

# SALINITY MAXIMA ASSOCIATED WITH SOME SUB-SURFACE WATER MASSES IN THE UPPER LAYERS OF THE BAY OF BENGAL

by V. V. R. VARADACHARI, C. S. MURTY and C. V. GANGADHARA REDDY

*Physical Oceanography Division, National Institute of Oceanography, Ernakulam*

The distribution of some sub-surface water masses in the western Bay of Bengal during the south-west monsoon period is presented. Based on the salinity maxima and  $\sigma_t$  values the existence of waters of Persian Gulf and Red Sea origin could be established. The studies show that the Persian Gulf and Red Sea waters enter the Bay at depths of about 200 m and 400 m respectively, and follow the circulation pattern at the respective depths of entry. The probable paths of entry are indicated. These waters sink to different depths subsequent to their entry into the Bay. The Persian Gulf water could be traced down to a depth of about 350 m while the Red Sea water could be traced down to 900 m depth.

## INTRODUCTION

Attempts were made in the past to identify and describe some of the water masses in the top layers of the Bay of Bengal (LaFond 1958; Poornachandra Rao 1956; Balaramamurthy 1957) but due to lack of extensive oceanographic data, these studies had to be confined mostly to the region of the continental shelf on the East Coast of India. An attempt was made by Gallagher (1966) to make a preliminary study of the variability of water masses in the Indian Ocean and to designate the broad areal limits of some sub-surface water masses of the Indian Ocean. The surveys conducted on I.N.S. KISTNA during the International Indian Ocean Expedition, afforded an opportunity for a detailed study of some of the sub-surface water masses in the upper 1000 metres of the western Bay of Bengal.

Water masses can be identified by one or more characteristic indicators such as relative maximum of salinity, oxygen or temperature or a combination of such factors. Rochford (1964), while identifying the water masses following the salinity maxima in the upper 1000 metres in the north Indian Ocean, indicated the existence of two water masses of Persian Gulf and Red Sea origin at depths of 300 to 400 metres and 400 to 500 metres respectively, in the Bay of Bengal, based on the inferences drawn from the oceanographic data collected by the Russian Research Vessel "Ob" in 1958. Since the stations of "Ob" were located only along 88°E long. in the Bay of Bengal, the presence of these waters over wide areas and the paths of their entry into the Bay could not be ascertained.

The present study, covering a considerable area in the Bay, revealed more information regarding the entry paths and pattern of distribution.

## MATERIAL AND METHOD

Figure 1 shows the distribution of stations occupied during the 15th and 16th cruises of I.N.S. "KISTNA" in the southwest monsoon season, under the Indian

Programme of International Indian Ocean Expedition. Treatment of the data in classifying and tracing the water masses is, as described by Rochford (1964), on the basis of salinity maxima.

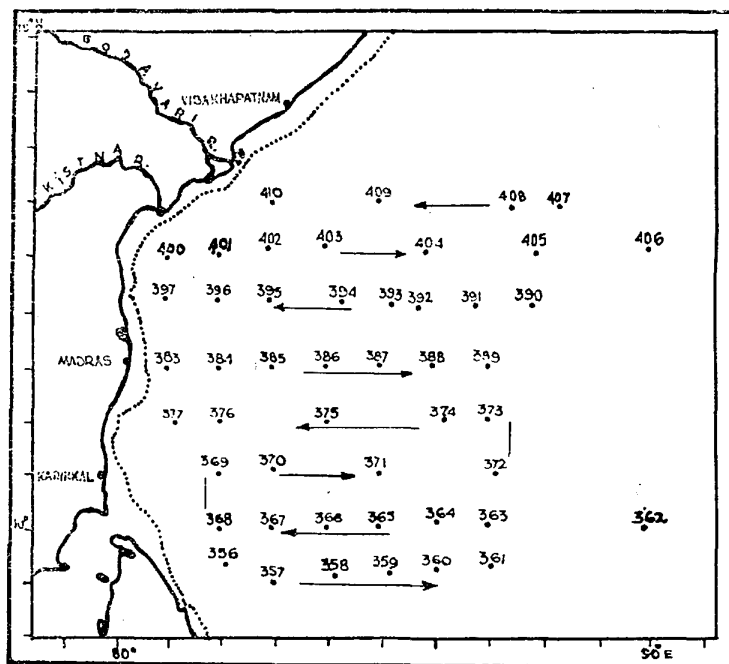


FIG. 1. Map showing the station locations.

## RESULTS AND DISCUSSION

Two distinct salinity maxima could be traced in the majority of the stations during the southwest monsoon season. Significant regional variations in the intensities of these maxima and the depths of their occurrence are noticeable. The  $\sigma_t$  limits of these water masses agree with those described by Rochford ( $\sigma_t=26.2$  to  $26.9$  for Persian Gulf water and  $\sigma_t=26.95$  to  $27.4$  for the Red Sea water).

### (a) First Salinity Maximum:

This salinity maximum lying between  $\sigma_t$  limits  $26.2$  to  $26.9$  and salinity limits  $35.03\%$  to  $35.35\%$  exists at depths of about  $200$  to  $350$  m excepting at station  $357$ , where the depth is  $140$  m. According to Rochford (1964) this high salinity water was absent around the Gulf of Aden. Hence, he considered Persian Gulf as the origin for this maximum. During its spread to the southwest and to the east, its average depth was found to be  $200$  m. Since the data is inadequate, he could not show by

which route it enters the Bay. An examination of the distributional charts of salinity maxima (Fig. 2) and the depths at which the maxima are noticed (Fig. 3) shows that

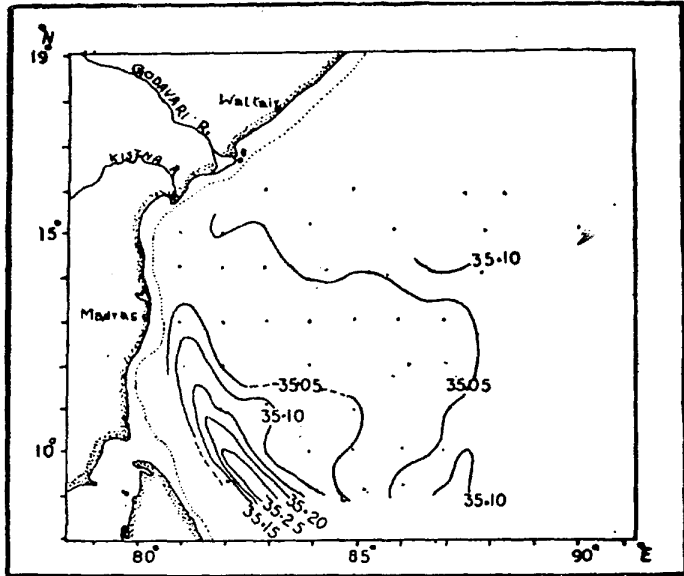


FIG. 2. Isoline of first Salinity maximum (Persian Gulf water).

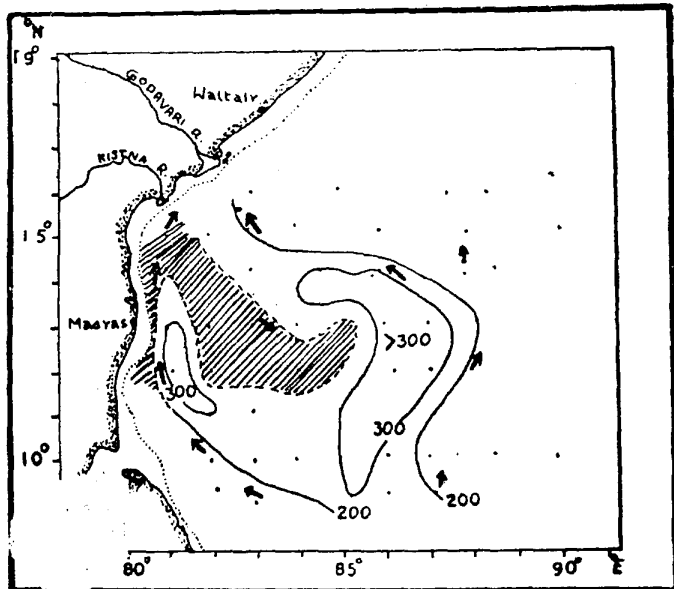


FIG. 3. Depth contours of first salinity maximum (Persian Gulf water).

the high salinity core appears at about 200 m depth south of 9°N lat. and the water enters the Bay of Bengal at least through two main paths, one around Long. 84°E and the other around Long. 87°E, following more or less the general circulation pattern at that level (Varadachari *et al.* 1967). Along the western side, the path of water appears to be north-north-westerly up to Lat. 11°N beyond which it could not be traced (shaded region in Fig. 3), perhaps because of excessive mixing with low salinity water in the region. However, in view of the existing circulation pattern, it is likely to take a turn towards the east around Lat. 15°N. The second entrance path appears to be mainly northerly. This northerly flow around 87°E meridian extends up to Lat. 14°N and then turns westerly following the circulation pattern. Between the two main paths of entry, this water could be traced at depths greater than 200 metres. From the available data, it may be said that the general spread tends to be more towards north-westerly. The progressive reduction of the salinity values in the salinity core from south to north, is indicative of lateral mixing and perhaps some vertical mixing.

Phosphate concentrations corresponding to the salinity maxima show some variations. According to Rochford (1964), the phosphate content at the depths of location of the Persian Gulf water is about 3  $\mu\text{g at/l.}$  In the present study, most of the stations show phosphate values between 1.0 to 1.9  $\mu\text{g at/l.}$  at the level of occurrence of the Persian Gulf water. High values (2.5 to 3.0  $\mu\text{g at/l.}$ ) are encountered only between Lat. 10°N and 11°N (station numbers 368 to 371). Corresponding salinity maxima also are high. The station 357 which is the western-most station of the southern-most section of these cruises, is also characterized by the highest value for salinity maximum and extremely high phosphate content, suggestive of a discrete water body, perhaps having a very long residence time. The high phosphate content may be due to oxidative regeneration of the suspended organic matter. It is interesting to note that the Persian Gulf water, at its source, contains high phytoplankton (Zernova 1962). The high values of salinity and phosphate at stations 368 to 371 could be traced to the waters at station 357 (Fig. 1).

#### (b) *Second Salinity Maximum :*

This core of high salinity, characteristic of Red Sea water (Rochford 1964), is found to be within the salinity and  $\sigma_t$  limits of 35.00‰ to 35.33‰ and 26.95 to 27.40 respectively. This water mass also appears to enter through two paths, south of 9°N around 84°E and 87°E Long. between 500 and 400 m level (Figs. 4, 5). Studies on the circulation for the same period in the area, show that the level of least motion is around 500 metres depth (Varadachari *et al.* 1967) and even at 400 metres depth the speed of the current is mostly less than 0.1 knot. Hence, the Red Sea water is likely to spread northward more slowly. But it may sink to different depths under the influence of the clockwise circulation or shoal under counter-clockwise circulation. It could be traced as far as 16°N. The water of 82°E Long. the salinity maximum could not be located except between 81°E. The maximum depth of occurrence is about 900 metres. The interesting region roughly coincides with that for Persian Gulf water (Lat. 11°N). At a few stations

two salinity maxima within the  $\sigma_t$  range of Red Sea water, appear at depths ranging from 400 to 900 m (Stations 356, 368, 394, 396 and 404). Low values of salinity

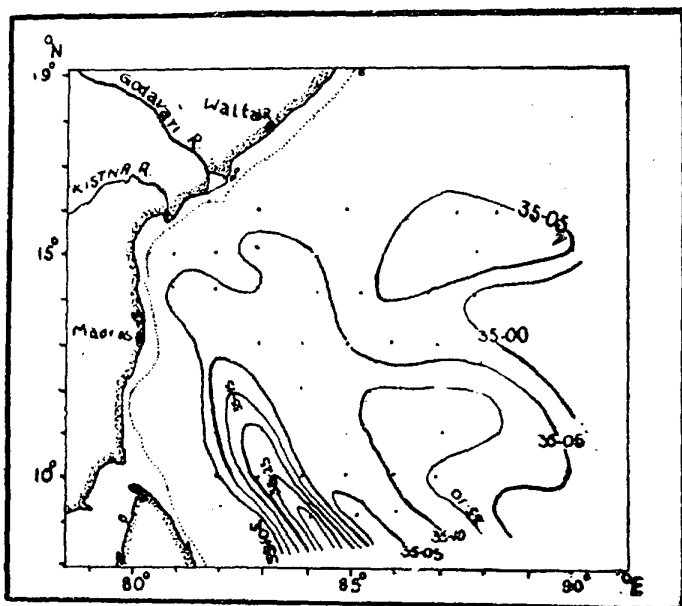


FIG. 4. Isolines of second salinity maximum (Red Sea water).

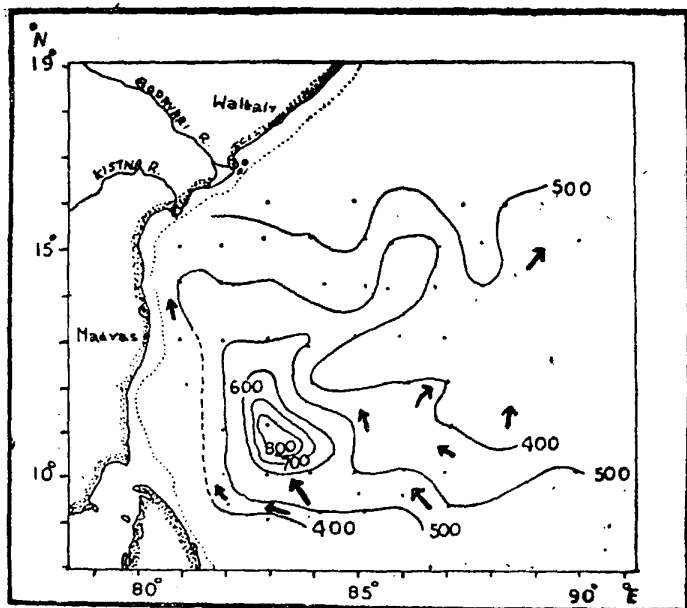


FIG. 5. Depth contours of second salinity maximum (Red Sea water).

maxima, in the northern part, indicate that the Red Sea water mixes and gradually loses its identity during its northerly spread. Inorganic phosphate concentrations associated with the salinity maxima are found to be predominantly between 1.0 and 1.9  $\mu\text{g at/l.}$  Higher values of phosphates (2.0 to 3.8  $\mu\text{g at/l.}$ ) are found at stations 370 to 374. It may be pointed out here that around the same region the Persian Gulf water also shows maximum phosphate concentrations, excepting that the high phosphate region is slightly extended towards the east for the Red Sea water.

#### CONCLUSIONS

Two water masses could be identified in the upper 1000 m of the Bay of Bengal with distinct salinity and  $\sigma_t$  characteristics. The upper water mass has the characteristics of Persian Gulf water and the lower one, that of Red Sea water. Both the water masses enter the Bay south of 9°N Lat. through two distinct paths. They move northward, sink and spread following the circulation pattern. From the available data ("Ob", 1958 and the present data), it appears that the two waters may be flushing in during the southwest monsoon period and retreating during the northeast monsoon period. The high phosphate concentrations of Persian Gulf water (3.0  $\mu\text{g at/l.}$ ) as reported by Rochford (1964) during the northeast monsoon period are higher than those found during the present investigation (1.0–1.8  $\mu\text{g at/l.}$ ) for the southwest monsoon period. The high values encountered during the northeast monsoon might be due to the oxidation of organic matter of planktonic origin and such conditions are favourable only for waters having long residence time. However, the retreat during the northeast monsoon appears to be far from complete before fresh influx commences during the southwest monsoon. The general high phosphate content of the Red Sea water as compared to the Persian Gulf water indicates the longer residence time of the former in the Bay.

#### ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Indian National Committee on Oceanic Research and Dr. N. K. Panikkar, Director, Indian Programme of International Indian Ocean Expedition and National Institute of Oceanography (C.S.I.R.), for their support and to the Captain, crew and the participating Scientists of the 15th and 16th cruises of I.N.S. "KISTNA", for their cooperation and assistance in the research programme.

#### REFERENCES

- Balaramamurty, C. (1957). Water masses of the western central Bay of Bengal during November. *Curr. Sci.*, **26**, 80.
- Gallagher, J.F. (1966). The variability of water masses in the Indian Ocean. *N. O. D. C. Publ.* 7-11, Washington; U.S. Naval Oceanographic Office, pp. 1-74.
- LaFond, E.C. (1958). On the circulation of the surface layers off the East Coast of India. *Andhra Univ. Mem. Oceanogr.*, **2**, 1-11.
- Poornachandra Rao, C. (1956). Water masses in the Bay of Bengal. *Curr. Sci.*, **25**, 51-53.
- Rochford, D. J. (1964). Salinity maxima in the upper 1000 metres of the north Indian Ocean. *Aust. J. mar. Freshwat. Res.*, **15**, 1-24.
- Sabinin, K.D. (1964). Layers of increased salinity in the northern part of the Indian Ocean. *Trudy Inst. Okeanol.*, **64**, 51-58.
- Varadachari, V. V. R., Murty, C.S., and Das, P.K. (1967). On the level of least motion and the circulation in the upper layers of the Bay of Bengal. *Proc. natn. Inst. Sci. India* (In Press).
- Zernova, V. V. (1962). Quantitative distribution of the phyto plankton in the northern Indian Ocean. *Trudy Inst. Okeanol.*, **58**, 45-53.