

Physical Characteristics of the Laccadive Sea (Lakshadweep)

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Received 26 May 1979; revised received 17 November 1979

Several physical properties of the Laccadive Sea were studied based on data collected in March/April and the results compared with the data earlier obtained from the same area during October and December. The mixed layer extended to 90-100 m depth with a 2-layered structure, an upper isothermal and a lower with weak thermal gradients. The Arabian Sea High salinity water was observed as a sub-surface high salinity core in the Laccadive Sea. Persian Gulf and Red Sea waters were also observed. Surface salinity showed wide variations which were related to the influx of water from the Bay of Bengal. Considerable meridional salinity gradients existed at the surface.

During the 31st cruise (20 March to 6 April 1978) of *R V Gaveshani* the Laccadive Sea area (Fig. 1) has been studied because of its geographical position¹ and features which influence the movement of water masses^{2,3}. The coral islands and shallow banks in this area would possibly promote eddy formations of large dimensions^{4,5}. Further, these eddies may introduce spatial changes in the structure of oceanic processes at mesoscale⁶.

Methods

Standard hydrographic casts were taken for the collection of temperature and salinity data. Salinity samples were analysed on a precision ($\pm 0.003\text{‰}$) laboratory salinometer. Bathythermograph dips were taken at 29 stations. Continuous records of surface salinity were collected, and records read at 5 min intervals, using a thermo-salinograph along some runs (Fig. 1). The values were compared with those obtained with a precision laboratory salinometer and the necessary corrections made. In addition, surface meteorological observations were carried out at all the stations.

Temperature and salinity data were utilised for studying the distribution of water masses. The variations in the mixed layer were studied from the bathythermograph records.

Data collected during the 31st cruise were compared with those collected during the 10th (October 1976) and 13th (December 1976) cruises⁷ of *R V Gaveshani* to determine variability in the area.

Results and Discussion

Temperature and mixed layer—Vertical distribution of temperature along the 3 sections is given in Figs 2a and 3a. In general, the surface temperature decreased

towards offshore and also from south to north. The upper 50 m layer was almost isothermal in the deep water sections. This feature was observed earlier, by Jayaraman *et al.*⁸ in April. The top of thermocline was generally found between 90 to 100 m depth in the vertical section. Between the thermocline and the upper isothermal layer, a layer with weak temperature gradients ($0.02\text{--}0.06^\circ\text{C/m}$) was recorded. These 2 layers together form the mixed layer. This layering is considered to be the result of winter deepening of the thermocline which persists through March-April⁹. In the zonal section (Fig. 3a) the thermocline became shallow towards the coast. The thickness of the main thermocline varied between 80 and 125 m. The temperature gradient in the thermocline gradually increased from north to south (Fig. 2a, A). In general, there was a strong upslope of isotherms towards the coast (Fig. 3a) as well as towards the south (Fig. 2a, A) extending down to a depth of about 300 m. The slope was more prominent in the thermocline region in both the sections. This upsloping, may be indicative of the 'rising' of subsurface waters by surface divergences. Below 300 m also the distribution of temperature showed a weak upsloping up to 700 m in both the sections. The water column in the inner shelf was almost isothermal (Fig. 2a, B).

During October and December (see Fig. 1 for stations) the mixed layer thickness in the open sea varied between 50 and 60 m. The thickness gradually decreased as the depths decreased and in very shallow waters the water column was homogeneous up to close-bottom depths with a sudden decrease in temperature very close to the bottom off Cochin⁷.

Salinity—Vertical distribution: Figs 2b and 3b present 3 vertical sections of salinity. The noteworthy feature in Fig. 2b is the spreading of the Arabian Sea

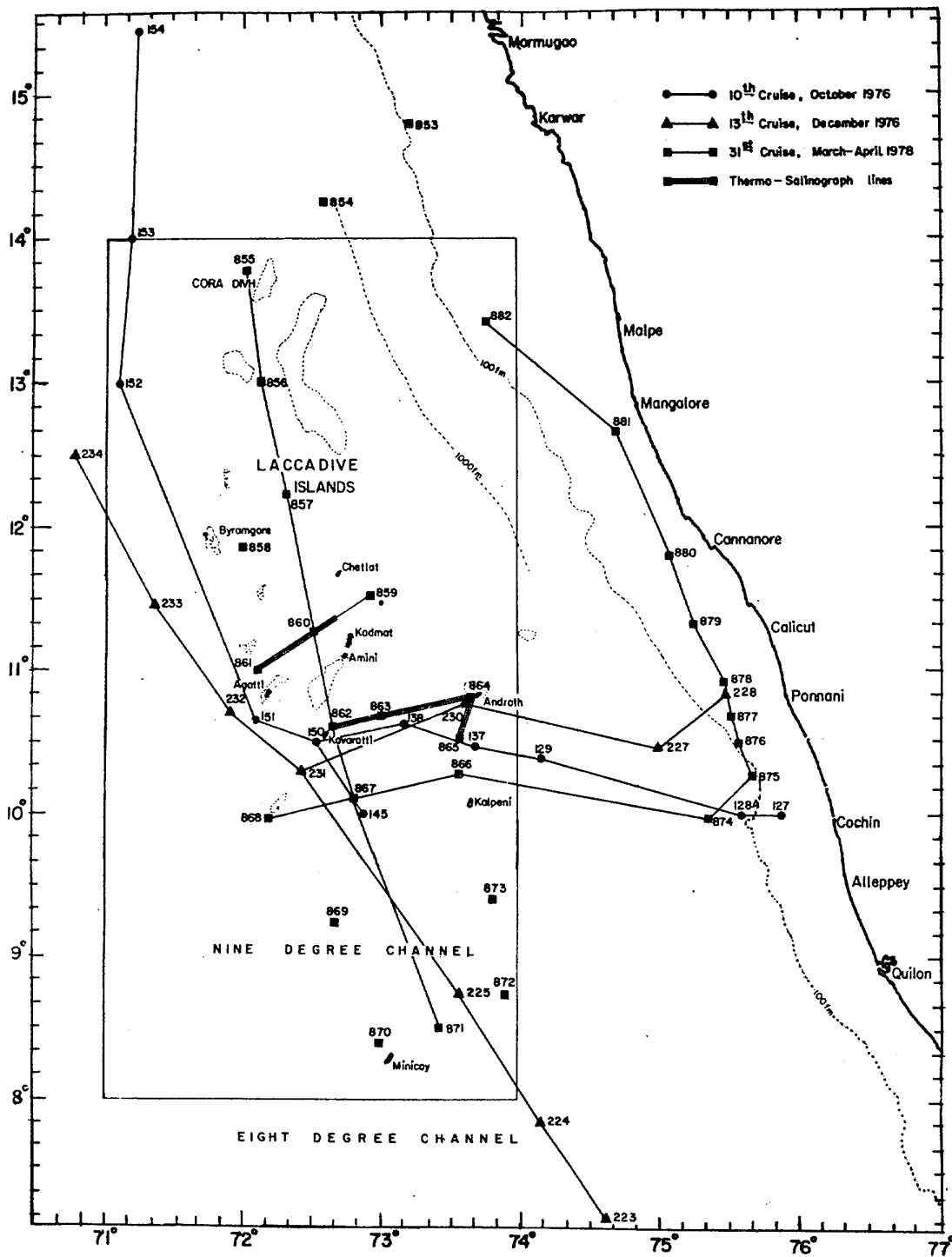


Fig. 1—Station locations in different cruises

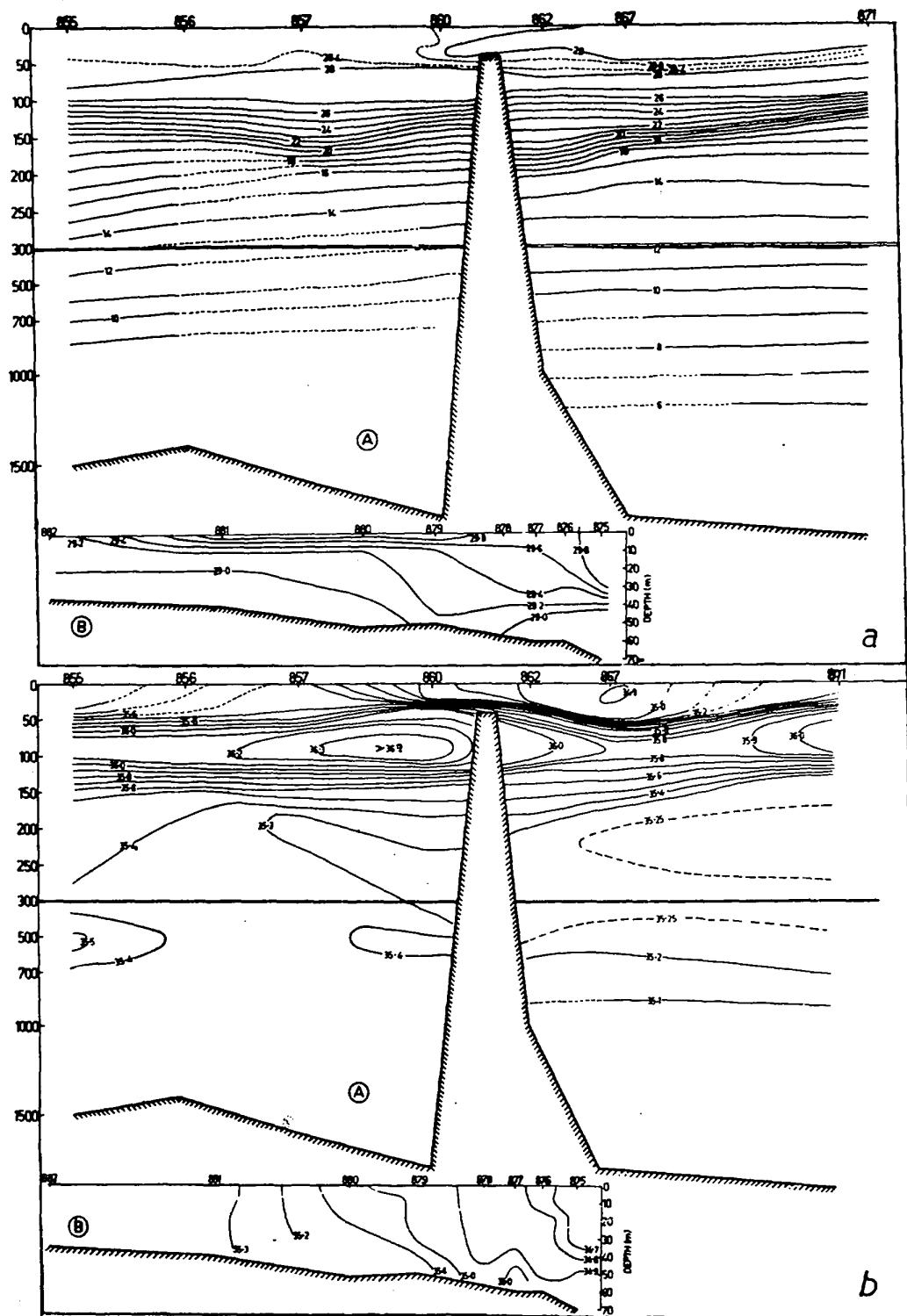


Fig. 2.—Vertical distribution of temperature (a) and salinity (b) along a deep section (A) and shallow section (B)

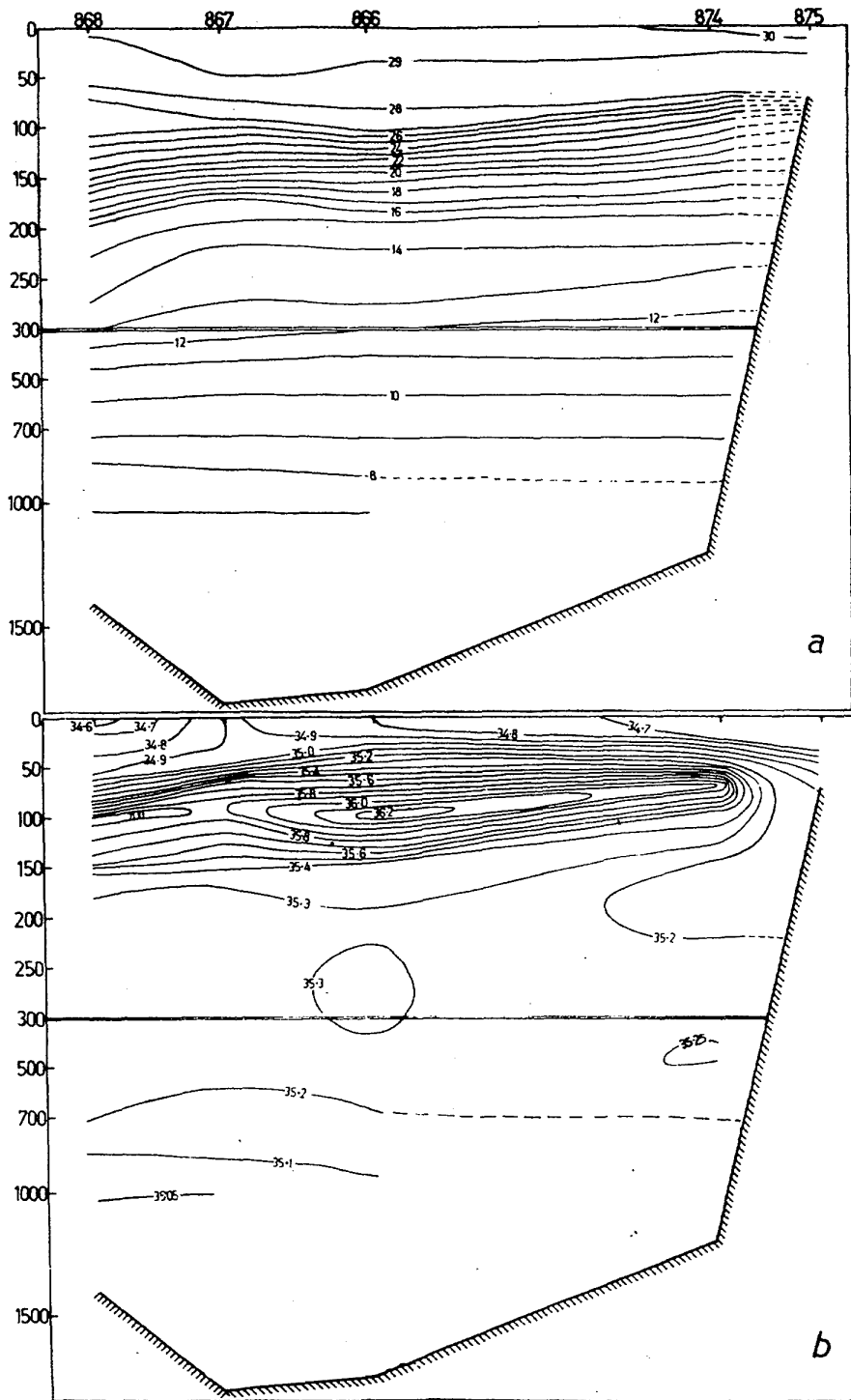


Fig. 3—Temperature (a) and salinity (b) distribution perpendicular (zonal) to the coast

high salinity water from north (st 855) to south (st 871). This high salinity water extends vertically between 30 and 150 m depths. The presence of this high salinity tongue in April was earlier reported by Jayaraman *et al.*⁸. The maximum core value observed was 36.38‰ at st 860 at 100 m. The presence of a steeply rising narrow oceanic reef (Fig. 2b, A) does not seem to affect the southward spreading due to the large width of the watermass core (Fig. 3b) compared to that of the reef. North of the reef, (Fig. 2b) high salinities ($> 35.4‰$) were observed between 400 and 700 m indicating the presence of the Red Sea water. South of the reef, below 150 m, only low salinities ($< 35.3‰$) were observed. Sts 867 and 871 were situated in such regions where the surface waters (see Figs 2b and 4) were distinctively different (see the bounded area surface minimum in Fig. 6). The low salinity surface water from the Bay of Bengal spreads into the Arabian Sea⁹⁻¹¹ in the area between these 2 stations extending down 30 to 40 m. Hence some of the near surface contours between these stations are completed by broken lines to show the unrealistic nature of the contours. The presence of low salinity surface water in the same area was earlier explained by Darbyshire⁹. St 869 (Fig. 1) situated about 60 km west of the section running north-south but almost equidistant from sts 867 and 871 (Fig. 2b, A) showed the presence of high salinities ($> 35.3‰$) up to a depth of about 600 m (Fig. 6). St 873, also situated between 867 and 871 but towards the east (~80 km) showed low salinities ($< 35.3‰$) below 200 m (Fig. 6). These observations indicate that east of 72°30'E and south of 11°N the cores of the Persian Gulf and Red Sea waters are much 'diffused'. Fig. 2b, B gives salinity distribution along the coast from st 875 to st 882. The water column in the inner shelf is almost isohaline with a general increase towards north. However, close to the coast, the salinity increases slightly (34.7 to 35‰) from surface to bottom; this vertical gradient progressively decreases up coast and finally disappears off north of Cannanore. The zonal section (Fig. 3b) shows the presence of Arabian Sea high salinity water all along the section with its core centred around 100 m depth.

The low salinity surface layer deepens at the east and west sides of the zonal section (Fig. 3b). The findings reveal that the Arabian Sea high salinity water is present all through the deep survey area. The absence of this high salinity water in the shelf confirms the earlier findings^{12,13}.

During December also the Arabian Sea high salinity water core is continuously seen at a depth of 75 m extending zonally from st 232 to st 227 (ref. 7). But the core values gradually decrease from offshore to the shelf. Meridionally, this high salinity core is observed from the north up to st 231. The low saline surface water as observed during March (Fig. 3b), along the

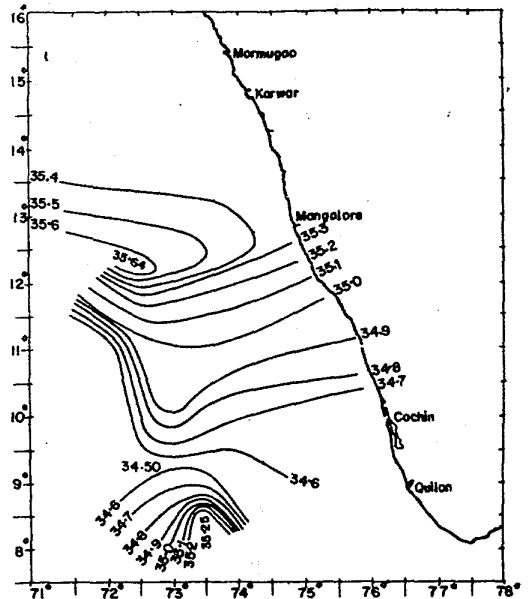


Fig. 4—Surface salinity distribution

zonal section was not present during December. Even at st 228 (depth 45 m), the water column showed almost isohaline (35.02 to 35.08‰) nature. A comparison of the situation in December to that in March shows⁷ that by December, the Bay of Bengal water has not advanced into the Arabian Sea to reach the section, off Cochin, while, by March (Fig. 4), it has spread extensively quite deep into the Arabian Sea. Similar features were noticed by Wyrski¹⁴ also.

Surface salinity: Surface salinity distribution is shown in Fig. 4. The presence of low saline water is very conspicuous. The source of the water is considered to be Bay of Bengal⁹⁻¹¹. The Bay of Bengal low saline water enters into the Arabian Sea and spreads in a north-westerly direction¹⁴. Its incursion begins during November-December and attains its maximum penetration during January-February. By May-June the tongue like surface distribution fades away. In the Arabian Sea, due to surface evaporation and mixing the salinity of the low saline surface water gradually increases and by March, the lowest salinity was only 34.5‰. Along the northern boundaries, 12°N, this water gets mixed with the high saline water of the northern Arabian Sea. Its southern boundary is formed by the waters from the equatorial Indian Ocean¹⁴. Along the coast the salinity increases from 34.6 to 35.3‰. An earlier survey¹³ showed much lower salinity ($< 34.3‰$) off Kerala Coast. In general, in the Laccadive Sea, the surface salinity increases from south (8.5°N) to north (12°N) with a sharp increase (34.6 to 35.64‰). Similar trend was noticed earlier also⁹.

Variation in the zonal surface salinity gradient west of 73°E was large meridionally and east of 73°E it was very small (see Fig. 5).

At the beginnings and the ends of the salinograph profiles (Fig. 5) the salinity values do not agree very closely with those in Fig. 4. This was due to the change in sampling positions between the timings of the hydrocast and the salinograph intake due to ship's drift. The largest difference in salinity was observed between sts 860 and 861. As can be seen from Fig. 5, these 2 stations were situated in different regions of the

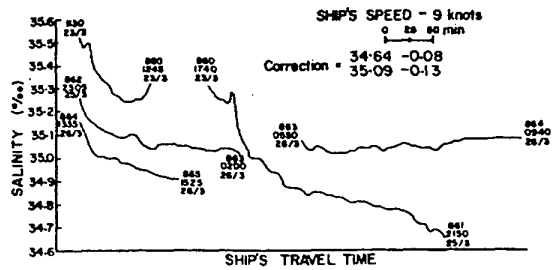


Fig. 5—Salinograph profiles collected during the 31st cruise (replotted)

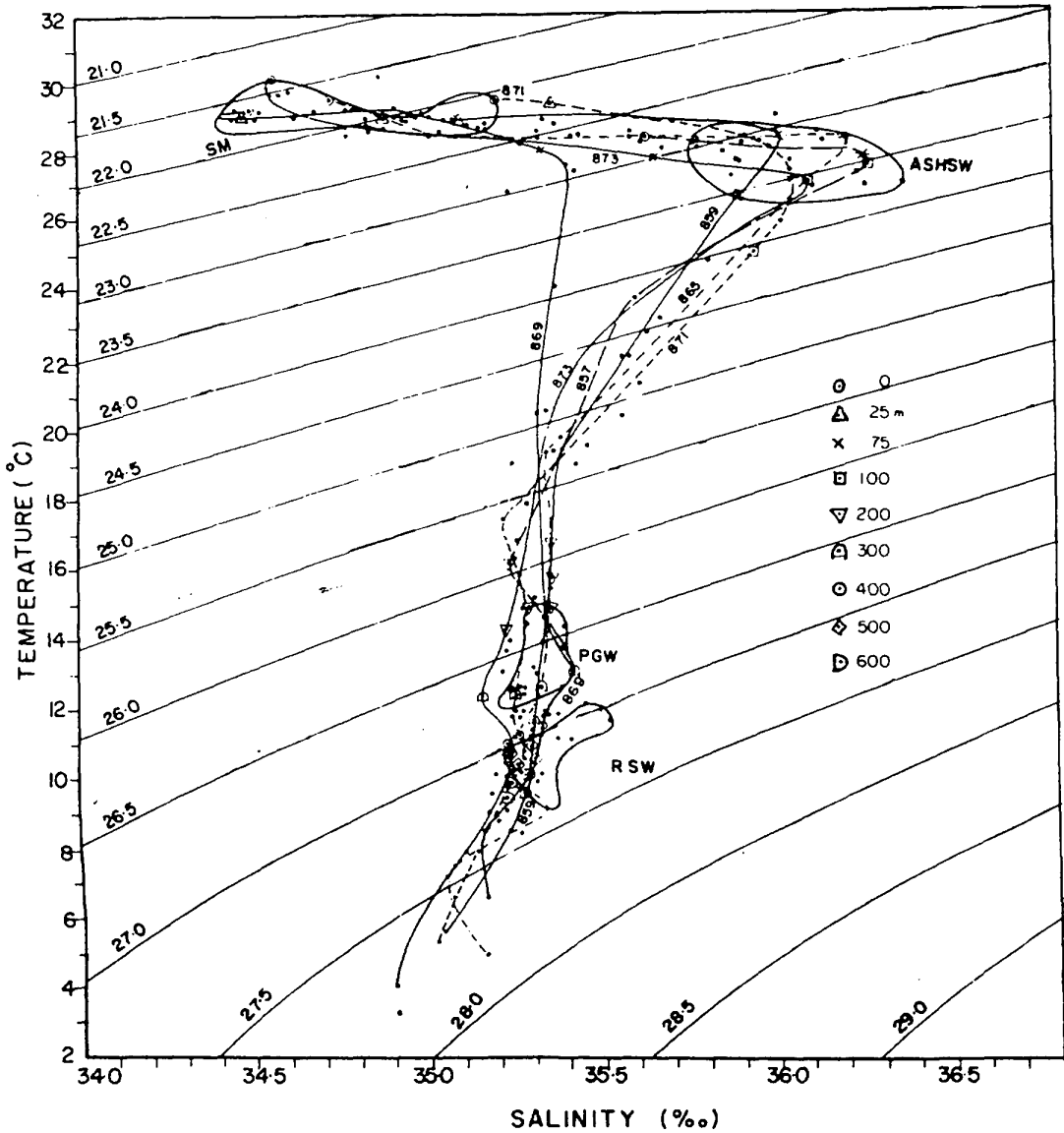


Fig. 6—T-S mapping [ASHSW, Arabian Sea high salinity water; SM surface minimum; PGW, Persian Gulf water; RSW, Red Sea water]

surface water masses; the north Arabian Sea surface water and the Bay of Bengal water. Between sts 863 and 864 the salinity profile was even. This agrees very closely with the surface salinity distribution shown in Fig. 4.

Water masses—Temperature-salinity values at the observed depths for sts 855 to 873 are given in Fig. 6. Also shown in the figure are 6 sample T-S curves from different parts of the survey area (sts 857, 859, 865, 869, 871 and 873) bringing out the wide variations in the vertical and horizontal T-S structure (see also Fig. 4). The observed core regions of salinity maxima and minima (surface layer minimum) are bounded in the same figure. At st 857, the surface water is of north Arabian Sea origin and the Arabian Sea high salinity water core is observed at 75-100 m depths (σ_t 23.5). The Persian Gulf water is observed at depths between 200 and 300 m (σ_t 26.2-26.8). St 859 is typical with high salinity (35.07‰) surface water compared to the southern coastal low saline water (34.7‰), extending up to a depth of about 30 m and of northern Arabian Sea origin. The Arabian Sea high salinity water mass is observed at about 75 m depth with a core value of 36.03‰ (σ_t 22.8-23.8). At st 865, the surface layer has a salinity of 34.73‰ and this layer extends to a depth of about 20 m. St 869 is characterised by very low surface salinity (34.5‰) and this layer of surface water is seen up to a depth of about 25 m. The Arabian Sea high salinity water core is conspicuously 'absent' or 'diffused' at this station. Persian Gulf and Red Sea waters are identifiable at this station. At st 871 the surface salinity is 35.25‰ and this layer extends to a depth of about 20 m. This surface water spreads into the area from the southern latitudes¹⁴ and the low saline surface water of the Laccadive Sea envelopes it around the northern boundaries (see also Fig. 4). The Arabian Sea high salinity water is observed around 75 m (σ_t 23.4). Persian Gulf and Red Sea waters are traceable at this southern most station but the salinity values are 35.29 and 35.28‰ respectively.

The Arabian Sea high salinity water is present all over the deep Laccadive Sea in the layer 50-150 m, as a distinct high salinity water mass (σ_t 22.8 to 23.8). The high salinity core lies in shallower depths in the northern region. As the water spreads down south, the core deepens. Similar features were observed during the 16th cruise of *R V Gaveshani* along a section more closer to the shelf¹³. Fig. 7 gives an idea of the spreading of this water mass. Whenever the salinity values appear low the core is situated below 75 m. At st 868 the Arabian Sea high salinity water layer (35.3‰) starts abruptly at a depth of 85 m; hence very low salinity (35.24‰) is obtained at 75 m (Fig. 7). A noteworthy feature of the Arabian Sea high salinity water core is its high vertical gradients and narrow

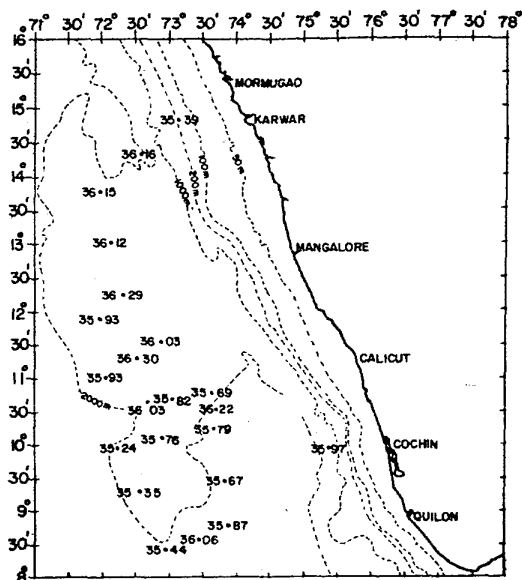


Fig. 7—Salinity distribution at 75 m level

vertical extensions. The core of this water mass extends down into the thermocline from the isothermal layer.

CSTD records collected at sts 868, 870, 872 and 873 show that the core of Arabian Sea high salinity water is 70 to 80 m thick and the core depth differs from station to station. The large variations in salinity at 75 m (Fig. 7) is due to sharp gradients and variations in the core depth. At st 869, the core is not clear and the maximum salinity observed in the layer 100 to 150 m is only 35.41‰. Yet the 'diffused' core might have existed between 100 and 150 m. A comparison with the CSTD record from st 870 (maximum core value 35.7‰) brings out the possibility of similar situations existing at sts 869 and 870. Whereas, at the nearby sts 868, 871, 872 and 873 the core values were > 36.1‰. This observation indicates a westward boundary for the core west of sts 869 and 870. Darbyshire⁹ observed a high salinity core at about 90 m, along 72°E with salinities between 35.5 and 35.75‰. This may be the 'diffused' western side lobes of the Arabian Sea high salinity water tongues spreading south from the northern Arabian Sea as observed in the present study. Persian Gulf water was present at most of the stations around 250-300 m only as a mild high salinity core between σ_t 26.2 and 26.8. Red Sea water was observed in the layer around 500 m between σ_t 27 and 27.4.)

In the Laccadive Sea below the typical water masses of the Arabian Sea (below ~600 m) the T-S structures show the trend (Fig. 6) of gradual decrease. At these depths the high salinity water masses mix with the low saline intermediate waters which rise to shallower depths and the resulting salinity structure shows much complexity¹⁵.

Acknowledgement

The authors are thankful to Dr S.Z. Qasim, Director, for encouragement and suggestions. Thanks are due to Dr V.V.R. Varadachari, Deputy Director and Dr J.S. Sastry for their keen interest.

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