

VERTICAL DISTRIBUTION OF OXYGEN IN THE BAY OF BENGAL AND THE ANDAMAN SEA DURING FEBRUARY—MARCH 1963

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Based on observations made on board INS KISTNA during the VI and VII cruises of International Indian Ocean Expedition (February-March 1963), an analysis of the vertical distribution of oxygen in the upper 500 metres of the Bay of Bengal and the Andaman Sea has been made. In general, the thickness of the upper oxygen-rich layer was greater in the Bay of Bengal than in the Andaman Sea. The thickness of the oxygen-poor layer in the Bay of Bengal increased towards the north. The concentration in the oxygen-poor layer was greater in the Andaman Sea than in the Bay of Bengal where it decreased towards the north suggesting a northerly flow at these depths.

INTRODUCTION

The distribution of oxygen in the different oceans has been investigated by several workers. Amongst these the most comprehensive account is by Richards (1957). Miyake and Saruhashi (1956) studied the oxygen distribution in the waters off the Japanese coast and they have discussed the vertical distribution of oxygen in relation to the factors influencing it.

Prior to the work of Jayaraman, Ramamritham and Sundara Ramam (1959) on the distribution of oxygen in the deeper waters of the Arabian Sea, the investigations were confined mostly to the shallow waters in respect of both the Arabian Sea and the Bay of Bengal. During the Indian Programme of the International Indian Ocean Expedition (1962-65) INS KISTNA carried out a number of cruises in the Bay of Bengal and the Andaman Sea. During these cruises, samples were collected at various stations for estimation of dissolved oxygen and other oceanographic parameters.

The principal hydrographic features of the southern and central Bay of Bengal for the period February-March, 1963, the transitional period between the winter and summer monsoons, have been discussed elsewhere in this volume by Gangadhara Rao and Jayaraman.* In the present paper the vertical distribution of oxygen in the same region for the same period is discussed.

DATA

The area covered in the present study and the hydrographic station positions are shown in Figure 1.

Sea water samples were collected from various depths at all the stations and were analysed following the modified Winkler's method (Strickland and Parsons

* (See Sec. 1, S. No. 17)

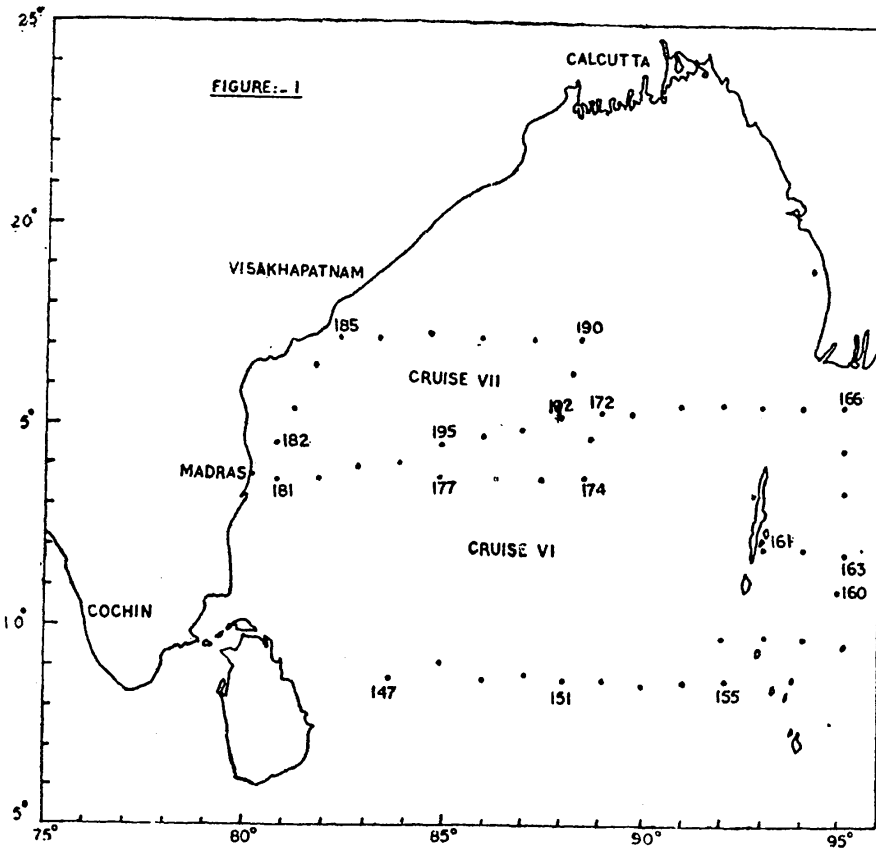


Fig. 1: INS KISTNA Station positions for cruises VI and VII, 21-2-63 to 20-3-63.

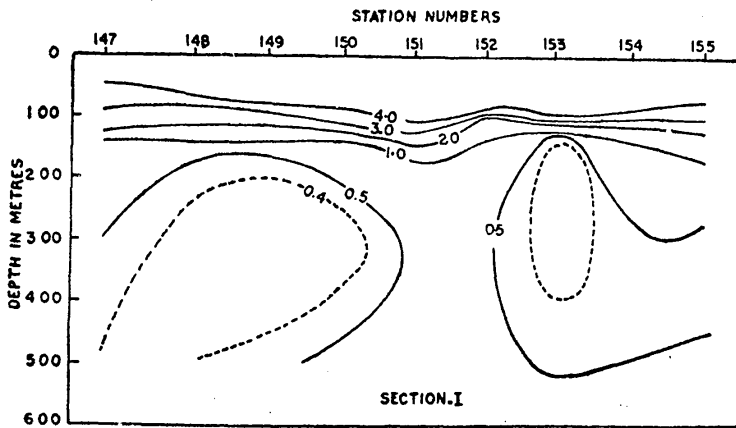


Fig. 2: Vertical distribution of oxygen (in ml/L) along $08^{\circ} 30'N$ between $83^{\circ} 00'$ and $92^{\circ} 00' E$.
 Section I (Fig. 2): Along $08^{\circ} 03'N$ latitude between $83^{\circ} 00'$ and $92^{\circ} 00' E$ longitudes.

1960). In order to study the vertical distribution of oxygen in the upper 500 metres, both the observed and interpolated values of concentration of oxygen (Anon 1963) have been used in the preparation of vertical sections.

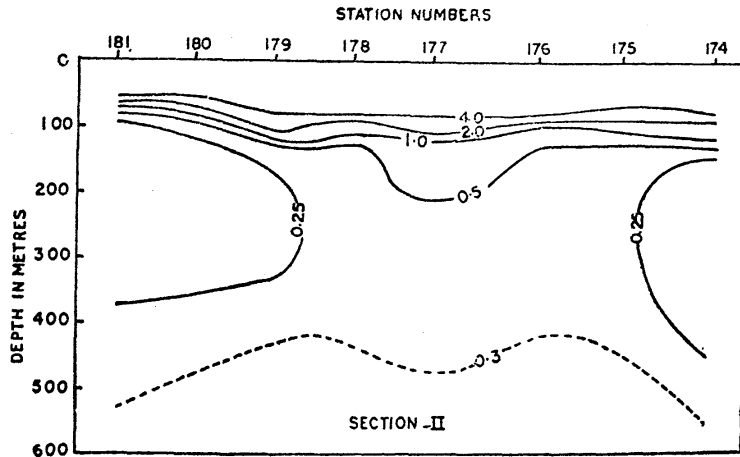


Fig. 3: Vertical distribution of oxygen (in ml/L) along 13° 20' N between 81° 00' and 89° 00' E. Section II (Fig. 3): Along 13° 20' N latitude between 81° 00' and 89° 00' E longitudes.

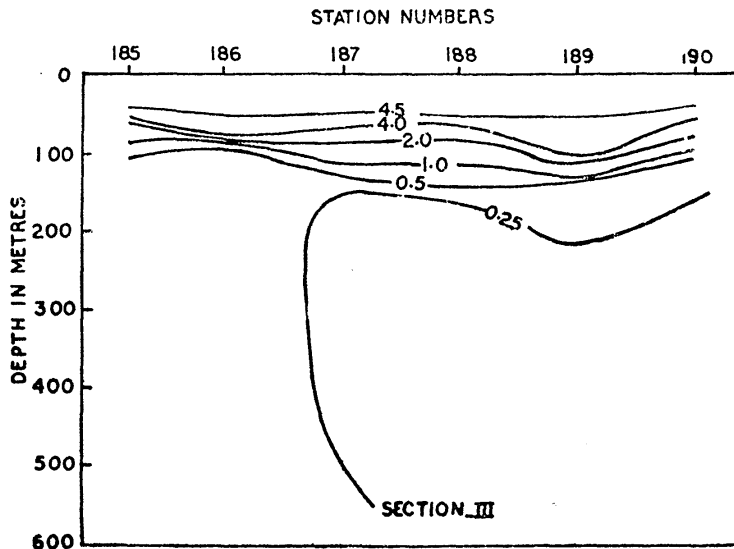


Fig. 4: Vertical distribution of oxygen (in ml/L) along 16° 30' N between 82° 00' and 89° 00' E. Section III (Fig. 4): Covers the central part of the Bay of Bengal and along 16° 30' N latitude between 82° 00' and 89° 00' E longitudes.

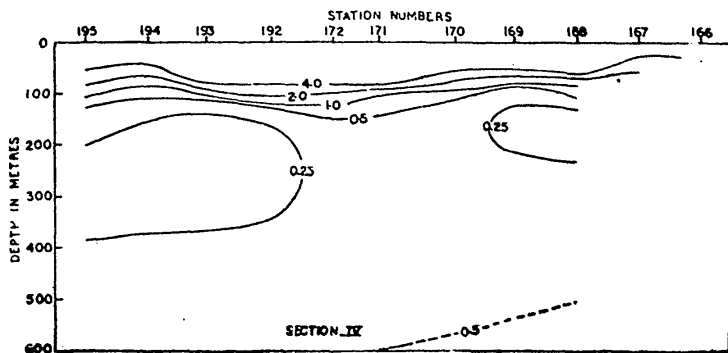


Fig. 5: Vertical distribution of oxygen (in ml/L) between 14° to 15 N and 85° 00' to 95° 00'E.

Section IV (Fig. 5): Partly along 15° 00'N latitude and extended diagonally to 14° 00'N between 85° 00' and 95° 00'E longitudes.

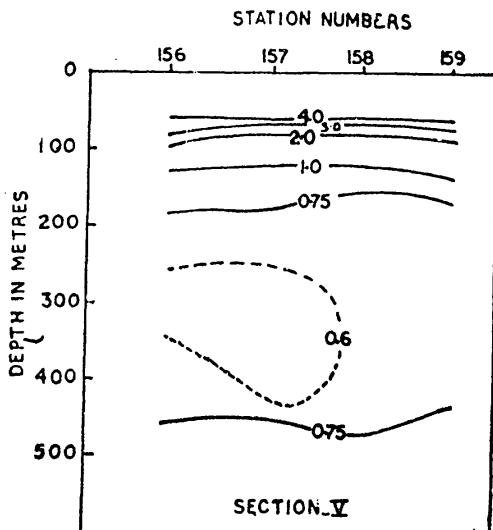


Fig. 6: Vertical distribution of oxygen (in ml/L) along 09° 30 N between 91° 00' and 95° 00'E.

Section V (Fig. 6): Along 09° 30'N latitude between 91° 00' and 95° 00'E longitudes.

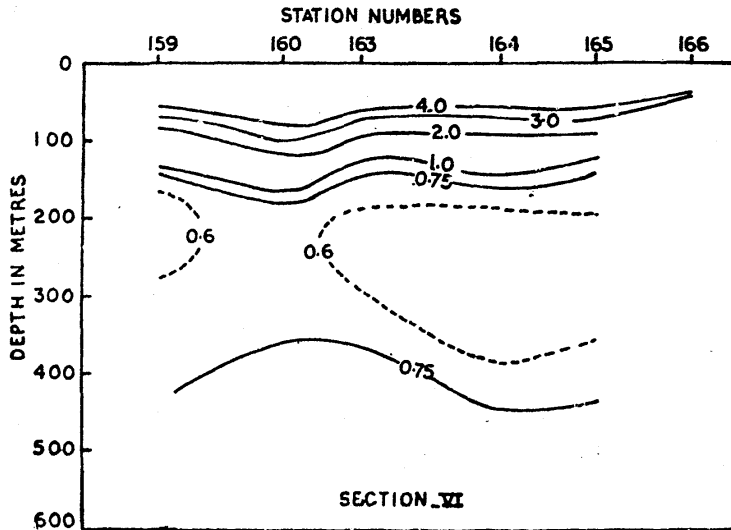


Fig. 7: Vertical distribution of oxygen (in ml/L) along $95^{\circ} 00' E$ between $09^{\circ} 30'$ and $15^{\circ} 00' N$.

Section VI (Fig. 7): A meridional section east of Andamans (along $95^{\circ} 00' E$) between $09^{\circ} 30'$ and $15^{\circ} 00' N$ latitudes.

RESULTS

Section I (Fig. 2): This section was occupied at the southern limit of the Bay of Bengal. The oxygen concentration (4.40 ml/L) in the upper layer was fairly constant over the entire section. The thickness of this layer (oxygen concentration >4.0 ml/L) increased from 40 m in the western end of the section to 100 m in the central part (Station 151) and then decreased to 70 m in the eastern part. The 4.0 ml/L isopleth roughly coincided with $27.0^{\circ} C$ isotherm. Below this layer the oxygen concentration steeply decreased to 1.0 ml/L between 120 and 170 m. The isopleths for values between 4.0 ml/L and 1.0 ml/L showed a tendency to spread in depth towards both ends of the section. In the western and eastern parts of the section, between 150 and 500 m, two cells with oxygen concentration less than 0.5 ml/L were observed. At stations 151 and 152, however, the oxygen concentration at these depths ranged between 0.5 and 1.0 ml/L.

Section II (Fig. 3): This section was occupied in the central part of the Bay of Bengal. The oxygen concentration (4.50 ml/L) in the upper layer was fairly constant over the entire section. The thickness of this layer (oxygen concentration >4.0 ml/L) was generally 80 m with a slight decrease towards the western end of the section. The isopleth of 4.0 ml/L roughly coincided with $26.0^{\circ} C$ isotherm. Below this layer, the oxygen concentration decreased sharply to 0.5 ml/L at depths varying between 80 and 130 m except at station 177 where the isopleth for 0.5 ml/L was depressed to a depth of 200 m. Two cells of oxygen-poor water (<0.25 ml/L) appeared in

the western and eastern parts of the section between 100 and 450 m. In the middle part of the section the oxygen concentration was slightly higher and ranged between 0.3 and 0.5 ml/L.

Section III (Fig. 4): This section also covered the central region of the Bay of Bengal northward of the previous section. The oxygen concentration (>4.5 ml/L) in the upper layer was generally constant over the entire section. The thickness of this layer was roughly 50 m with slight decrease on both the western and eastern ends of the section. All isopleths showed marked depression at station 189 at which even 4.0 ml/L was depressed to a depth of 100 m. A sharp decrease in the oxygen concentration was observed at station 186 between 75 and 100 m. At the remaining stations the isopleths were fairly well separated from each other indicating the absence of a marked gradient. A cell of poor oxygen (<0.25 ml/L) appeared on the eastern flank of the section between 150 and 500 m. The oxygen concentration at these depths at Stations 185 and 186 was somewhat higher and ranged between 0.3 and 0.5 ml/L. Unlike in the case of the first two sections where cells of oxygen-poor water were found at either ends, in this section only one such cell was present on the eastern side.

Section IV (Fig. 5): This section was also occupied in the central region of the Bay of Bengal but mostly towards the east of both the earlier sections. The thickness of the oxygen rich layer (>4.0 ml/L) increased from 45 m in the western end to 80 m in the central part (Stations 193, 192, 172, 171) and then decreased to 50 m on the eastern side. The thickness was only 30 m at two shallow stations off the mouths of the Irrawaddy river. The 4.0 ml/L isopleth coincided with the 26.0°C isotherm in the eastern part of the section. Below this layer the oxygen concentration sharply decreased to 0.5 ml/L at a depth varying between 90 and 150 m. The isopleths for values between 4.0 ml/L and 0.5 ml/L tend to spread in depth in the western end of the section. The thickness of the oxygen-poor layer (>0.25 ml/L) was much greater (nearly 200 m) in the western part as compared with the eastern part where it was hardly 100 m. Also, the upper level of oxygen-minimum was shallower in the eastern part. This could be partly explained by the fact that this part of the Section was situated off the mouths of the Irrawaddy river where a shallow bank was present. The oxygen concentration at these depths was slightly higher in the central part of the section and varied between 0.25 and 0.5 ml/L.

Section V (Fig. 6): This section was occupied in the area south of the Nicobar Islands. The oxygen concentration (4.40 ml/L) in the upper layer was fairly constant over the entire Section. The thickness of this layer (>4.0 ml/L) was 60 m except at Station 159 where it was 50 m. The isopleth of 4.0 ml/L roughly coincided with 27.0°C isotherm. Below this layer the oxygen concentration sharply decreased to 0.75 ml/L at a depth of about 150 m. A cell of oxygen-poor water (0.6 ml/L) appeared between 250 and 420 m.

Section VI (Fig. 7): This section represented conditions east of the Andamans. The oxygen concentration (4.50 ml/L) in the upper layer was fairly constant throughout the section. The thickness of this layer (>4.0 ml/L) increased from 35 m in the northern end of the section to 80 m in the central part (Station 160) and then

decreased to 55 m at Station 159 towards south. This 4.0 ml/L isopleth roughly coincided with 27°C isotherm. The oxygen isopleths showed the same pattern as the isotherms up to a depth which varied between 140 to 180 m (0.75 ml/L). Two separate cells of oxygen-poor water (0.6 ml/L) were observed in the southern and northern parts of the section between 170 and 380 m. However, the oxygen concentration at these depths at Station 160 ranged from 0.6 to 0.75 ml/L.

DISCUSSION

It is clear that the oxygen distribution in the upper 150 m generally corresponds to the distribution of temperature. The surface oxygen-rich layer and sub-surface layer of steep gradients (4.0—1.0 ml/L) coincide with the isothermal layer and the upper part of thermocline layer respectively. The pattern of oxygen isopleths in the oxygen-minimum layer is, however, different from that of the isotherms. This would indicate that apart from the other processes governing the distribution in the upper layers, the variations are controlled by vertical mixing.

A comparison of the data from the Bay of Bengal and the Andaman Sea as presented above shows that the thickness of oxygen-rich surface layer (>4.0 ml/L) was greater (60 to 80 m) in the Bay of Bengal than in the Andaman Sea (40-60 m). The concentration in the oxygen-poor layer in the Andaman Sea varied between 0.75 ml/L and 0.55 ml/L as against 0.50 ml/L and 0.20 ml/L in the Bay of Bengal. This oxygen-poor layer started between 120 and 150 m and was observed up to 450 to 600 m in the Bay of Bengal. In the Andaman Sea the oxygen-poor layer started between 150 and 200 m. Thus, while the concentration in the oxygen-poor layer was greater in the Andaman Sea, its thickness was greater in the Bay of Bengal.

Miyake and Saruhashi (1956) pointed out that the extent of oxygen deficit and the generation of carbon dioxide within the oxygen minimum layer could be related to the local productivity while the depth of the oxygen minimum layer depended on the vertical density distribution of the sub-surface waters. In explaining the causes for the development, distribution and structure of oxygen minimum, Wyrтки (1962) stated that while the biochemical processes were responsible for oxygen consumption in the oxygen-minimum layer, its position and distribution were determined by circulation and that the shape of the oxygen profile, especially the high position of its minimum, was due to the exponential decrease of oxygen consumption with depth.

The decrease of oxygen concentration towards the north at sub-surface depths, as a result of biochemical processes, in the Bay of Bengal suggests a general northerly flow at those depths. Such a northerly flow has been substantiated by the results of dynamic computations presented elsewhere in this volume by Varadachari, Murty and Das (*See Sec. I, S.N.33*).

While presenting the results, it was pointed out that within the oxygen-minimum layer, water of slightly higher oxygen concentration separated the two cells of lower concentration on either side of the section (Figs. 2, 3, 5). The watermass which was observed at Station 151 in Section I (Fig. 2) below a depth of 75 m could also be

observed at Station 177 in Section II (Fig. 3). Similarly, the watermass which was observed at Station 160 in Section VI (Fig. 7) could be traced through Station 172 in Section IV (Fig. 5) to Station 189 in Section III (Fig. 4).

A reference to the surface current charts (Admiralty 1953) indicates intrusion of water of Pacific origin into the Bay of Bengal during the period under study. This intrusion was first reported by Sverdrup *et al.* (1946) and has been discussed by Balarama Murty (1958), Gangadhara Rao and Jayaraman*. The latter authors have also mentioned that Indian Equatorial watermass could be traced at depths below 100-150 m. These factors may be, at least in part, responsible for the features of the oxygen-minimum layer mentioned above. Further work in this regard is necessary before definite conclusions are arrived at.

CONCLUSIONS

The close relationship between the distribution of oxygen and temperature in the upper layers of the Bay of Bengal and the Andaman Sea during February-March, 1963 has been brought out. The thickness of the surface oxygen-rich (>4.0 ml/L) layer in the Bay of Bengal generally ranged between 60 and 80 m while that in the Andaman Sea was 40 to 60 m. The thickness of the oxygen-minimum (>0.5 ml/L) layer in the Bay of Bengal ranged approximately between 300 m and 450 m while in the Andaman Sea the thickness of the oxygen-minimum (>0.75 ml/L) layer was 250 m to 300 m. While the concentration of the oxygen in the surface layer was nearly the same in both the Bay of Bengal and the Andaman Sea, it was slightly greater in the oxygen-minimum layer in the Andaman Sea.

The northward increase in the thickness of the oxygen-poor (<0.5 ml/L) layer in the Bay of Bengal associated with the decrease in concentration of oxygen within it, could be interpreted as being the result of bio-chemical processes and a northerly flow at those depths. In fact, if the rate of consumption of oxygen at those depths is known, the speed of the northerly flow could have been estimated.

ACKNOWLEDGEMENTS

The authors are thankful to Mr. S. K. Ranganathan, Director, Directorate of Scientific Research (Navy), and Dr. N. K. Panikkar, Director, National Institute of Oceanography, for their interest in this work and encouragement extended to them. The authors wish to express their appreciation of the fruitful co-operation between the scientists and the officers and crew on board INS KISTNA and the efforts of the scientists of the Directorate of Scientific Research (Navy) responsible for the processing of the data.

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