

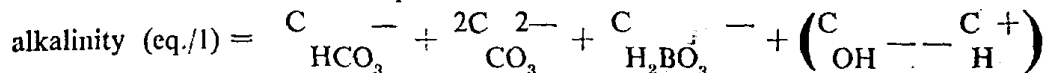
# SPECIFIC ALKALINITY IN THE NORTHERN INDIAN OCEAN DURING THE SOUTH WEST MONSOON

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Titration alkalinity was measured for a total of 500 water samples from the northern Indian Ocean during the south-west monsoon cruises of I.N.S. KISTNA in 1963 and the specific alkalinity were calculated from the chlorinity values. Results are represented along two sections in the Indian Ocean, two in the Arabian Sea and three in the Andaman Sea. Observations were restricted to a depth of 200 metres in the Indian Ocean and to about 500 metres in the Arabian and the Andaman Seas. In the Indian Ocean the values decreased between 25 and 50 metres where the optimal conditions for the lime secreting organisms seem to exist. The values then increase to about 100 metres and then show a slight decrease to 200 metres. The higher values appear to be in the core of the equatorial under-current, which has been found to exist in the Indian Ocean, as well. In the Arabian Sea the values vary little with depth and slightly higher values are found below 150 meters. These higher values may be due to the high salinity intermediate water in the Arabian Sea whose origin has been traced to the Persian Gulf. The values in the Andaman Sea are comparatively lower at the surface than at the depths slightly below it (between 20 and 40 metres). This may either be due to the 'island effect' or this area being in a zone where precipitation exceeds evaporation, and the observations were taken at the time of almost the highest precipitation. The surface values at the eastern section is in general higher than those at the western part, which may be due to the effect of the discharges from the River Irawaddy and its tributaries. The values gradually decrease towards the depth which may also be due to the fact that this is an area of intense south-west monsoon upwelling.

## INTRODUCTION

The alkalinity of sea water is a measure of the quantity of anions of weak acids present in it and of the cations balanced against them (Sverdrup *et al.* 1942). In most sea water, the cations of weak bases are present in negligible concentration and the only anions that need be considered are those of carbonic and boric acids, and in a sea water sample, the alkalinity (defined as 'titration alkalinity' by Harvey 1955) is the sum, in terms of equivalent per litre, of the analytical concentrations of these anions. This can be expressed as:



Wattenberg (1933) used the term 'specific alkalinity' in the Atlantic waters, which can be defined as:

$$\text{Specific alkalinity} = \frac{\text{Alkalinity} \times 10^3}{\text{Chlorinity}}$$

and found a constant value of 0.123. Koczy (1956) found that this value varies between 0.119 and 0.130 in all the oceans. The specific alkalinity indicates the changes due to the calcium precipitation or dissolution, but should not be affected by the mixture of water masses with different salinities, if not the history of the water in respect of the geochemistry of calcium carbonate is different. With rising pres-

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sure of carbon dioxide, increasing depth and decreasing temperature the solubility of carbonate increases. Therefore, the specific alkalinity increases with depth. Depending on the state of the calcium carbonate system at the origin, the specific alkalinity can be used as a tracer for the flow of different water masses.

### MATERIALS AND METHODS

As part of the Indian programme for the International Indian Ocean Expedition, titration alkalinity was measured in samples from the northern Indian Ocean, during the south-west monsoon cruises of I.N.S. KISTNA in 1963 (Fig. 1), and the specific alkalinity was calculated from the chlorinity values. The titration alkalinity was measured according to the method of Gripenberg (1937). 10 ml of N/20 HCl

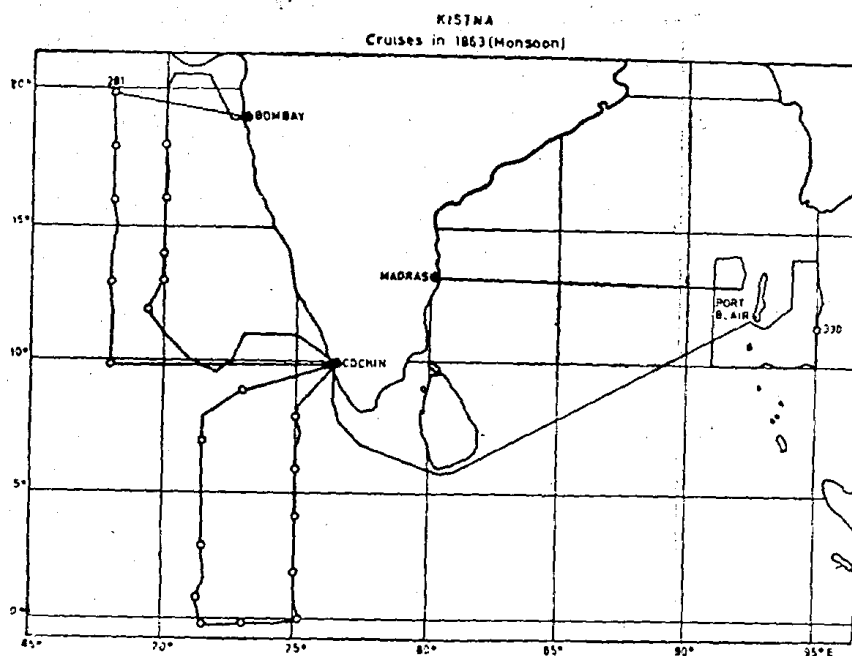


FIG. 1

was put in a polyethylene bottle (ca. 200 ml volume) and it was then filled up with sea water. When the ship reached the harbour the samples were boiled, on board, for 5 minutes in order to drive off all the carbon dioxide set free by the acid. The hot liquid was then back-titrated with a N/20 carbonate-free sodium hydroxide solution to a pH of 7 using a mixture of 3 parts of Brom-cresol green and 2 parts of Methyl red as indicator. During the titration carbon dioxide-free air was bubbled through the sample.

### RESULTS AND DISCUSSION

The values for the same depths at all the stations along the sections are represented as scatter in the diagrams. The mean values have been drawn as a line to show the variations of the values around the mean.

(i) *Indian Ocean*: Figure 2 represents two sections in the Indian Ocean. Line 1 is for a section along the equator between  $71^{\circ}$  and  $75^{\circ}$ E longitude and line 2 is for a meridional section between  $4^{\circ}$  and  $8^{\circ}$  N latitude along the  $75^{\circ}$  E longitude. Observations along both the sections represent values down to the depth of 300 metres.

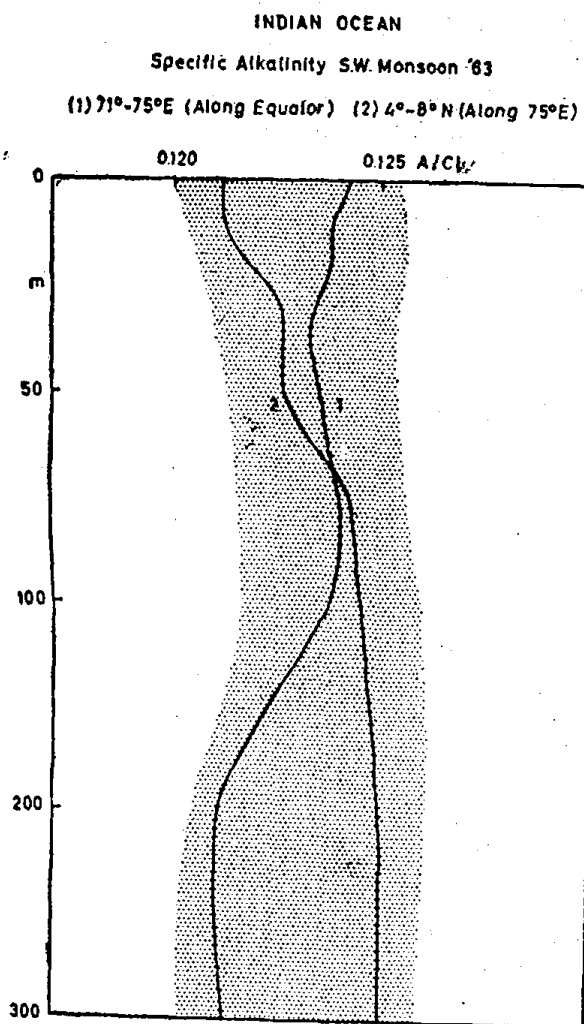


FIG. 2.

A look at line 1 will show a decrease in the values to about 50 metres, followed by an increase to about 100 metres and a slow decrease to about 200 metres, below which it becomes almost steady. The equatorial surface waters, in which the main production of calcareous shells goes on, show a low specific alkalinity and the depth between 25 and 50 metres, is the region where the optimal conditions for lime-secreting organisms exist (Koczy 1956) as a result of the oversaturation in the car-

bonate content by the increased temperature, which is the reason for the lowering of the specific alkalinity values.

Line 2 of the Fig. 2 shows a steady increase in the values of specific alkalinity in the surface layers associated with lower salinity values. Such higher values have also been reported in the northern part of the Indian Ocean near Ceylon (Koczy 1956), and also around the New Hebrides and Fiji Island in the Pacific Ocean (Rotschi 1965). This increase may not be representative of general conditions in the Indian Ocean but may be an 'island effect', where the surface waters have been modified by a variety of runoff products (Waterman 1964).

Figure 3 shows the horizontal distribution of specific alkalinity along the equatorial section. It can be seen that there is an increase in the values in the surface layers from the west to the east. Similar observations have been recorded by Bruneau *et al.* (1953) who have noted changes in specific alkalinity values in the surface layers from 0.120 at 66° 16'E to 0.123 at 77° 28'E almost along the equator. Figure 3 also illustrates the gradual increase of the specific alkalinity values to about 100 metres and then a slow decrease. The same nature of variation has also been observed during the Swedish Deep Sea Expedition (Bruneau *et al.* 1953). One of the reasons for this increase in specific alkalinity values can be correlated with the change in the slope of the surface of the Indian Ocean from west to east, which has been observed to be of opposite sign from that in other oceans (Knauss and Taft 1964). Figure 4, which has been taken from their observations, illustrates this. Ivanenkov (1964) has also reported a gradual increase in values of the surface specific alkalinity along the equator in the Indian Ocean from west to east.

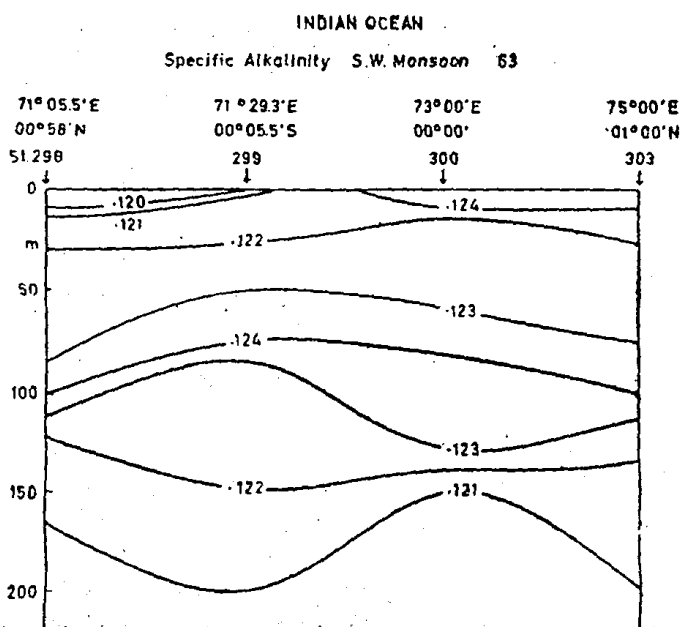


FIG. 3.

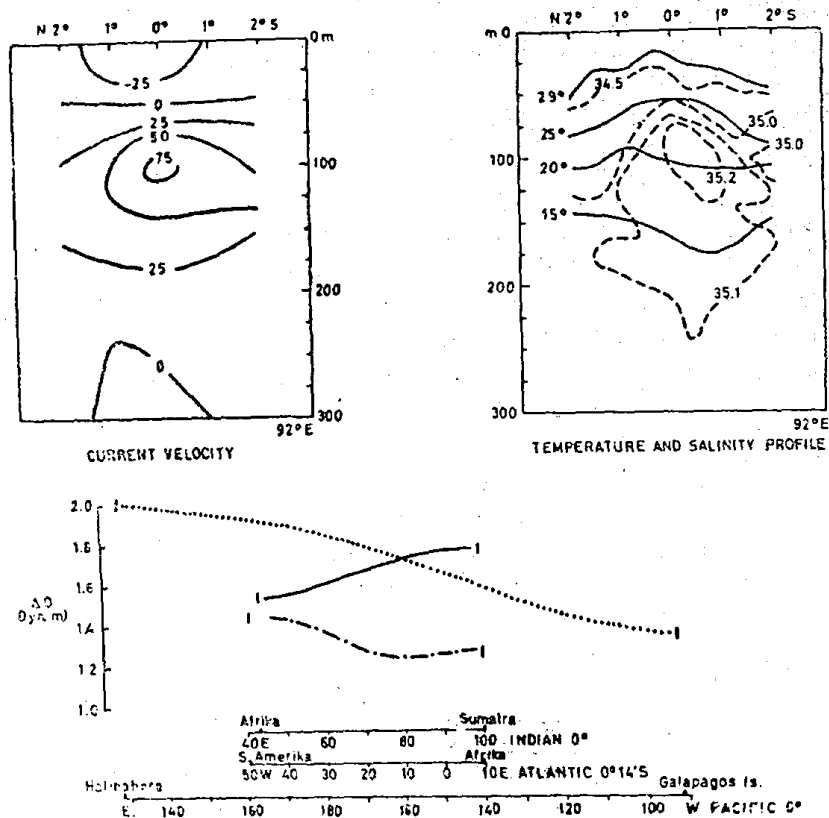


FIG. 4

A comparison of Figs. 3 and 4 shows that the region of the maximum specific alkalinity almost coincides with regions of high salinity and with the core of the weakly developed equatorial under-current in the Indian Ocean, which has been observed to exist by Knauss and Taft (1964).

(ii) *Arabian Sea*: Figure 5 represents two sections in the Arabian Sea. Line 1 represents a section along 70°E and line 2 along 68°E. Both the sections represent values between 10° and 20°N, the first to a depth of 100 metres and the second to 500 metres.

Line 1 shows the slight increase of the values to about 25 metres below which it becomes steady. A comparison between these values and those at station 4890 (Ivanenkov 1964) show an almost identical nature of variation. Since the present observations were taken during the south-west monsoon and the latter observations during the north-east monsoon, though at different years, it may be assumed that the values of specific alkalinity are slightly increased during the south-west monsoon but the nature of variations remains the same.

Line 2 shows a gradual increase from the surface values to the deeper ones, which becomes almost steady at about 100 m. Figure 6 shows an attempt at correlating the specific alkalinity values with the corresponding  $\sigma_t$  surfaces. In general,

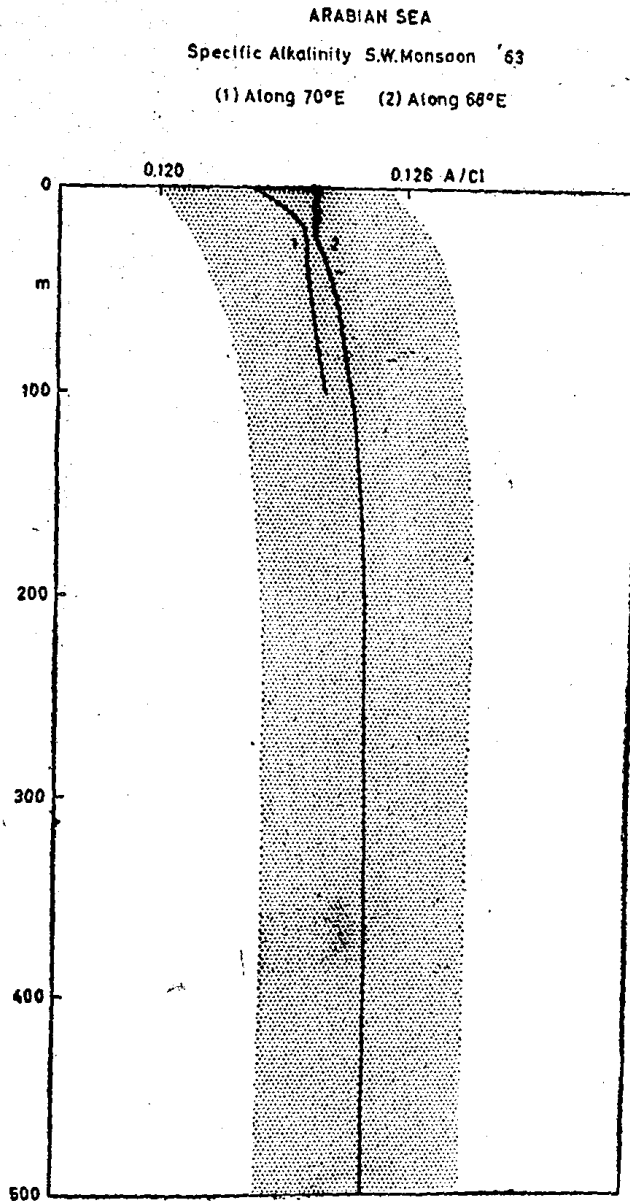
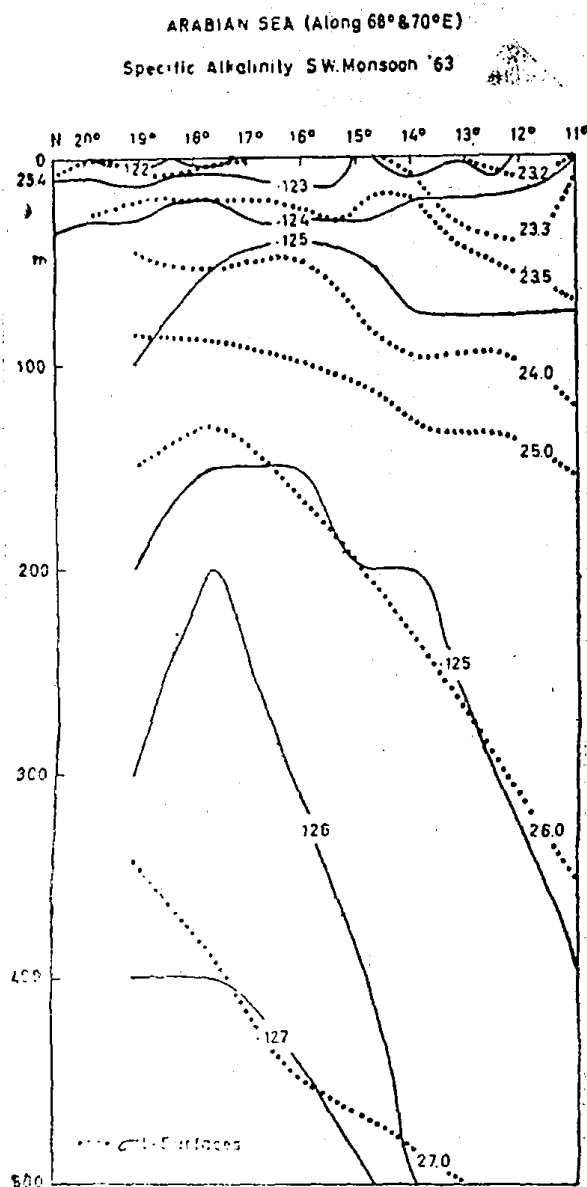


FIG. 5.

it is seen that they agree within a fair amount of approximation. Three different water masses are apparent from the figure, the first, the surface and the sub-surface layers to about 100 metres, coinciding with  $\sigma_t 25$  surface, the second, to about 200 metres, coinciding with  $\sigma_t 26$  surface, and the third, to about 500 metres, coinciding with  $\sigma_t 27$  surface. All the surfaces are found to slope downward from north to south. The surface layer may be said to be originated in the Arabian Sea itself



(Sabinin 1964). The intermediate layer is formed by the tributary of the high salinity water of the Persian Gulf—the salinity maximum of this water is found to lie between 150 and 300 metres (Sabinin 1964). The specific alkalinity values, characteristic of this water (0.125) is observed between 200 and 300 metres in the section along 75°E (Fig. 2). Hence, from these observations, it can be said that the waters of the Persian Gulf-origin has been traced down to 4°N latitude. The lower layer of  $\sigma_t 27$  (specific alkalinity 0.125—0.126) can be said to be of the Red

Sea origin—the salinity maximum of which is observed between 400 and 800 metres in the Arabian Sea. It is apparent from the Fig. 6 that this layer extends below 500 metres as both the specific alkalinity and the  $\sigma_t$  values show a gradual increase southwards from about  $13^\circ\text{N}$  latitude. The Red Sea water seems to have a higher specific alkalinity associated with higher salinity and calcium contents.

(iii) *Andaman Sea*: Figure 7 represents the specific alkalinity values from three sections covered around the Andaman Islands. Line 1 represents the eastern section between  $11^\circ$  and  $14^\circ\text{N}$  and  $93^\circ$  and  $95^\circ\text{E}$ ; line 2 represents the western

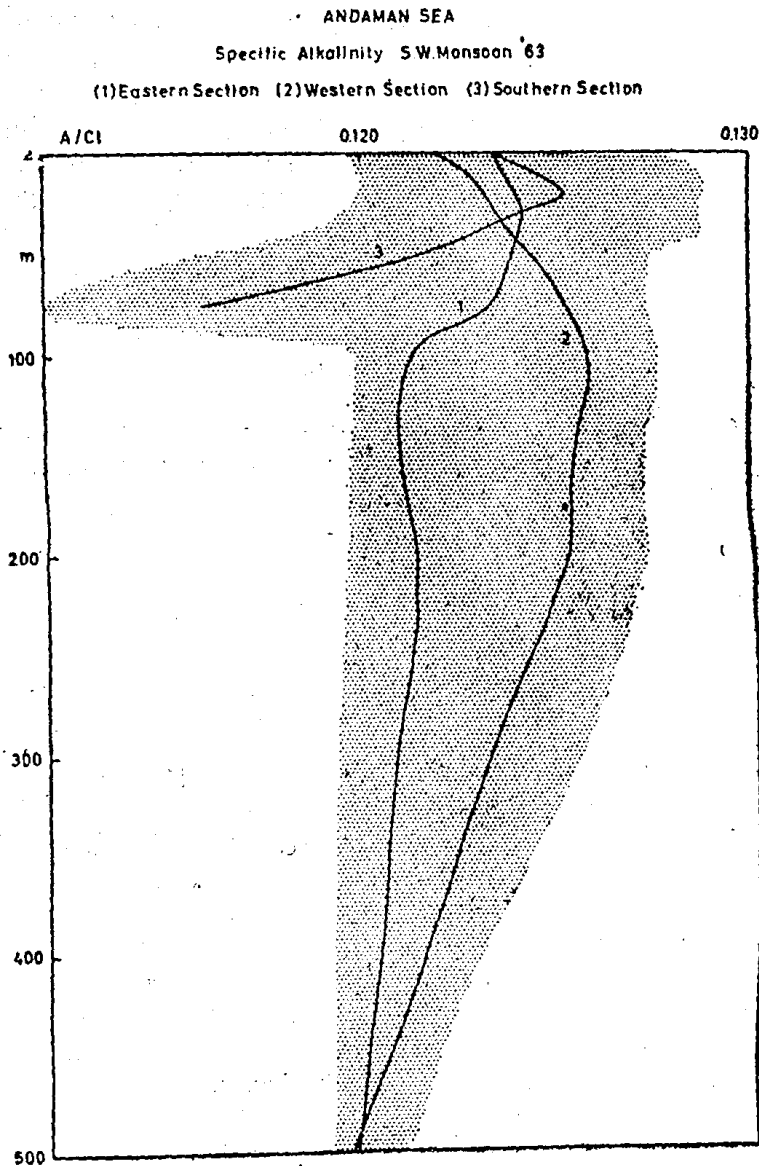


FIG. 7.



section between 11° and 14°N and 91° and 92°E; and line 3 along 10°N between 91° and 95°E. Observations were confined to 500 metres in the eastern and the western sections while in the southern it was only to 75 metres. The wide scatter of the values in the figure is the cumulative result of observations at all the stations along the three sections.

In the north-eastern Indian Ocean precipitation exceeds evaporation (Ivanenkov 1964) and it is an area of intense upwelling, specially during the monsoons (LaFond 1963).

The high surface values in all the sections in this area may be correlated with this factor. Also, the observations were taken at the time of very high precipitation, if not the highest (early September). In the eastern section of this area, the River Irawaddy from Burma discharges, and hence, it can be said that, in general the recently mixed river water and the rain of continental origin enhances the specific alkalinity values in the surface layers, associated with low salinity values lying between 31‰—33‰. The gradual increase in the specific alkalinity values with depth to (ca. 200 m) in the western section (line 2) probably indicates that upwelling is more intense in this part of the Andaman Sea than in the others. The gradual lowering of the values in the southern section with depth probably indicates that the water masses in this region are influenced more by the waters of oceanic origin.

#### GENERAL REMARKS

It can be noted from these observations that: (1) the specific alkalinity behaves as a conservative property of sea water and with certain limitations, the mean values can be used approximately as a tracer for the flow of water masses of different origin, and (2) the specific alkalinity values along the equator in the Indian Ocean during the monsoon follows fairly well the modulations of the equatorial under-current, the high values almost coinciding with its core, and the dynamic topography of the ocean surface.

#### ACKNOWLEDGEMENTS

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