulf water below or due to the northward spreading of a low saline

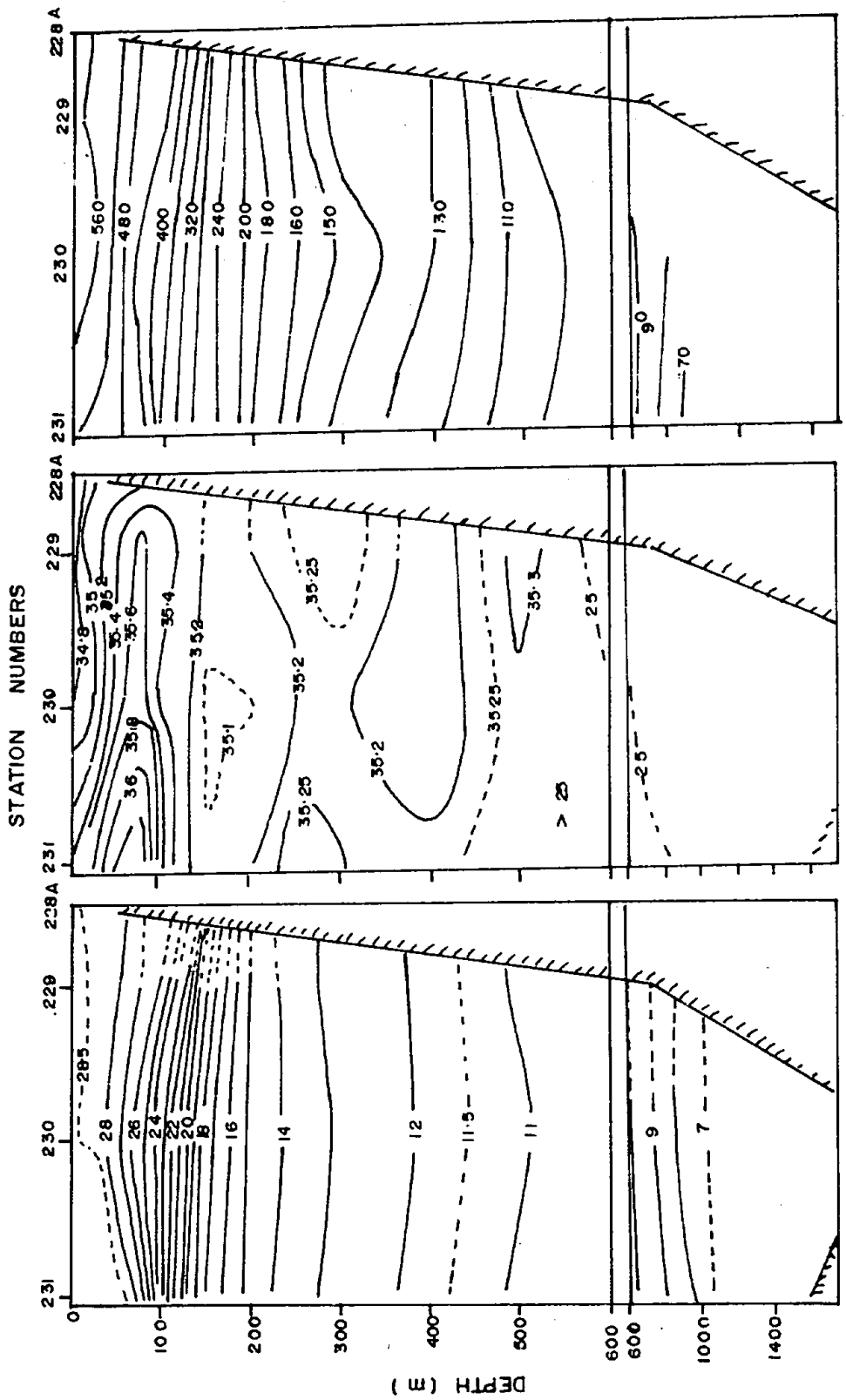


Fig. 4. Temperature (a), salinity (b), and thermocline (c) along section III.

water from the equatorial region. It is more likely that this salinity minimum is due to the equatorial water spreading towards north. A northward tongue of low salinity water was observed in the month of March also (Ramesh Babu *et al*, 1980).

Another salinity maximum is observed around 300 m depth at a few stations. This is due to the presence of Persian Gulf water in this area. This maximum is much diffused towards south and east (Figs. 2b, 3b, 4b & 5b). Below this maximum, salinity decreases monotonically but for yet another salinity maximum encountered between 500 and 600 m at a few stations in sections I & II (Figs. 2b and 3b). This is the salinity maximum of Red Sea water which spreads towards east and south after entering the Arabian Sea from the Red Sea (Wyrcki, 1971; Rochford, 1964). It appears from the vertical distribution along all sections that the waters at the intermediate layer between 200 and 800 m depth, would have been nearly isohaline, but for the two salinity maxima described above. It can be seen that salinity in this layer generally, increases towards north. Below 800 m salinity decreases monotonically.

The two sections perpendicular to the coast (Figs. 4b and 5b) indicate that the influence of the three salinity maxima observed at various levels is considerably reduced towards the coast. The surface salinity along these two sections shows significant variations. While the section IV off Cape Comorin (Fig. 4b) shows low saline surface water extending down to a depth of 75 m, it confines to a thin layer in the section III off Calicut (Fig. 5b). The 34.8‰ isohaline is found at the surface in the section off Calicut but it is found between 30 and 80 m off Cape Comorin. The salinity maximum of the Arabian Sea high salinity water is found at a depth of 75 m in section III (Fig. 4b) with decreasing salinity towards the coast from 36.3 to 35.4‰. Another noticeable feature is that the salinity maximum of the Red Sea water is not found in the section off Cape Comorin. All this indicate that the salinity structure varies considerably meridionally and zonally, in the Lakshadweep Sea.

Thermosteric Anomaly:

In general, thermosteric anomaly increases considerably from north to south in the surface layer from 560 to 680 cl/t in section I (Fig. 2c) and 470 to 610 cl/t in section II (Fig. 3c) indicating low density water in the southern region. In the southern region of the sections I & II, the isanosteres slope downwards upto a depth of about 150 m in section I and 250 m in section II. This may also be indicative of an onshore flow in that region. There is a strong vertical gradient in the southern region which corresponds to the gradient in salinity. In the northern part of the sections, the stericline more or less follows the pattern of the thermocline. The intermediate layers are exhibiting wavy pattern as observed in the thermal structure indicating considerable movement of waters as mentioned earlier. Thermosteric anomaly distribution shows an increasing trend towards the coast in sections III & IV (Figs. 4c & 5c). Also downsloping of isanosteres towards the coast is noticed in the upper layers upto a depth of about 200 m. Similar trend is observed in temperature distribution also (Figs. 4a & 5a). The trend of sloping reverses below this depth and

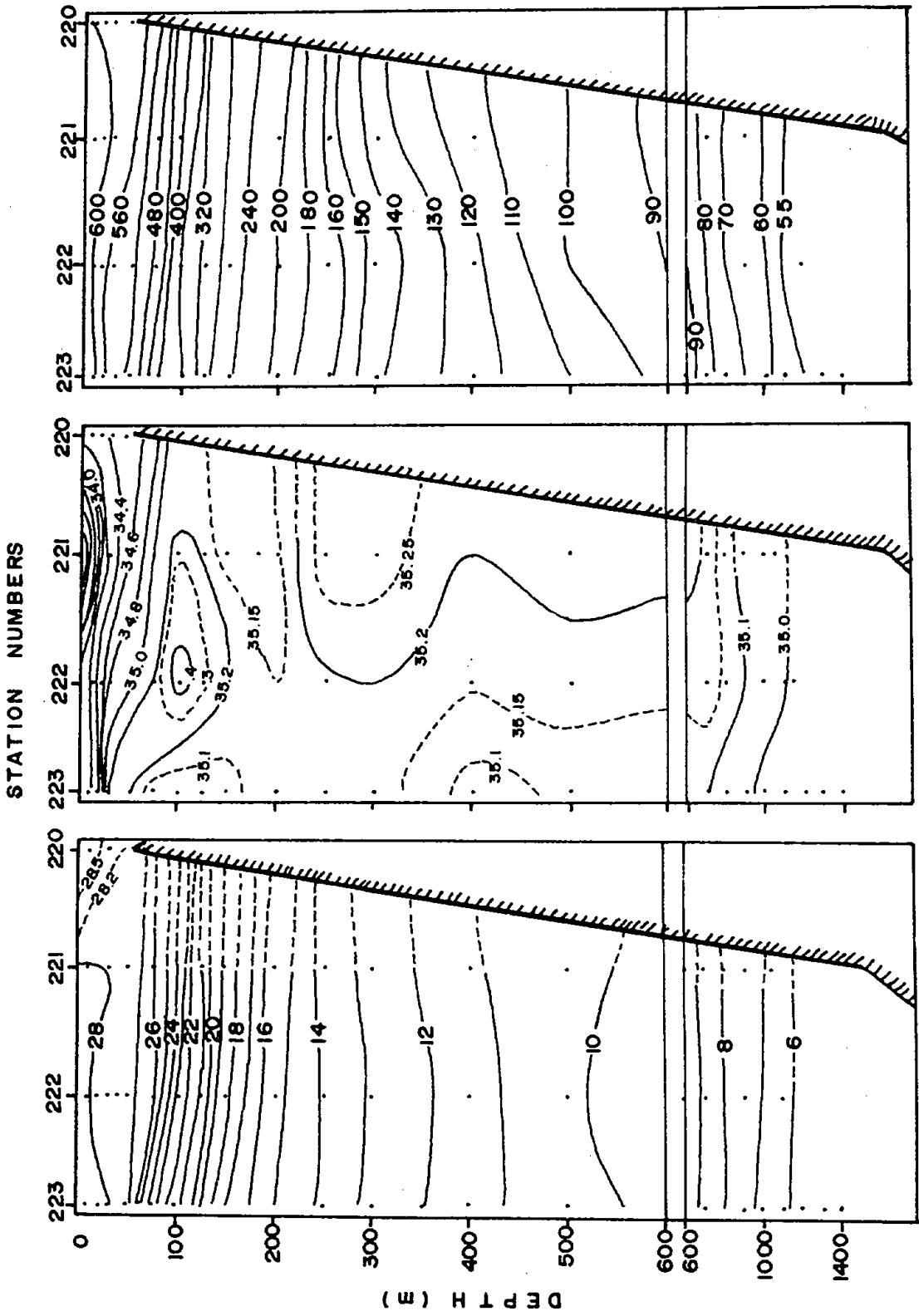


Fig. 5. Temperature (a), salinity (b), and thermocline depth (c) along section IV.

is more conspicuous in section IV (Fig. 5c) which indicates a northward flow in the surface layer and a counterflow in the subsurface layers in the outer shelf/slope region. It is worth mentioning that coastal surface currents during this period is northerly and consequently sinking occurs along the west coast of India (Sharma, 1968; Varadachari, *et al*, 1974).

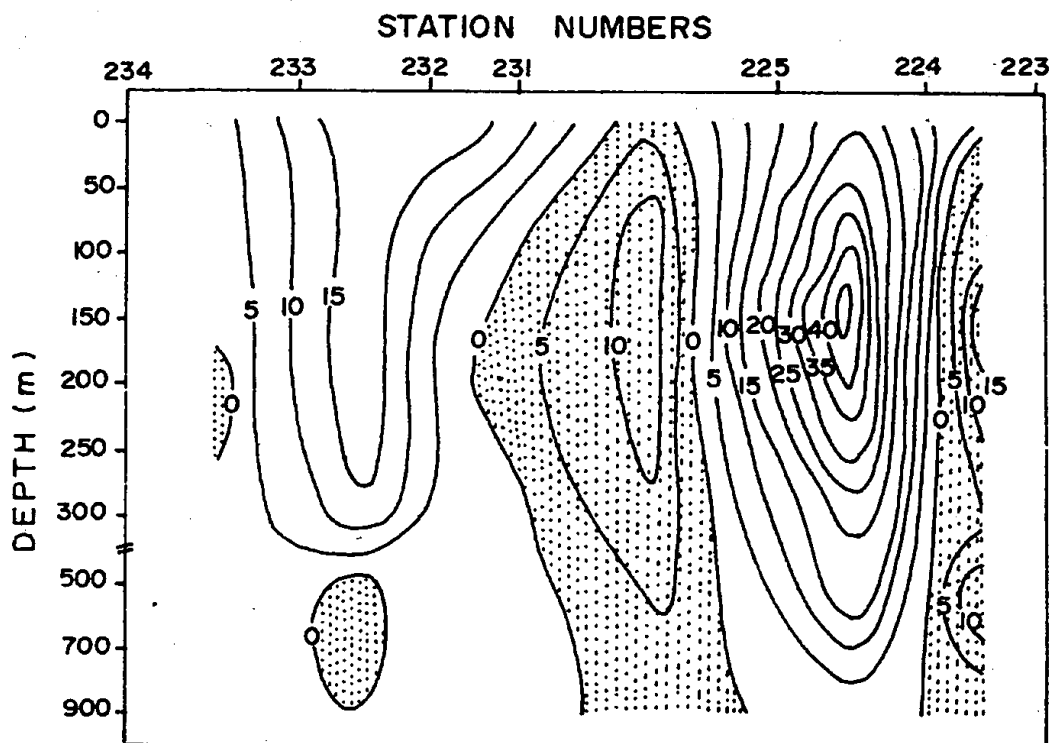


Fig. 6. Geostrophic currents along section II (Hatched area represents westerly components and blank area represents easterly components).

Watermasses

Different watermasses are found in the study region as distinct salinity maxima and minima. Bay of Bengal low saline water is found as a salinity minimum in the surface layer between surface and 50 m depth (Fig. 6). This water enters the Arabian Sea from the Bay of Bengal due to the northerly currents in this season. The thermohaline anomaly of this water varies between 450 and 600 cl/t in the study area. Intrusion of this water into the Arabian Sea and its spreading towards north along the Kerala coast has been reported earlier by several other investigators during different periods (Varkey *et al*, 1979; Wyrki, 1971; Ramesh Babu *et al*, 1980). The salinity of this water increases from south to north as a result of mixing with the Arabian Sea high salinity water spreading towards south. The surface salinity distribution shown by Wyrki (1971) indicates that this water begins to spread into the southeastern part of the Arabian Sea during November-December and reaches its maximum penetration in February. Then, as a consequence of the reversal of coastal currents the water slowly retracts. A look at the comparative position of the

35‰ contour in the surface (approximately the northern limit of this watermass) in the present study and earlier studies during other months reveal that the presence of this watermass in this area is only a seasonal feature. In the early March, the 35‰ contour is observed near the surface just north of Mangalore (Ramesh Babu *et al*, 1980). In the early April, it is observed between Mangalore and Cochin while in the present study it has been observed off Cochin. This establishes the fact that the Bay of Bengal water spreads towards north with the onset of northerly currents and reaches off Mangalore by February/March and then retreats with the reversal of coastal currents.

The Arabian Sea high salinity water is found in the offshore region as a shallow salinity maximum between 40 and 100 m depth (Figs. 2b and 3b). It spreads as a distinct core towards south beyond the shelf region. Its steric level is found to be between 310 and 510 cl/t. Ramesh Babu *et al* (1980) observed the Arabian Sea high salinity water during March between 325 and 485 cl/t (23-24.7 σ_t). This watermass loses its salinity as it spreads towards south probably by mixing up with the low saline surface water.

The salinity minimum observed at the southern ends of the sections I & II (Figs. 2b and 3b) below the Arabian Sea high salinity water at around 200 m depth is the subsurface equatorial water spreading towards north. This feature was observed in the early March also (Ramesh Babu *et al*, 1980). The steric level of this watermass is found to be between 150 and 230 cl/t. Persian Gulf water is found only as pockets of high salinity around a depth of 300 m at a few stations. It is much diffused as it spreads towards east and south. It is observed between the steric levels 120 and 190 cl/t. Red Sea water is present in the study region as a sparse maximum between 500 and 600 m depth. Its steric level is found to be between 85 and 105 cl/t. This is in agreement with the earlier studies (Rochford, 1964; Ramesh Babu *et al*, 1980). This watermass also loses its identity as it spreads towards east and south.

The movement of watermasses appears to be influenced by the topography of this region marked by the presence of islands which can cause generation of eddies. This may be the reason for finding the intermediate watermasses in scattered pockets only as spin-offs. It appears that several watermasses from different parts of the northern Indian Ocean intrude into the Lakshadweep Sea.

Geostrophic currents

Geostrophic currents along section II is presented in Fig.6. The alternate bands of westerly and easterly components clearly indicate the presence of eddies in this region. Between the stations 224 and 225 intense current field is noticed with a maximum speed of about 45 cm/sec. The maximum speed is noticed around 150 m depth. Similar features could be more or less discernible from the distribution of thermohaline anomaly along the same section (Fig.3). This region with spread out islands offer peculiar topography which can cause generation of eddies.

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