HYDROGRAPHIC FEATURES OF NORTH INDIAN OCEAN

T. C. S. Rao

Directorate of Scientific Research (Navy), Naval Headquarters, New Delhi.

(*Received* 17 *April* 64 ; *revised* 7 *July* 64)

Vertical distribution of temperature, salinity and density in the first 500 meters of the North Indian Ocean Water has been discussed here. Vertical sections for each parameter are drawn to identity different types of water masses. Spatial distribution of these water masses in relation to the existing surface currents is also described.

Two types of water masses are present to the North of the Equator. The water from Bay of Bengal with its characteristic low salinity (32·60—34·00°/$_{oo}$) is found upto 5°N and is spreading in all directions. To the South of 5°N the water mass is found with solinity between 35·00—35·20°/$_{oo}$. This water is existing upto 300 meters with uniform salinity along the equator. The sub-tropical salinity maximum which occurs in a thin layer just above the thermocline is observed to the North and Southof Eqautor, similar to the one encountered by Defant in the Atlantic Ocean. The sub-tropical salinity maximum along the equator has not been found to be well defined.

EXPERIMENTAL PROCEDURE

The Indian Oceanographic vessel INS KISTNA, during her participation in the International Indian Ocean Expedition, completed two cruises in the North Indian Ocean during the period January 17, 1963 to February 15, 1963. These cruises were planned to study the vertical distribution of temperature, salinity and density with depth. For this purpose, water samples were collected at the International standard depths and analysed on board the ship for salinity and oxygen. Except for one leg, which runs along 01° 30′ S all the other observations were taken between 8°N and the Equator (Fig. 1). The oceanographic stations were distributed for each degree of latitude or longitude whichever was possible. In total 44 stations were occupied and at each station the temperature and salinity measurements were made up to 500 m depth. Temperature readings were taken by using reversing thermometers attached to the Nansen reversing bottles[1]. Contours were drawn for the vertical distribution of temperature, salinity and Sigma T. A possible interpretation for the identification of different types of water masses and their distribution is presented in this paper.

DISTRIBUTION CHARACTERISTICS

Temperature

All the vertical sections have been drawn from the readings of the reversing thermometers after applying the Index correction and the correction for the thermal expansion of the thermometer system due to the difference in temperature at the reversal and the temperature at which the thermometer was read. The surface sea water temperatures were always higher than the air temperatures depicting the ideal winter conditions of the ice-free oceans. To the north of the equator the surface temperatures were almost uniform with a little amount of increase towards the equator. To the south of the equator surface temperatures were found to be higher. The thickness of the isothermal layer to the north of equator was found to vary from 50—70 m (Figs. 2B, 4B, 6B). Its maximum thickness (80—100 m) was recorded along the equator (Fig. 5B). At the equator (Fig. 2B) the movement of isotherms nearer to the surface supported by similar movement of isophycnals and oxygen minimum layer has indicated the zone of divergence. Similar phenomenon was reported by Varadhachari[2] in the same area. The drift of thermal equator to the south of geographical equator has reduced the thickness of the isothermal layer from 20—30 m along 01° 30′S.

Thermocline was very strong and well defined along the equator. The thermoc line slopes towards the surface at the equator compared with the northern boundaries of the same sections (Figs. 2B, 4B). This has been explained by Defant[3] as the movement of

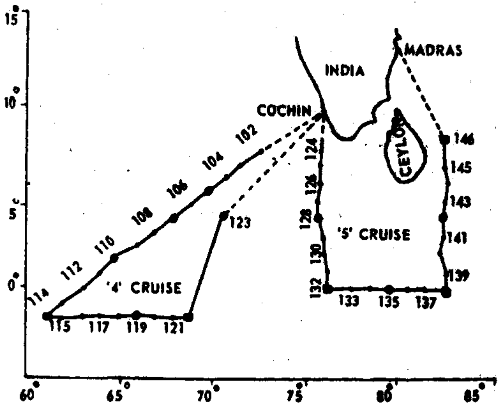


FIG. 1—Details of two cruises on board INS KISTA —'4' cruises (17-1-63 to 29-1-63) and '5' cruises (5-2.63 to 15-2 63)

[● =Observations upto 500 m; = ⊙ observations upto 1500 m and ☐ observation upto 3000 m]

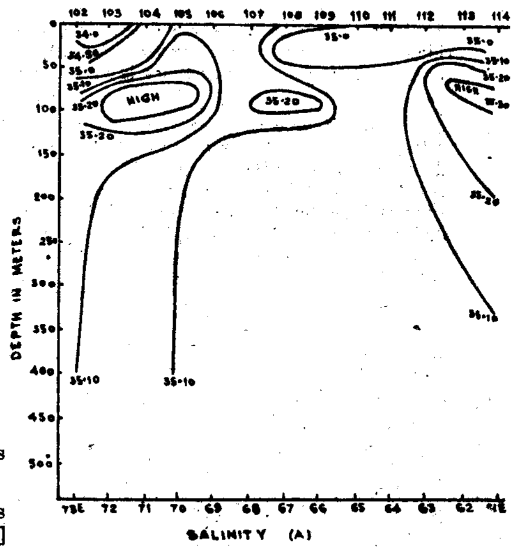


FIG. 2A

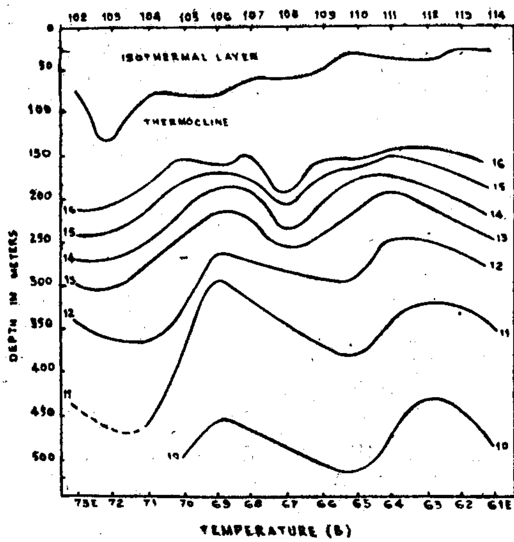


FIG. 2B

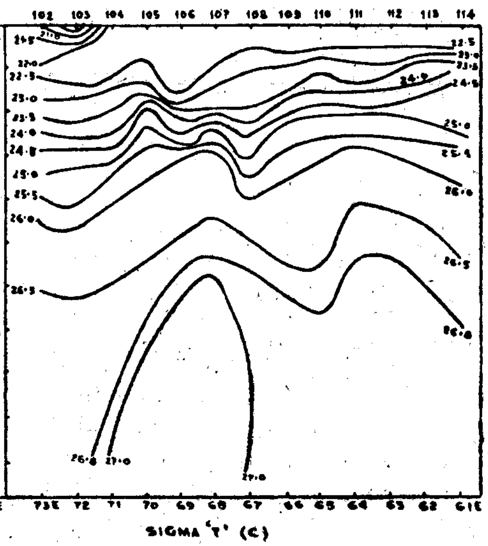


FIG. 2C

lower denser water masses towards the surface in the equatorial area due to the process of divergence prevailing along the equator. In contrast to this, the thermocline is moving towards the surface between 6°N and 8° 30′ N compared to that at the equator (Fig. 6B). The distribution of oxygen in this section has also shown the movement of oxygen minimum layer towards the surface. From this it can be inferred that the movement of the thermocline and the oxygen minimum layer towards the surface has been caused due to the divergence occuring in this area. Along the equator (Fig. 5B) as East-West slope of the thermocline is observed similar to that encountered by Austin[4] in the Pacific Ocean.

Except for this slight deviation, most of the isotherms are found to be almost horizontal along the equator. This shows that even if there is a certain amount of divergence as indicated by East-West slope (Fig. 5B), this is not of sufficient intensity to effect the stratification that has been found in Pacific and Atlantic oceans as mentioned by Svedrup[5]. Except along the equator the isotherms show the characteristic doming and depressions which have probably been caused by the extensive water movements at different levels. This feature is more predominant to the south of the equator (Fig. 3B).

Salinity

Two types of salinity distributions were recorded in the surface waters of the North Indian Ocean. The surface salinities are particularlyl ow (32·60′ °/$_{oo}$ to 34·00″ °/$_{oo}$) between 8°N and 5°N). A moderately high salinity values (35·00′ °/$_{oo}$ to 35·20″ °/$_{oo}$) were observed between 5°N and the equator. The low saline water which appears approximately in the first 50 m is the water from Bay of Bengal which has been brought to this area through the Pak strait and then the Gulf of Mannar. The surface water circulation in Bay of Bengal from December to February might be the reason for the existence of the low saline water between 5°N and 8° 30′ N along 83° E (Fig. 6A). The interesting point to be noted in the spreading of low saline water is that it is not seen to the south of 5°N in all the sections. This may be explained in favour of the formation of the Northern boundary for the north equatorial current near 5° N which did not allow the low saline water to spread towards the equator.

Between 5°N and the equator an almost uniform salinity between 35·00′ °/$_{oo}$ and 35·20″ °/$_{oo}$ is recorded on the surface representing the typical Indian Ocean equatorial water mass. This uniform saline water is found upto 300 m depth at and near the equator. The vertical run of the isohalines (Fig. 5A) shows the presence of uniform saline water down to 300 m through the process of vertical mixing.

A tongue of high salinity water (35·3′ °/$_{oo}$ to 35·8″ °/$_{oo}$) is found in a thin layer in all the sections except to that running along the equator. This salinity maximum is always found just on the top of the thermocline where the first drop in temperature occurs. But in the regions where the Bay of Bengal water is present, it is observed that the salinity maximum has slightly deepened into the thermocline region. Similar phenomenon has been investigated in Atlantic by Defant[3]. He has explained this as one of the most characteristic phenomenon of the vertical salinity distribution of the upper troposphere. The salinity maximum occurring in a thin layer has been named as the sub-tropical sub-surface salinity maximum which occurs in all the regions of the tropics and sub-tropics. Jayaraman *et al*[6]. also investigated the salinity maximum round the Laccadive Islands in April, 1958. The occurrence of this sub-tropical salinity maximum in Atlantic Ocean throughout the year as reported by Defant[3] cannot be confirmed since the data in this region is not available in other seasons of the year. Sub-tropical salinity maximum was not recorded in Bay of Bengal[7]. This indicates that the sub-tropical salinity maximum in this area is caused by the Arabian Sea water, as stated earlier by Svedrup[5].

To the south of equator, the surface salinity is much higher than in other sections. Below the sub-tropical salinity maximum the salinity distribution is almost uniform down to 500 m. This has been represented by the vertical run of the isohalines in the deeper layers.

Density

The vertical distribution of density in various sections is shown in Figs. 2C, 3C, 4C, 5C and 6C. The Sigma T surfaces in general resemble the isotherms with the characteristic doming and depressions. These are more predominant in the thermocline regions and in the

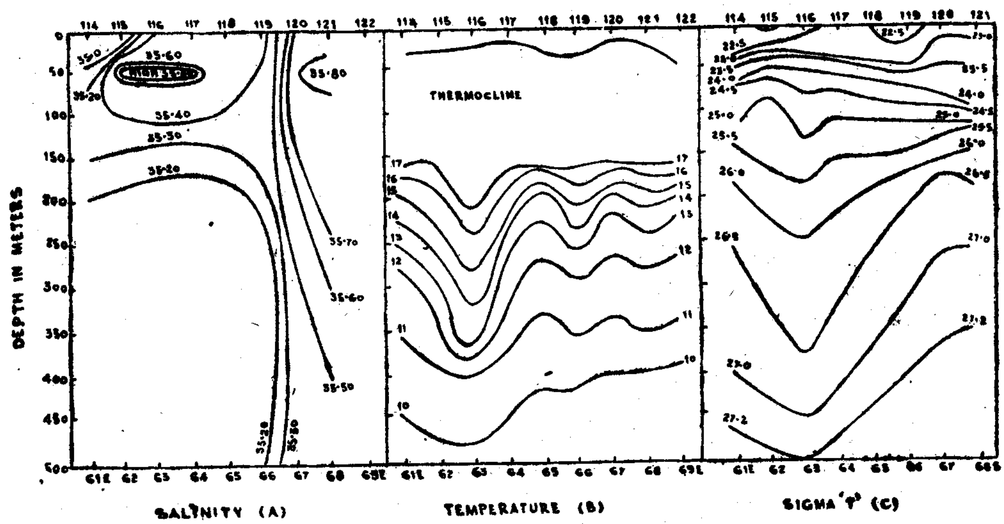
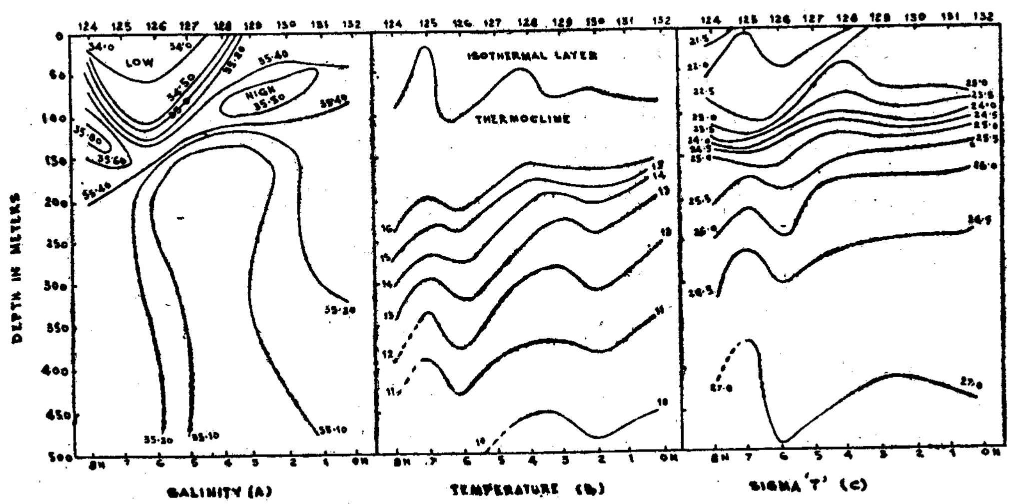


FIG. 3.



FGI. 4.

deeper layers. An examination of the slopes of the sigma T surfaces in the sub-surface layers give the impression that there are water movements of greater intensity in these layers. According to Deacon[8] the slopes of the density surfaces are generally prone to give an exaggerated picture of the strength of the deep currents and the slopes of the layers involve several other factors besides the movement of a particular water mass. The density discontinuity layer in the north Indian Occean is best developed near and along the equator. This is in general associated with the salinity maximum. The density maximum is observed near 5°N in all the three sections running from north to the equator (Figs. 2C, 4C and 6C).

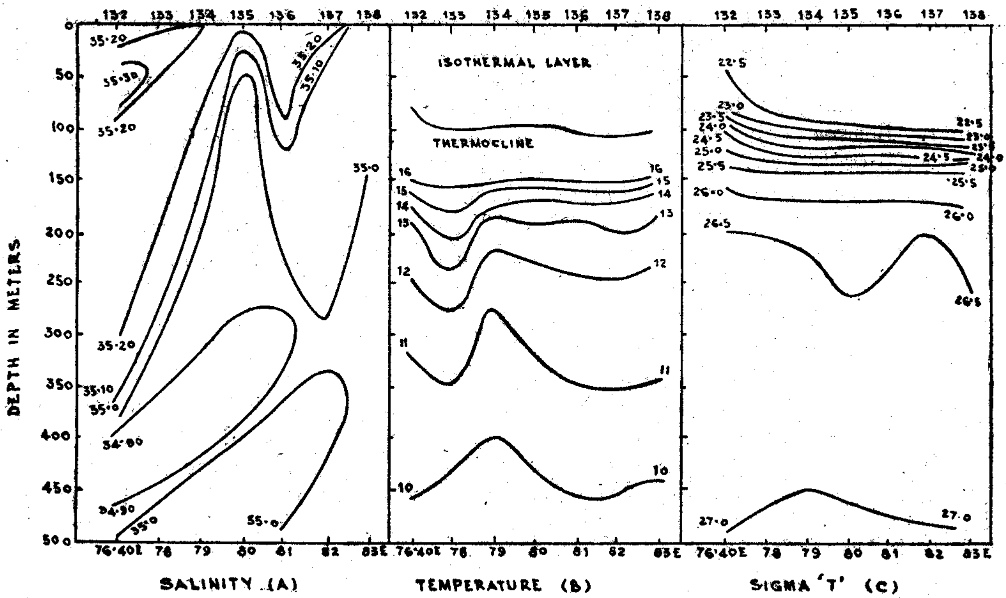


FIG. 5

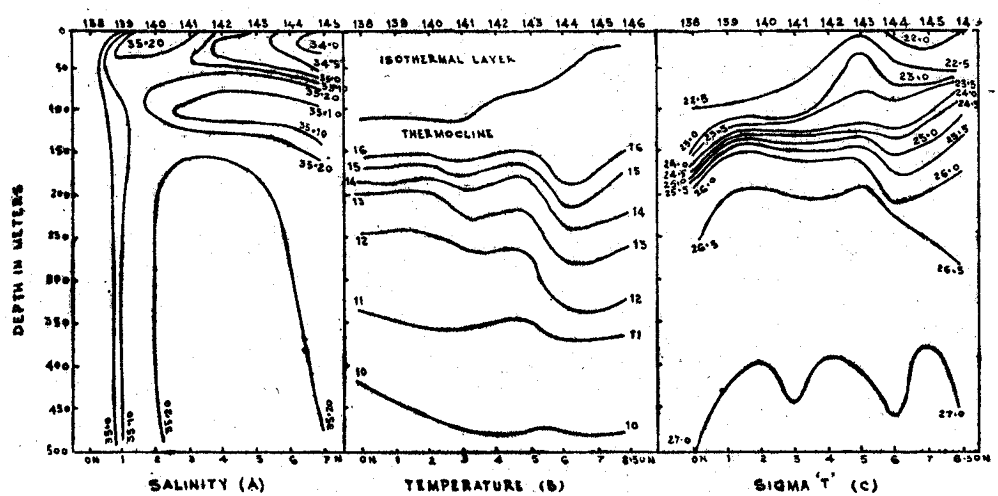


FIG. 6

The consistent existence of density maximum near 5°N, which incidentally also coincides with the southern limit for the spreading of Bay of Bengal water, indicates the Northern boundary of the north equatorial current. Indication of the divergence zones at the equator and to the east of Ceylon by the upward movement of isotherms is further supported by an upward movement of the Sigma *T* surface (Figs. 2C and 6C). Along the equator (Fig. 5C) the Sigma *T* surfaces are very nearly horizontal and parallel to each other with the formation of well stratified layers.

CONCLUSION

The water from Bay of Bengal with its characteristic low salinity ($32\cdot80'\ ^{\circ}/_{\circ\circ}$ to $34\cdot00''\ ^{\circ}/_{\circ\circ}$) is found on the surface of the north Indian Ocean upto 5°N. It is nearly 50 m thick between 8°N and 5°N. The Bay of Bengal water existing in this region has been brought by the prevailing surface currents through the Pak strait and then the Gulf of Mannar. Between equator and 5°N the surface salinity is moderately high and keeps to be uniform ($35\cdot00'\ ^{\circ}/_{\circ\circ}$ to $35\cdot20''\ ^{\circ}/_{\circ\circ}$) representing the typical equatorial water mass similar to that encountered by Svedrup[5] and Deacon[8] in the equatorial regions of Pacific and Atlantic Oceans. A tongue of high saline water ($35\cdot00'\ ^{\circ}/_{\circ\circ}$ to $35\cdot80''\ ^{\circ}/_{\circ\circ}$) in a thin layer just above the thermocline, is present in this region. The sub-tropical salinity maximum has not been seen along the equator.

ACKNOWLEGDEMENTS

The author is grateful to Dr. S. S. Srivastava, Director, Scientific Research (Navy) for guidance and encouragement in carrying out these investigations. The valuable assistance given by Shri J. N. Garg, Shri B. M. Aggarwal and Shri P. N. Soni in preparing the charts is also gratefully acknowledged. Thanks are due to Shri R. Jayaraman, Indian Ocean Expedition, C.SI.R., New Delhi for suggestions in preparing this paper. The author also wishes to extend his thanks to Indian National Committee on Oceanic Research, the crew of INS KISTNA and the scientists who have participated in collecting the data.

REFERENCES

1. "Instruction Manual for Oceanographic Observations" (U.S. Hydrographic Publication No. 607), 1959 p. 210.
2. VARADACHARI, V.V.R. & SHARMA, G. S., *Bull. Nat. Geophys. Res. Inst.*, C.S.I.R., **2** (1964) 1.
3. DEFANT, ALBERT, "Physical Oceanography, Vol. 1" (Pergmon Press, New York), 1961, p. 729.
4. AUSTIN, T. S., *Trans. Amer. Geophys. Union*, **39** (1958), 1055.
5. SVEDRUP, H. V., JOHNSON, M. W. & FLEMING, R. H., "The Oceans" (Prentice-Hall, Inc., New York), 1949, p.1060.
6. JAYARAMAN, R., RAMAMRITHAM, C. P., SUNDERAMAN, K. V. & NAIR, C.P.A., *J. Marine Bio. Ass. India*, **2** (1960), 24.
7. RAO, T.C.S., "Vertical Distribution of Temperature, Salinity and Density in Oxygen of the Bay of Bengal" (Departmental Report), 1964, p. 1.
8. DEACON, G.E.R., "The Hydrology of the Southern Ocean—Discovery Report No. 15" (The Royal Society London), 1937.