

Boron-Chlorinity Relationship in Western Bay of Bengal

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Significant scatter in B/Cl beyond the limit of experimental error indicates that the ratio is not truly constant. B/Cl maximum, centred around 100 m, appears to be influenced by colloidal and particulate matter while the maximum at 400 m appears to be due to the influence of Persian Gulf and Red Sea water and also due to the release of boron by oxidative degradation of organic matter. At 3000 m depth the ratio is typical of Antarctic bottom water.

Boron, considered as one of the major elements in sea water, is present at a concentration of 4.5 mg/kg at 35‰ salinity¹. Significant scatter in the natural occurrence of boron^{1,2} suggests that the concept of a constant B/Cl calculated for a multitude of samples collected from widely different locations and depths and at various times is not strictly correct. Most of the earlier work is confined to the upper layers and the data on vertical distribution are rather scanty. Although much information is available on the chemical oceanography of the Northern Indian Ocean, most of it pertains to spatial and temporal variations of nutrients, dissolved oxygen and a few major elements in sea water. The present work on B/Cl relationship in the Bay of Bengal is undertaken to examine the depthwise variations in the water column up to a depth of 3 km.

Samples were collected from standard hydrographic casts at stations marked in Fig. 1, using transparent TPN samplers (HYDRO BIOS, KIEL, F.R.G.) and stored in well-cleaned polyethylene bottles. In the laboratory, the samples were kept under refrigeration till used. It has been confirmed that the samples kept at room temperature give unaltered results even after 6 months of storage³. Samples stored under refrigeration also gave unaltered results.

Procedure developed by Hulthe *et al.*⁴ for use on autoanalyser was applied for analysis with a few modifications for the determination of boron. Propionic anhydride and oxalyl chloride were replaced by acetic anhydride and hydrochloric acid and acetone with methyl isobutyl ketone. Beer's law was obeyed up to a boron concentration of 5 mg/litre. Standard deviation (SD) for the concentration range 2.4-4.56 mg/litre was $\pm 1.2\%$ and is quite comparable to the value reported by others⁵ for similar concentration range.

Salinity was determined on board using an 'Autosal' inductive salinometer and counter-checked in the

laboratory by the argentometric titration procedure. The results compared very well. Oxygen was determined on board by Winkler method.

As the general trend of variation of boron and chlorinity was similar at all stations, the results were pooled to present a general picture of the area (Fig. 2). B/Cl varied from 0.225-0.254. Relative SD of the method used for boron determination is $\pm 1.2\%$ and for chlorinity is $\pm 0.01\%$. This allows a limit of ± 0.003 for the spread of B/Cl due to experimental uncertainties. The observed significant scatter indicates that the ratio is not strictly constant and small lateral and vertical variations are possible. Variation from 0.216-0.26 has been reported for Tokyo Bay⁶. For the tropical Atlantic Ocean, its variation⁷ was from 0.232 to 0.26. A wide variation in the range 0.212 to 0.272 has been reported in the Baltic Sea². Introduction into and elimination from sea water of boron in partly independent ways has been given² as a probable explanation for irregularities in B/Cl.

Depth profile of dissolved oxygen, with decrease from 4.5 ml/litre at the surface to below 1 ml/litre at depths 200-1000 m followed by a steady increase up to 3000 m, is typical for the western Bay of Bengal⁸.

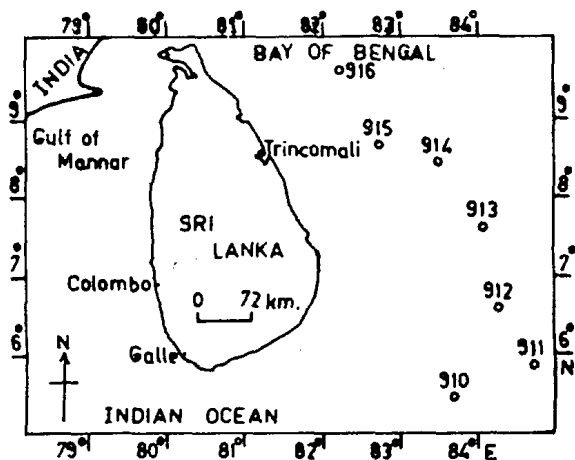


Fig. 1—Location of stations in the Bay of Bengal

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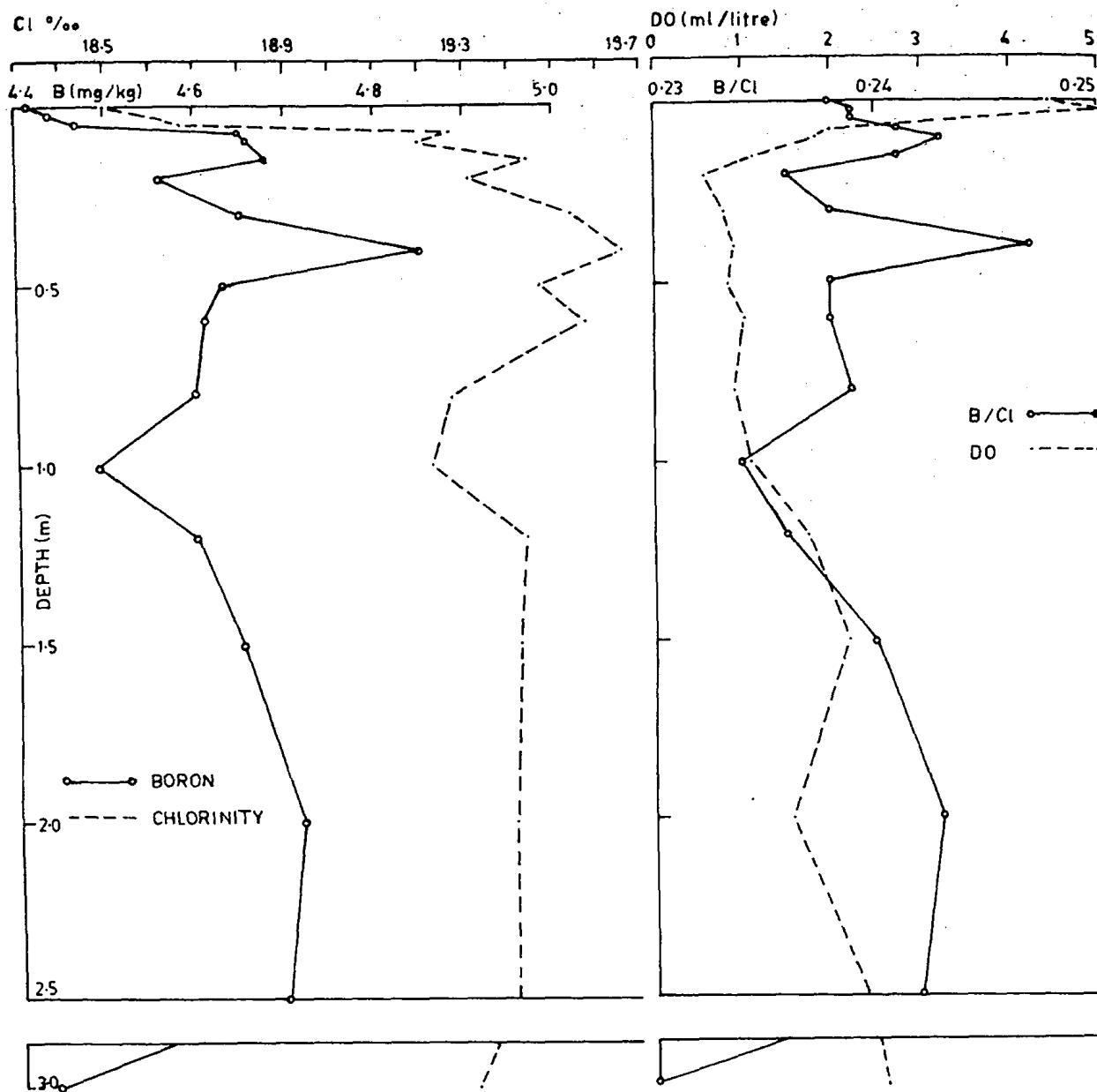


Fig. 2 ---Depth profiles of average values of boron (mg/kg), chlorinity (‰), boron-chlorinity ratio and oxygen (ml/litre) in the Bay of Bengal

Lower values of boron in the upper layer of the Bay of Bengal are mainly due to dilution. The Bay of Bengal is an area of positive water balance with about 1500 km³ average annual excess of precipitation over evaporation⁹. In addition, several major rivers of India, Bangladesh and Burma can be expected to add about 2000 km³ of fresh water every year to this basin. An annual dilution of 5.5% in the upper 25 m (the maximum depth of riverine influence) has been considered as a reasonable approximation⁹. Although, boron is an essential micro-nutrient, low levels of boron in phytoplankton¹⁰ indicate that the uptake of boron may not be the primary factor responsible for lower boron levels at the surface.

The global average of boron and chlorinity in river water is 0.013 mg/litre and 0.01‰ respectively¹¹. This gives B/Cl of 1.3. The ratio observed for the surface water is, however, not indicative of any increase due to riverine influence. It is considered that the major fraction of the riverine boron is removed by adsorption on detrital clays on mixing with higher ionic strength of sea water. Some fraction is also removed from sea water during formation of authigenic silicate and by adsorption onto siliceous oozes¹². Therefore, low boron concentration at the surface may be the combined effect of dilution and removal.

The interesting features which can be seen from the depth profiles (Fig. 2) are 2 maxima of boron and B/Cl

between 50 and 200 m, and 300 and 500 m. Chlorinity also shows maxima in these regions. Although some amount of uncertainty exists over the occurrence and distribution of sub-surface water masses in the Bay of Bengal, from the study of temperature-salinity structure, the existence of Persian Gulf and Red Sea water in the Bay has been established^{13, 14}. Persian Gulf and Red Sea water enters the Bay at depths of about 200 and 400 m respectively and follow the circulatory pattern at their respective depths of entry¹⁴. The first maximum is at about the thermal discontinuity layer and appears to be the result of accumulation of colloidal and particulate matter. This may also be influenced by the Persian Gulf water. Unfortunately, boron analysis data are not available at the source of this water mass. The 2nd maximum centered around 400 m which lies in the region of maximum apparent oxygen utilisation (AOU)¹⁵ is possibly due to the combined effect of the higher boron in the oxygen minimum zone and the high boron levels associated with the Red Sea water flowing at its characteristic density level. The observed ratio (0.247) is, however, higher than that reported for the Red Sea (0.242)¹ which may be due to the release of boron in oxygen minimum zone. The slightly higher ratio in the oxygen minimum zone of North East Pacific was attributed to the breakdown of soluble organic borate complex in this zone thereby liberating detectable quantities of uncomplexed boron¹⁶. Later, occurrence of such complexes was reported¹⁷ and the lowest concentration of complexed boron observed in the oxygen minimum zone of Gulf of Mexico¹⁸, supported the release of boron through degradation of organo-boron complexes.

Boron profiles for upper 500 m are quite comparable to total nitrogen and total phosphorus profiles reported for the western Bay of Bengal⁸ supporting the view that boron is released in the zone of high AOU. At 500-1000 m the decrease in boron is associated with the corresponding decrease in chlorinity with the minimum B/Cl at 1000 m. Below 1000 m chlorinity almost remains constant while boron increases steadily with the increase in B/Cl with depth. This is contrary to the reported constant B/Cl below oxygen minimum zone¹⁸. At depths 100-1000 m oxygen concentration in the Bay of Bengal hardly exceeds 1 ml/litre. Although average rate of photosynthetic productivity in oceanic

areas has been considered as $137 \text{ mg Cm}^{-2} \text{ day}^{-1}$, the rate in the Bay of Bengal is about 20% more⁹. Due to the limited availability of oxygen the decomposition of organic matter is a slow process and organic matter may sink downward in undecomposed or partially decomposed state. Presence of organic nitrogen and phosphorus at depths of 1000-3000 m has been reported⁸, confirming this. The increase in boron at 1000 to 2500 m may, therefore, result from the release by decomposing organic matter.

Only 2 samples, collected at 3000 m were available for analysis and they gave the same B/Cl of 0.23. From 12 replicate determinations made on a sample of sea water collected at a depth of 3958 m in the southern Indian Ocean (lat. $16^{\circ}58'S$, long. $64^{\circ}42'E$)¹⁹ a B/Cl of 0.23 was obtained². This ratio may represent the characteristic of Antarctic bottom water.

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