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VERTICAL TEMPERATURE STRUCTURE OF THE SEA ALONG THE SOUTH COAST OF INDIA

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ABSTRACT

Using bathythermographs, the sea temperature was studied at 37 stations and to a depth of 900 feet during a cruise from Visakhapatnam around Ceylon to Cochin. Vertical temperature cross sections have been constructed for 2°F. intervals. The results were compared with those of Raghu Prasad who recently made a study up to 200 feet in the Bay of Bengal. Detailed discussion of the structure is presented.

Introduction

There is little knowledge about the subsurface temperatures in the Bay of Bengal and in the Arabian sea. In two Memoirs of the Asiatic Society of Bengal Dr. Sewell [5,4] has published the existing knowledge about the surface temperatures (1929) and the deep sea temperatures (1932) in Indian waters together with his own researches. His data comprise of 450 observations of deep sea temperatures in the Bay of Bengal and the Andaman sea. A good number of these were taken by means of " Miller-Casellas " thermometers of the maximum and minimum type. The remaining observations were made with the reversing thermometers manufactured by Negretti and Zambara, London. With such an arrangement the observations would generally be extended to depths below 1000 fms. and occasionally to depths greater than 3000 fathoms. However, with this type of work the results are rather speculative as far as the detailed vertical temperature structure is concerned, as it is not possible to obtain temperature as a continuous function of depth with such thermometers. For this purpose Spilhaus (1938) designed an instrument called a bathythermograph which records temperature as a function of depth. Tracings in the upper 150 ft, where the most pronounced vertical thermal charges are usually noticed, are made on smoked glass plates. Bathythermographs which can be used up to 150 fathoms (nearly 274 m) have recently been developed and manufactured. Raghu Prasad (1952) used a bathythermograph to study the temperature gradients in the upper 200 ft of water of the Bay of Bengal. In the present investigation the author used two bathythermographs for shallow and deep water, respectively. The shallow bathythermograph (B.T. No. 6158$\times$B) can be used up to 200 ft. whereas the deep one (B.T. No. 8505$\times$A) can be used to 900 feet. Hence a vertical thermal structure upto 900 feet could be obtained. Observations were also made by the author on one of the oceanographic cruises conducted by the Andhra University, and an Indian Navy " Minesweeper ", I. N. S. Bengal left Visakhapatnam Harbour at 1000 hours I. S. T. on the 8th March and reached Madras on the 10th March at 0900 hours during which period observations at eleven stations were made. She left Madras for Cochin at 0800 hours on the 15th March and arrived at Cochin 0630 hours on the 20th March. On the way from Madras to Cochin observations at twenty-six stations were obtained. The station location has been indicated in figure 1. The ship was stopped every four hours for observations. At each station a bathythermograph was lowered either upto the bottom in case of shallow water or upto 150m fathoms. Surface Salinity samples were also collected and the usual metereological observations were made at each of the stations.

A summary of observations is reported in Table 1.

TABLE 1

Summary of the Observations.

Station No.	Date (March) 1953	Time of observation (I.S.T.)	Station Position		Sea Surface Temp. °F	Atmospheric Temperature °F
			Latitude °N	Longitude °E		
220	8	1255	17° 37·4′	83° 14·8′	80·8	83
221		1605	17° 20·0′	83° 06·0′	82·7	83
222		2007	17° 02·0′	82° 54·5′	81·5	82
223	9	0010	16° 40·0′	82° 36·0′	81·4	80
224		0405	16° 20·0′	82° 29·0′	81·4	80
225		0805	15° 56·5′	82° 18·0′	81·7	83
226		1205	15° 28·0′	81° 55·0′	81·6	90
227		1557	15° 00·0′	81° 35·0′	82·3	87
228		1958	14° 43·0′	81° 39·0′	82·7	82
229		2342	14° 16·0′	81° 16·0′	82·4	82
230	10	0358	13° 45·0′	80° 49·0′	81·4	79
231	15	1205	12° 47·5′	80° 24·6′	82·2	85
232		1602	12° 21·5′	80° 34·5′	84·3	86
233		2000	11° 55·0′	80° 48·0′	83·3	82
234	16	0001	11° 24·0′	80° 56·0′	82·2	83
235		0401	10° 53·0′	81° 04·0′	82·5	83
236		0720	10° 27·0′	81° 07·0′	83·0	82
237		1145	10° 06·5′	81° 11·0′	83·8	93
238		1556	9° 31·0′	81° 21·0′	83·0	85
239		2002	8° 55·0′	81° 30·5′	82·6	85
240	17	0002	8° 20·1′	81° 40·6′	83·1	83
241		0406	7° 48·0′	81° 53·0′	82·3	82
242		0829	7° 22·0′	82° 16·0′	83·7	85
243		1203	6° 50·8′	81° 55·2′	84·7	86
244		1602	6° 16·0′	81° 42·0′	85·3	89
245		2004	6° 00·5′	80° 52·0′	83·5	86
246	18	0002	5° 51·0′	80° 32·7′	83·5	84
247		0406	6° 04·0′	79° 59·0′	84·3	83
248		0803	6° 23·0′	79° 30·0′	83·7	84
249		1203	6° 45·0′	79° 3·0′	84·5	82
250		1601	7° 05·0′	78° 35·0′	85·2	93
251		2003	7° 22·0′	78° 35·5′	84·9	89
252	19	0002	7° 40·0′	77° 45·0′	85·3	87
253		0505	7° 50·0′	77° 24·0′	85·2	86
254		2005	8° 41·0′	76° 36·5′	85·3	87
255	20	0003	9° 06·0′	76° 23·5′	85·4	86
256		0405	9° 39·2′	76° 12·2′	84·7	86

Thermal Structure

The observations have been divided into three sections and for each a vertical cross-section of temperature has been constructed. They are (1) from Visakhapatnam Harbour to Madras (*i.e.*, from station 220 to 231). (2) from

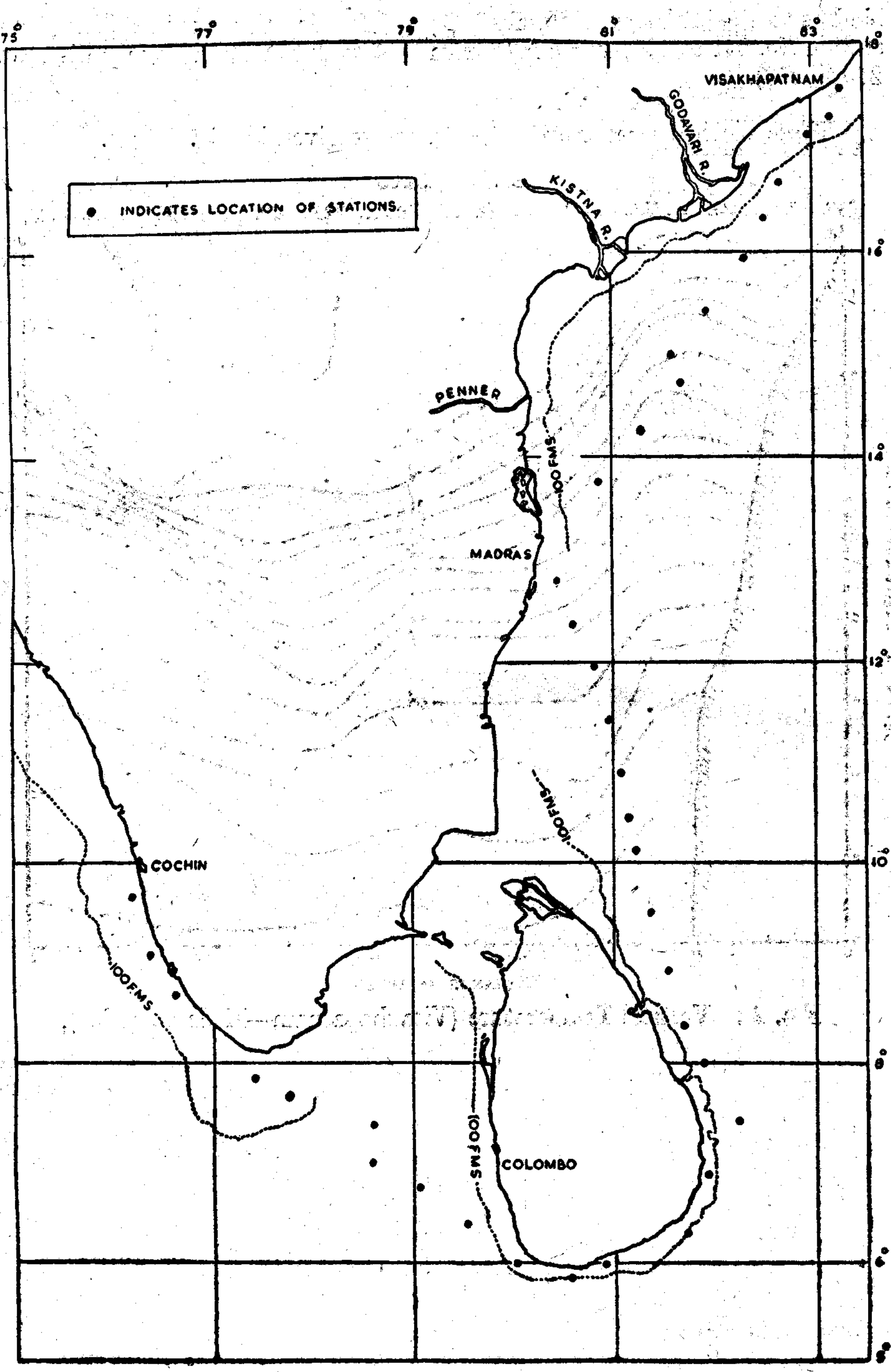

Fig. 1 : Location of Stations

Madras to a point between Hambantots and Dondra Harbour in Ceylon (from station No. 231 to 245) and finally from this point to Cochin (from station No. 245 to 256).

These vertical temperature structures are given in Fig. 2 to 4.

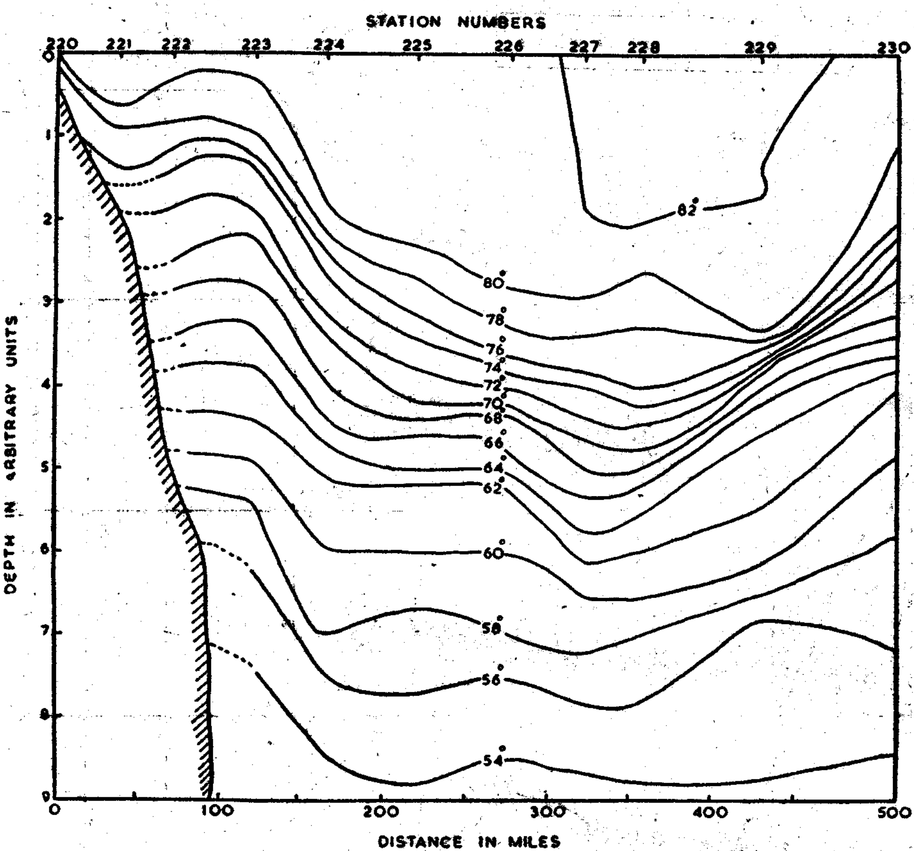

FIG. 2 : Vertical Temperature (Visakhapatnam—Madras Section).

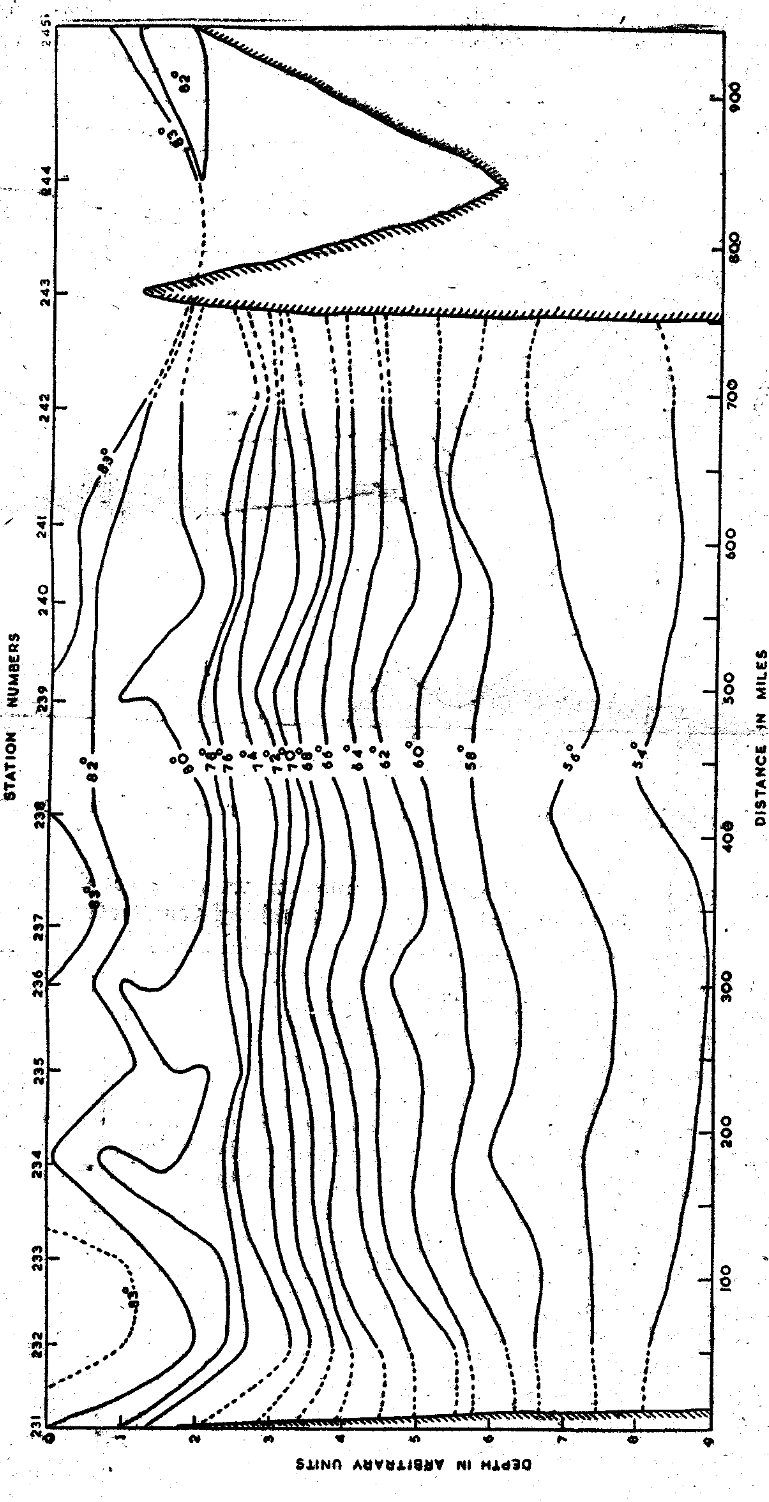

FIG. 3 : Vertical Temperature Structure (Madras-Dondra Harbour Section).

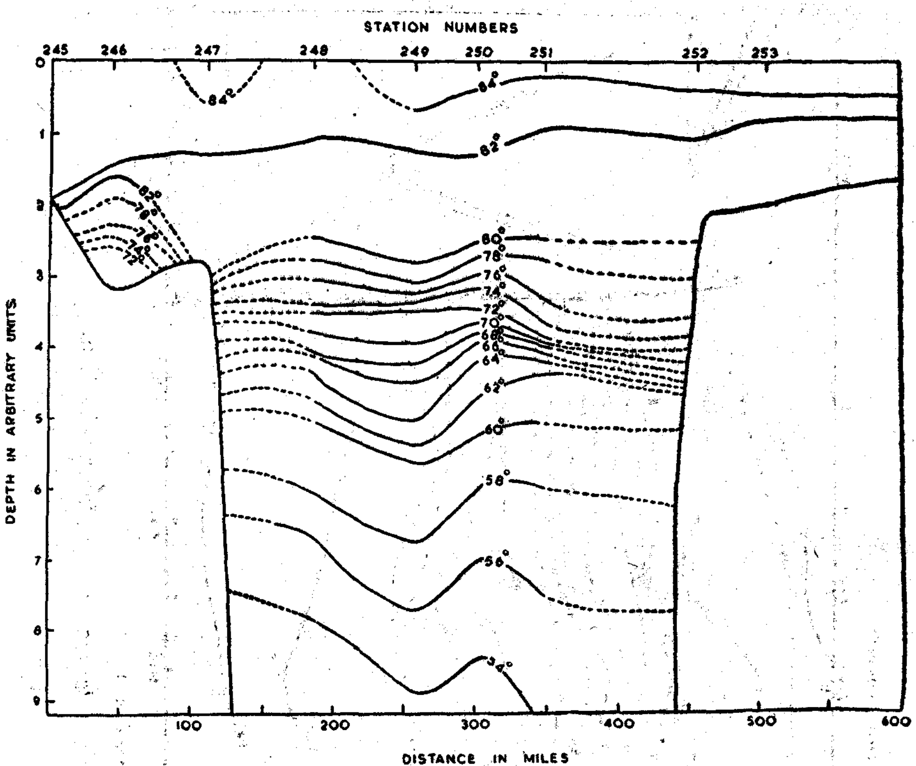

FIG. 4: Vertical Temperature Structure (Dondra Harbour-Cochin Section).

These figures clearly show that upto 2 units (except between Visakhapatnam and Cocanada) the rate of fall of temperature is very small. The greatest temperature gradient is observed between 2 units and 6 units, below which once again a slow fall of temperature is observed. A thermocline is a region in which the temperature changes by not less than 2°C (3·6°F) in 25 vertical meters (about 82 ft.). According to this definition a thermocline was observed at stations 20 and 26 at ·6 and 1·10 unit depths respectively. In the present investigation except at the stations 200 to 223, 231 and 243, the thermocline was below 2 units. Occasionally in the Bay of Bengal and generally in the Arabian sea upto Cochin, the thermocline developed below 2·40 units. The fact that the thermocline starts from deeper depths in the Arabian sea than in the Bay of Bengal can be explained by considering the salinity distribution of the surface waters. Due to the large masses of fresh water delivered by the rivers into the Bay of Bengal, the salinity will be lower than in Arabian sea. Raghu Prasad's (1952) observations in the head of the Bay of Bengal clearly indicate that here the thermocline forms in the topmost layers only, in comparison with the southern part of the Bay where it is observed to be deeper. He attributes this feature to the large runoff from the Ganges, Mahanadi, and Brahmputra rivers, with a consequent lowering of the salinity in the upper layers of the sea water. However the thermocline between stations 220 to 223 begins almost from the uppermost layers of the sea. This is due to the upwelling of water in shore off Visakhapatnam coast. La Fond (1953) found upwelling inshore off the east coast of India during March and April. He attributes this to the prevailing currents and weather. Raghu Prasad's observations for August also indicate a slight upwelling off Visakhapatnam. During August the temperatures for all levels in the Bay of Bengal are always greater than the corresponding temperatures during March. Sewell (1929) studied the diurnal variation of sea surface temperature in the Bay for the month of March 1924, and found the range of variation to be 4·2°F. His data show a good correlation between the air temperature and the sea surface temperatures as far as the maximum and minimum are concerned. The maximum in the open sea for both air and surface temperatures occurs at 12 noon. But the air temperature is minimum at 4 A.M. while the corresponding sea temperature occurs 4 hours later (*i.e.*, at 8 A.M.). The present observations also show the same variations. However, the maximum for the sea surface temperature is not well pronounced as the curve is flat between 0800 and 1600 hours I. S. T. Hence the range of temperature in a day is only 1·2°F. This cannot be taken as a true picture without the following reservation :

(1) The observations of the sea surface temperature were along a section extending between stations 220 to 246.

(2) The variation of temperature with latitude was not considered in the calculations. These results are reproduced in Table II. In view of these facts it appears from Table II that there exists relation similar to that discovered by Sewell between air temperature and sea surface temperature.

TABLE II

DIURNAL VARIATION OF SEA SURFACE AND AIR TEMPERATURE LOWER HALF REPRODUCED FROM SEWELL AFTER CONVERTING THE CENTIGRADE TO FAHRENHEIT SCALE FOR COMPARISON.

Time of the day	0	4	8	12	16	20	Range
Sea surface Temp.(Ts) °F	82·5	81·9	82·8	83·1	83·1	82·8	1·2 oF
Air Temp (Ta) °F ..	82·4	81·0	83·3	87·4	86·0	83·4	6·4 oF
(Ts—Ta) °F	—0·1	0·9	—0·5	—4.3	—2·9	—0·6	
Sea surface Temp. (Ts) OF (Sewell)	81·9	80·0	82·2	84·2	83·5	82·6	4·2 oF
Air Temp (Ta) OF Sewell	81·9	91·4	81·6	83·2	83·3	82·5	1·8 oF
(Ts—Ta) OF	0·0	—1·4	—0·6	—1·0	—0·2	—0·1	

Ice-free oceans in all latitudes absorb a surplus of radiation. Therefore heat is given off from the ocean to the atmosphere in the form of sensible heat, or latent heat of water vapour.

The sea-surface temperature must, therefore, be higher than the air temperature. According to the *METEOR* observations the difference between the sea-surface and air temperatures in the South Atlantic Ocean is on an average, 0·8°F. It is known that the sea surface temperature is always greater than air temperature, average conditions being considered. According to Sewell (1929) the surface temperature was greater by about 0·1°F. This agrees with the above results, as the temperatures measured on the ship were slightly higher due to the ship's heat. It was estimated by Sverdrup (1946) that the ship's measurement gives values on an average about 0·7°C higher. However, Table II shows that the air temperature is greater than the sea surface temperature during a major part of the day, the average difference being 1·2°F. Even with the limitations of the present investigation referred to earlier, and considering that the air temperature measured on the bridge might be higher it is felt that the difference is on the negative side. This means that heat will be transferred from the atmosphere to the sea. As the data at hand are quite scanty and other observations such as the ocean currents etc. are not known it is not possible at present to draw any definite conclusions.

Thermal Structure (Visakhapatnam-Madras Section)

There is a tendency for the isotherms to rise, both at Madras and at Visakhapatnam (Fig. 2). From this it may be inferred that there is upwelling inshore off the East Cost of India There is a slight oscillation in all layers with regard to the temperature, the maximum oscillation being at a depth of about 5 units. At this depth there may be a slight change in the currents. In this region the thermocline is also very deep and it starts only at about 2·5-3·00 units. Sixty degree isotherm which runs between 5 and 6 units differentiates the upper layer of sharp drop in tempreature from the still deeper layer where there is only a slow change in temperature. There is a marked difference in the characteristic curvatures of the isotherms in both these strata. Between 6 and 9 units the isotherms show a characteristic wave from. For the 58° isotherm a crest is observed at station 225. This feature is displaced at the station 226 by the 56° isotherm. A similar feature is also observed for the troughs. Thus the lower isotherms appear as if the upper isotherms are displaced almost bodily towards south probably due to internal waves. At station 229 there is a concentration of isotherms in the layer between 3·40 and 4·40 units, above and below which the rate of change of temperature is less marked.

Thermal Structure—(Madras-Dondra Harbour Section)

The temperature changes in the upper 2 units in this region (Fig. 3) are very interesting. Here also the thermocline is deeper and has formed only at about 2 units. Even though only two isotherms are running completely throughout this section the 80 degree isotherm is very interesting in its shape. At stations 234 and 236 the same temperature (*i.e.*, 80°F) occurs at three different depths. For station 234 they are at ·70 units, 1·30 units and 1·80 units and for station 236 at 1·00, 1·10 units. At station 236, water of low temperature extends as a tongue above and below water of higher temperature. The 82 degree isotherm except for this characteristic, runs almost parallel to the 78° isotherm, which slopes slightly upwards towards Ceylon.

This means that there is water of higher temperature and most likely of low salinity, probably due to the three main rivers Pannaiyar, Vellar and Coleroon in this region. The course of the rivers is such that if their course could be extended into the Bay they would converge near the station 234. Due to the run off from these rivers, there must be local turbulent mixing of surface waters superimposed on the existing surface currents as well as a lowering of salinity. This current, as is indicated by the thermal structure, is flowing towards the coast. This turbulent mixing and the waters of low salinity and high temperature are responsible for the character of the isotherm in question. Sewell (1932) also observed such abnormal temperatures in the Bay of Bengal in much deeper waters and according to him, they may be frequently observed in the months April and May. However further investigation is necessary to confirm this feature. At stations 235 and 239 there are two depths at which the same temperature occurs. Station 235 will be influenced by the current system just discussed. There is a tendency for all the isotherms up to 6 units to rise upwards at station 239, and to slope down on either side, and this is more pronounced for the 82 degree isotherm. Here also the 60° isotherm running between 5·50 and 6 units differentiates the two strata of different temperature gradients. In the upper layer, the isotherms bend slightly upwards towards Ceylon and they show more stratification in this region than in the previous sections. The isotherms in the deepest layer (6 to 9 units) are again in a wave form.

Thermal Structure—(Dondra Harbour-Cochin Section)

The deep sea observations for this section are quite meagre. Consequently between station 247 and 248, and 251 and 252, the isotherms are extrapolated (Fig. 4). Except at stations 245 and 246 the thermocline formed below 2·40 units. From 2·00 units to 5·6 units the greatest fall in temperature is noticed. Below this a slow rate of change of temperature with depth is again observed. At about the 4 units depth at station 251 there is a concentration of the isotherms. All the isotherms in the thermocline region are in the form of waves. The maximum oscillation for the 64 degree isotherm is observed to be roughly between 4 and 6 units. Also, the deeper layer below 6 units, slopes as do those above, but the oscillations are more pronounced. The thermal structure as a whole indicates a good stratification of water with some internal waves.

The thermocline has the temperature of 80°F in all the three sections, even though the depth and sea surface temperature vary in individual section. Temperature at various depths in the Arabian sea are greater than the corresponding temperatures in the Bay of Bengal. Stratified water masses are found in the Arabian sea and around Ceylon, whereas there are upwelling processes in the Bay.

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