

## Physical Characteristics of Waters & Water Masses Off the West Coast of India during Late Spring

V. V. R. VARADACHARI, C. S. MURTY & V. N. SANKARANARAYANAN  
National Institute of Oceanography, Panaji

Received 8 August 1973 ; revised received 5 February 1974

The paper presents an approximately synoptic distribution of temperature, salinity and  $\sigma_t$  and the associated hydrographic features of the shelf and slope waters off the west coast of India for late spring, based on data collected between Bombay and Alleppey during 22 March to 1 April 1965. Significant space variations have been noticed in all the parameters. The salient features are : (1) Surface temperature shows a gradual increase from north to south (temperature variation about  $3.5^\circ\text{C}$ ) while salinity and  $\sigma_t$  show a decrease (salinity variation about  $1.4\text{‰}$  and variation in  $\sigma_t$  about 2.0). (2) A tongue of high salinity water (with salinity greater than  $36.0\text{‰}$ ) extends from the offshore region towards the shelf. The depth of the core varies mostly between 70 and 80 m over the shelf region. (3) The thermocline tilts upward towards the coast and is found up to the mid-shelf in most of the areas. There is a general increase of temperature of the top of the thermocline and a decrease in its depth from north to south. (4) Vertical sections of temperature, salinity and  $\sigma_t$  indicate the tilting up towards the coast, of isolines of these parameters in the shelf and slope regions, revealing the existence of upwelling. This feature is more pronounced off Karwar and Mangalore but the upwelled waters do not seem to reach the surface in any of the areas. (5) The density of waters decreases from north to south in the surface waters but the reverse is the case at 100 m depth. This indicates commencement of upwelling in the south earlier than in the north. (6) The presence of Persian Gulf waters (between 200 and 385 m depth) and the spread of Red Sea waters (between 436 and 643 m depth) is noticed in the more offshore regions.

GENERAL hydrographic conditions of the waters off the west coast of India have been reported earlier<sup>1-13</sup>, but the information is inadequate to have a clear understanding of the regional variations in the features of the waters for the entire coast in different seasons or even in a particular month. In view of the changing hydrographical conditions from month to month, a fairly synoptic study of the waters is desirable for understanding the regional differences in the hydrographic conditions.

The present study has been made as part of the Indian Programme of the International Indian Ocean Expedition. A diagrammatic representation of the distribution of temperature, salinity and density ( $\sigma_t$ ) of the coastal waters between Bombay in the north and Alleppey in the south during late spring is presented. A special feature of this paper is that it gives a fairly synoptic picture of the physical conditions of the waters of the shelf and slope regions of the entire west coast of India.

### Materials and Methods

Oceanographic data collected during 25th and 26th Cruises of *I.N.S. Kistna* were utilized for the present investigation. The location of the stations is shown in Fig. 1. The observations were made during the period 22nd March to 1st April 1965. Space sections were prepared for temperature, salinity and density of the waters selecting 5 places along the coast, viz. Bombay, Karwar, Mangalore, Cochin and Alleppey. The sections run roughly normal to the coast at each of these places.

In order to identify different high salinity water-masses in the area, the temperature and salinity

at different depths were plotted and the T-S curves shown on a T-S diagram for all the deeper stations occupied along the different sections. The depths of occurrence of the different high salinity water-masses were identified based on the salinity maxima. The corresponding temperature, salinity and  $\sigma_t$  values are presented.

### Results and Discussion

The space sections of temperature, salinity and  $\sigma_t$  are shown in Figs. 2 to 6. There is a gradual increase of surface temperature from north to south ( $26.7^\circ$  to  $30^\circ\text{C}$ ) while the reverse is the case for

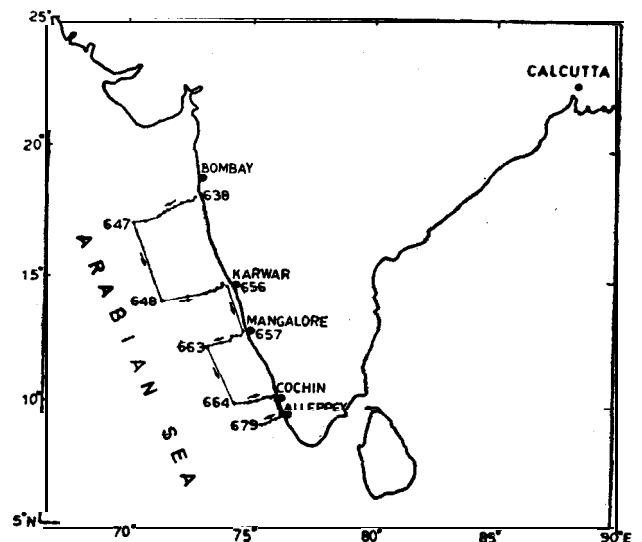


Fig. 1 — Location of stations

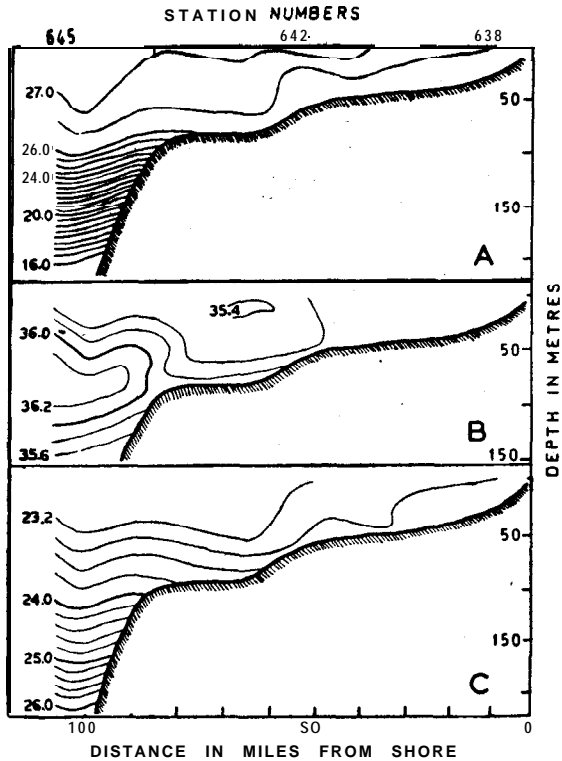


Fig. 2 — Vertical sections of (A) temperature, (B) salinity, and (C) sigma-t off Bombay

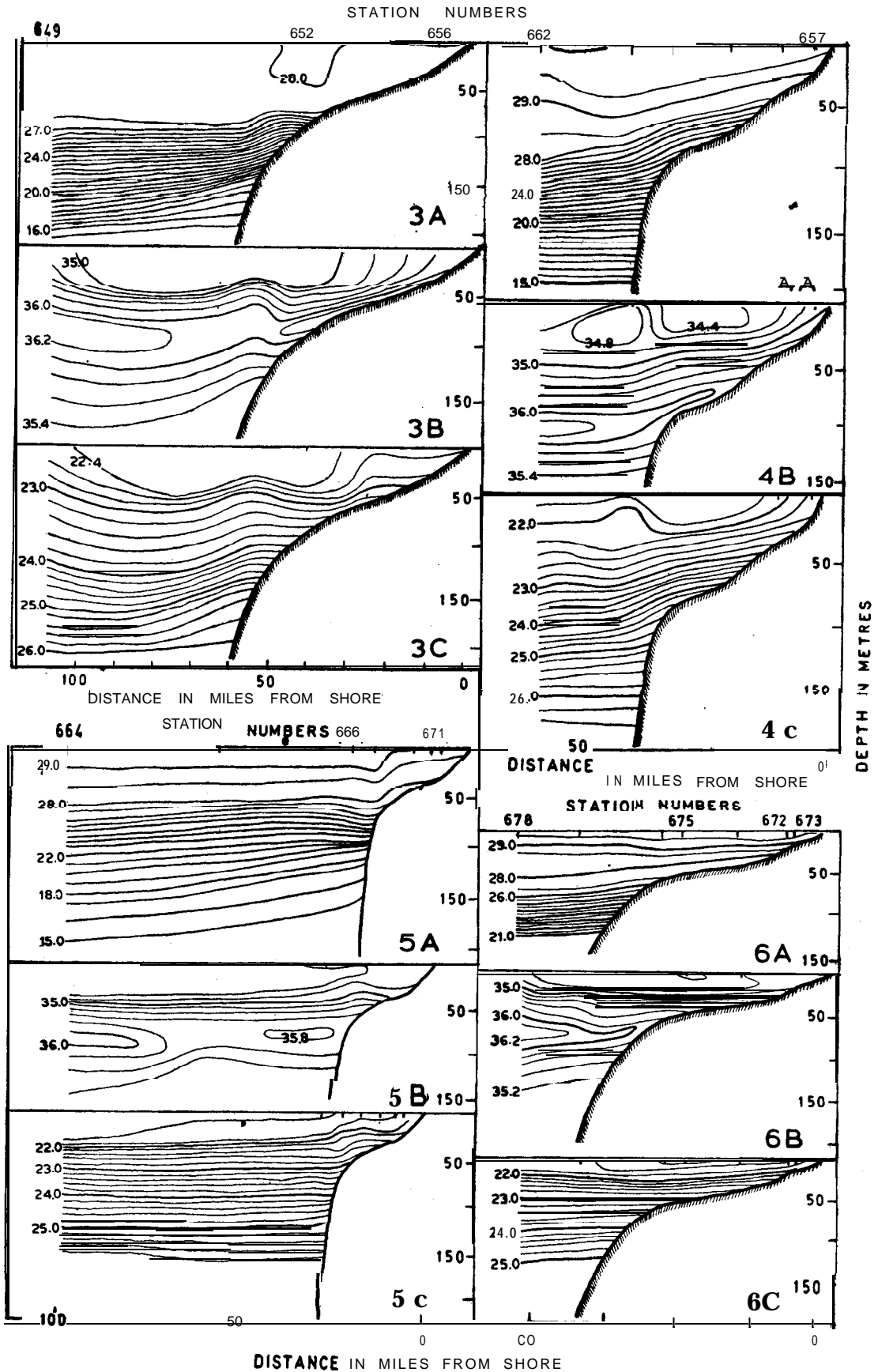
salinity (35.8 to 34.4‰) and density (23.3 to 21.3). The depth of the top of thermocline varies along the coast from 35 to 80 m with a general decrease of its depth from north to south, except off Alleppey where the depth is 50 m. The thermocline slopes up towards the coast in all the sections and is found up to mid-shelf in most of the areas indicating that there is upwelling along the coast, but that the upwelling has not reached the surface. There is a general increase of temperature of the top of the thermocline from north to south, the temperature varying from 26°C off Bombay to 28°C off Cochin. A tongue of high salinity water occurs mostly around 70-80 m depth with salinity values greater than 36.0‰. While the density decreases from north to south in the surface waters, the reverse is the case at 100 m depth where the  $\sigma_t$  values increase from 24 off Bombay to 24.6 off Alleppey. The possibility for such a condition is that the upwelled water in the south reaches that depth earlier, indicating commencement of upwelling in the south earlier than in the north.

From the general pattern of the temperature, salinity and density in various sections, it is, found that the isolines slope up towards the coast showing the presence of upwelling. This is conspicuous off Karwar and Mangalore but there is no indication of upwelling, reaching the surface in any of the sections.

*Water masses* — Three water masses could be identified in the shelf and slope regions of these coastal waters, based on the relative maximum of salinity and the  $\sigma_t$  characteristics, following the classification of Rochford14. These are, the Arabian, Sea high salinity water, the Persian Gulf water and the Red Sea water. The characteristics of these water

TABLE 1 — DEPTHS OF OCCURRENCE AND TEMPERATURE, SALINITY AND SIGMA-T VALUES OF DIFFERENT WATER MASSES IDENTIFIED BY THEIR SALINITY MAXIMA IN THE ARABIAN SEA

Section	Stn No.	Stn depth m	Depths of occurrence of											
			Arabian Sea high salt water			Persian Gulf water			Red Sea water					
			Depth m	Temp °C	Sal. ‰	Sigma-t	Depth m	Temp °C	Sal. ‰	Sigma-t	Depth m	Temp °C	Sal. ‰	Sigma-t
Off Bombay	646	2,633	40	26.89	36.22	23.69	312	14.31	35.66	26.65	643	11.50	35.66	27.21
	647	3,403	88	26.33	36.19	23.85	355	13.40	35.55	26.76	564	11.82	35.50	27.03
Off Karwar	648	1,866	69	27.93	36.46	23.54	380	12.61	35.47	26.85	576	11.28	35.47	27.11
	649	1,973	74	27.77	36.40	23.54	275	13.81	35.44	26.59	436	11.99	35.52	27.01
Off Mangalore	662	1,536	98	27.15	36.26	23.64	200	13.51	35.35	26.58	482	10.86	35.26	27.02
	663	2,195	77	26.92	36.09	23.59	385	11.91	35.33	26.88	522	10.87	35.34	27.08
Off Cochin	664	2,523	74	26.89	36.11	23.61	330	12.21	35.32	26.90	496	10.81	35.26	27.03
	665	2,177	75	25.64	35.74	23.72	—	—	—	—	442	11.30	35.24	26.93
Off Alleppey	678	457	75	27.77	36.26	23.44	217	13.61	35.17	26.42	—	—	—	—
	679	557	75	26.17	36.16	23.88	200	13.61	35.34	26.55	—	—	—	—



DISTANCE IN MILES FROM SHORE

Figs. 3-6 -Vertical sections of (A) temperature, (B) salinity, and (C) sigma-t off Karwar (3), off Mangalore (4), off Cochin (5), and off Alleppey (6)

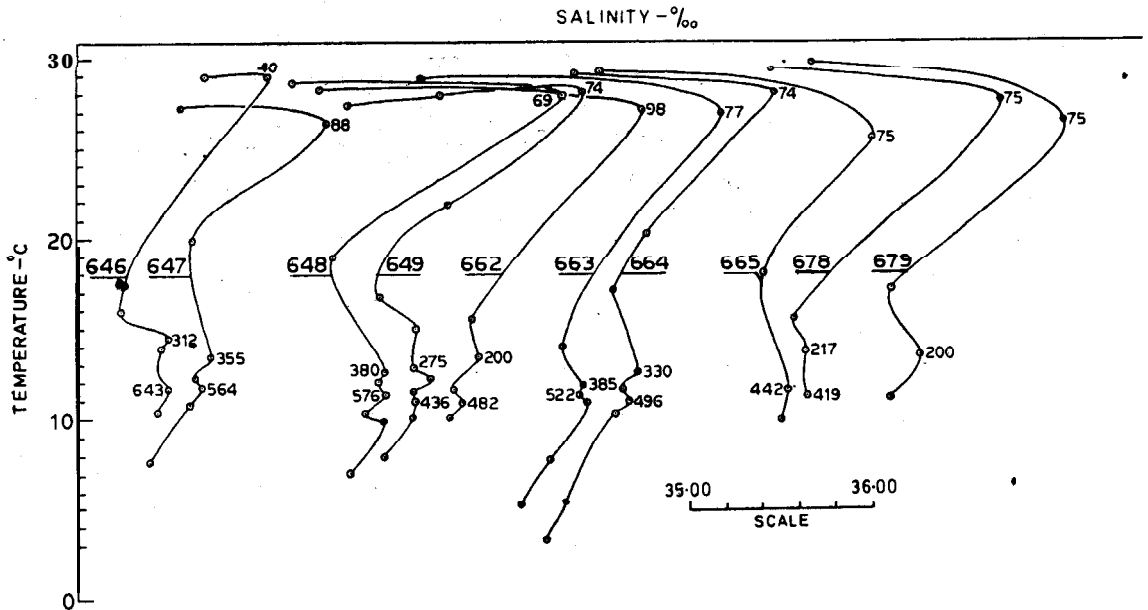


Fig. 7 — Temperature-salinity plots for stations (numbers underlined) in the slope regions showing depths of occurrence in metres of high salinity waters

masses are presented in Table 1. While the Arabian sea high salinity water extends to the midshelf, the other two water masses appear only in the slope region of these coastal waters. The T-S (temperature-salinity) plots for the oceanographic stations covered in the more offshore regions and the depths of occurrence of different high salinity water are shown in Fig. 7. The depths of occurrence as inferred from the salinity maxima vary between 40 and 98 m for the Arabian Sea high salinity water, between 200 and 385 m for the Persian Gulf water and between 436 and 643 m for the Red Sea water. The sigma-t values vary from 23.44 to 23.88 for the Arabian Sea high salinity water, from 26.42 to 26.90 for the Persian Gulf water and from 26.93 to 27.21 for the Red Sea water. It has been found that in general, the depths of occurrence of the Persian Gulf and Red Sea waters increase from south to north while the depth of occurrence of the Arabian Sea high salinity water does not vary much along the coast.

#### Acknowledgement

The authors wish to express their thanks to the Indian National Committee on Oceanic Research and to the Director, Indian Programme of the Inter-

national Indian Ocean Expedition, for their keen interest and support and to the Captain, crew and participating scientists of the 25th and 26th cruises of *I.N.S. Kistna*, for their cooperation and assistance.

#### References

1. JAYARAMAN, R. & GOGATE, S. S., *Proc. Indian Acad. Sci.*, 45B (1957), 151.
2. BANSE, K., *J. mar. biol. Ass. India*, 1 (1959), 33.
3. RAMA SASTRY, A. A., *J. mar. biol. Ass. India*, 1 (1959), 233.
4. RAMA SASTRY, A. A. & MYRLAND, P., *Indian J. Fish.*, 6 (1959), 223.
5. RAMAMIRTHAM, C. P. & JAYARAMAN, R., *J. mar. biol. Ass. India*, 2 (1960), 199.
6. JAYARAMAN, R., VISWANATHAN, R. & GOGATE, S. S., *J. mar. biol. Ass. India*, 3 (1961), 1.
7. PATIL, M. R., RAMAMIRTHAM, C. P., UDAYA VARMA, P., ARAVINDAKSHAN NAIR, C. P. & MYRLAND, P., *J. mar. biol. Ass. India*, 6 (1964), 151.
8. RAMAMIRTHAM, C. P., L. S. PATIL, M. R., *J. mar. biol. Ass. India*, 7 (1965), 150.
9. PANIKKAR, N. K. & JAYARAMAN, R., *Proc. Indian Acad. Sci.*, 54 (1966), 231.
10. SHARMA, G. S., *J. mar. biol. Ass. India*, 8 (1966), 3.
11. DARBYSHIRE, M., *Deep Sea Res.*, 14 (1967), 295.
12. BANSE, K., *Deep Sea Res.*, 15 (1968), 45.
13. SHARMA, G. S., *Bull. natn. Inst. Sci. India*, 38, (1968), 263.
14. ROCHFORD, D. J., *Aust. J. mar. Freshwat. Res.*, 15 (1964), 1.