

A study on inorganic carbon components in the Andaman Sea during the post monsoon season

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Abstract – Extensive data have been collected on the carbon dioxide system during the post monsoon season in the eastern Bay of Bengal and the Andaman Sea of the northeastern Indian Ocean. The vertical distribution of temperature and salinity in the eastern Bay of Bengal were similar to that in the Andaman Sea down to 700–800 m. Below 1200 m depth the salinity remained constant at 34.90 in the Andaman Sea whereas it decreased to 34.80 in the eastern Bay of Bengal. On the other hand, deep waters (> 1200 m) of the Andaman Sea were warmer than those of the Bay of Bengal by approximately 2°C. Dissolved oxygen concentrations in the subsurface waters were higher in the Andaman Sea than in the central Bay of Bengal and Arabian Sea due to lower rates of regeneration. Total alkalinity, and pCO_2 showed similar distribution patterns both in the eastern Bay of Bengal and the Andaman Sea up to a depth of 1000–1200 m. Below this depth, their concentrations were higher in the latter than compared to former due to warmer waters. Carbonate saturation depth with respect to aragonite was shallow (approximately 300 m) in the Andaman Sea whereas deeper waters were found to be under saturated with respect to calcite. © 2001 Ifremer/CNRS/IRD/Éditions scientifiques et médicales Elsevier SAS

Résumé – Étude du système dioxyde de carbone en mer d'Andaman après la mousson. Des données extensives sur le système dioxyde de carbone ont été recueillies en saison post-mousson dans la partie est du golfe du Bengale et la mer d'Andaman (océan Indien NE). La distribution verticale de la température et de la salinité est similaire dans ces deux parties jusqu'à l'horizon 700 à 800 m. En dessous de 1200 m, la salinité demeure constante, autour de 34.90, en mer d'Andaman, alors qu'elle décroît à 34.80 dans le golfe du Bengale. D'un autre côté, l'eau profonde, au-dessous de 1200 m est plus chaude en mer d'Andaman d'environ 2°C comparé au golfe du Bengale. Les teneurs en oxygène dissous des eaux de subsurface sont plus élevées en mer d'Andaman qu'au cœur du golfe du Bengale ou qu'en mer d'Arabie, en raison d'une moindre régénération. L'alcalinité totale et la pCO_2 présentent des distributions similaires dans les deux zones jusqu'à une profondeur de 1000 à 1200 m. En dessous, les concentrations sont plus élevées en mer d'Andaman en raison de la présence d'eaux plus chaudes. La profondeur de saturation en carbonates en regard de l'aragonite est moindre (environ 300 m) en mer d'Andaman, alors que les eaux plus profondes sont sous-saturées en calcite. © 2001 Ifremer/CNRS/IRD/Éditions scientifiques et médicales Elsevier SAS

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1. INTRODUCTION

The Andaman Sea is a basin of the Indian Ocean that extends between the Malayan Peninsula on the east and the Andaman and Nicobar islands on the west. The Andaman Sea forms the far eastern part of the northern Indian Ocean, separated from the western Bay of Bengal by the Andaman–Nicobar island chain. These two parts of the northeastern Indian Ocean are connected by deep Preparis Channel, Ten Degree Channel, and the Great Channel. In the last two decades, a considerable amount of scientific work has been done on the physical oceanographic aspects of the Andaman Sea. However, a very few chemical observations on the distribution of nutrients have been reported (Mathew and Pillai, 1990; Sen Gupta et al., 1980). The Andaman Sea is one of the sites in the world's ocean where extraordinarily large solitons have been encountered (Apel et al., 1985; Osborne and Burch, 1980 and references therein). Although the Andaman Sea is connected to the Bay of Bengal, the processes occurring in these seas are comparable only up to a depth of 1000 m. The deep waters of the Andaman Sea are warmer than Bay of Bengal deep waters by 1.7°C (Sewell, 1932; Varkey et al., 1996) with no salinity variations between the two (Sen Gupta and Naqvi, 1984). Warmer deep waters of the Andaman Sea make it interesting to study variability in forms of inorganic carbon as no information is available on the carbon dioxide system. This paper discusses biogeochemical cycling of carbon and nitrogen in the Andaman Sea based on the first observation made in this region.

2. MATERIAL AND METHODS

The data sets used for this study were obtained from the locations shown in *figure 1*. Observations in the eastern Bay of Bengal and Andaman Sea were carried out during October–November 1996 on board ORV *Sagar Kanya* during Cruise 118. Water samples were collected using a Seabird CTD-rosette system fitted with 12 Niskin bottles. Dissolved oxygen was estimated following a spectrophotometric method (Pai et al., 1993). The analyses of nitrite and nitrate were carried out using a Skalar Autoanalyser model 5100/1. The pH was measured at 25°C by a spectrophotometric technique using cresol red (Byrne and Breland, 1989). This pH_{25} was first converted to $\text{pH}_{\text{in situ}}$ according to Millero (1979). The pH, as a function of temperature and salinity, was computed using the con-

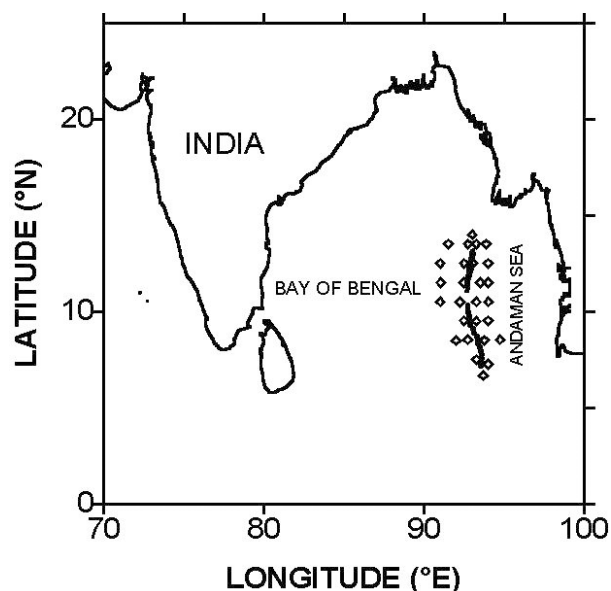


Figure 1. Map showing sampling stations.

stants given by Hansson (1973) for the conversion of $\text{pH}_{\text{in situ}}$ to pH_T . The effect of pressure was computed based on the formulations given by Millero (1983). Total sulphate was calculated from salinity based on the principle constancy of ionic composition. The effect of fluoride ions is not considered since it should not be significant (Dickson, 1993). The total alkalinity (*TA*) was measured at room temperature by the spectrophotometric technique involving bromocresol green (Breland and Byrne, 1993). Total alkalinity of the certified reference materials (CRM, Batch No. 28 supplied by Dr. Andrew Dickson, Scripps Institution of Oceanography, La Jolla, CA, USA) was found to be $2195 \pm 4.5 \mu\text{mol kg}^{-1}$, which agreed with the standard value of $2223 \mu\text{mol kg}^{-1}$ (Millero et al., 1998) with an accuracy of 1.27%. This correction was applied to the complete data set used here. The carbonic acid ionisation constants obtained from the equations of Goyet and Poisson (1989) were used for computing $p\text{CO}_2$ and carbonate components. Oxygen saturation was calculated according to Benson and Krause (1984). Analytical precisions for *TA* and pH were $\pm 2.0 \mu\text{mol}$ and ± 0.002 , respectively, while those derived for the calculated parameters $p\text{CO}_2$ and CO_3^{2-} (from *TA* and pH) were $\pm 4.0 \mu\text{atm}$ and $\pm 4.3 \mu\text{mol}$, respectively.

3. RESULTS AND DISCUSSION

Surface water salinities in the study region were low and ranged from 31.8 to 33.4 (*figure 2a*). Low salinity waters in the surface layers are largely due to the influence of fresh water discharge through the Irrawady–Salween river system (Janekarn and Hylleberg, 1989; Varkey et al., 1996). A sharp vertical gradient in the salinity occurred between 50 to 75 m. Maslennikov (1973) noted that the vertical distributions of temperature and salinity in the northeastern part of the Bay of Bengal were similar to that in the Andaman Sea down up to 700–800 m. However, at depths below 1000 m, salinity remained constant at 34.90 in the Andaman Sea whereas in the eastern Bay of Bengal it was decreased to 34.80 (*figure 2a*). The surface layers in the Andaman Sea are nearly homogeneous with temperatures around 29°C and a thickness of 50 m. Permanent stratification in this region, a feature also characteristic of the entire Indian Ocean, as reported by Sen Gupta and Naqvi (1984), hinders the vertical mixing. Below the mixed layer, temperature fell rapidly to 13°C at 200 m. A thermocline thickness of 150 m was observed (*figure 2b*). Temperature structures in both the Bay of Bengal and Andaman Sea are comparable to a depth of 1200 m, but deep waters (> 1200 m) of the Andaman Sea are consistently warmer than those of the Bay of Bengal. At 2000 m the temperature difference between the two was ~2°C. This difference is consistent

with the value of 1.7°C at 1829 m depth reported by Sewell (1932). Varkey et al. (1996) observed small vertical temperature gradients (1°C drop over 600 m) in the depth range of 1100–1700 m in the Andaman Sea whereas the same in the Bay of Bengal was 2.4°C during both winter and summer. This interesting feature is attributed to the enclosed nature of the Andaman Basin (Rao and Jayaraman, 1968; Sen Gupta et al., 1981). Ramesh Babu and Sastry (1976) suggested that the depth of the sill in the channel connecting the Bay of Bengal and the Andaman Sea should lie at about 1300 m. Due to poor water exchange restricted by the sill, the water masses in the mid-depth region on the eastern side of the Andaman islands remain relatively stagnant. Shallow sill depths at Duncan Passage between South and Little Andamans and at the Ten Degree Channel between the Little Andamans and Car Nicobar are also responsible for this.

The vertical distribution of dissolved oxygen is depicted in *figure 3a*. Surface oxygen concentrations ranged between 210 and 230 $\mu\text{mol kg}^{-1}$. Higher concentrations observed in the Bay of Bengal could be attributed to higher rates of primary production. Low concentrations (20–60 $\mu\text{mol kg}^{-1}$) observed in the subsurface waters in the study region were due to combined effect of consumption of oxygen during the decomposition of organic matter and entrance of oxygen poor intermediate water

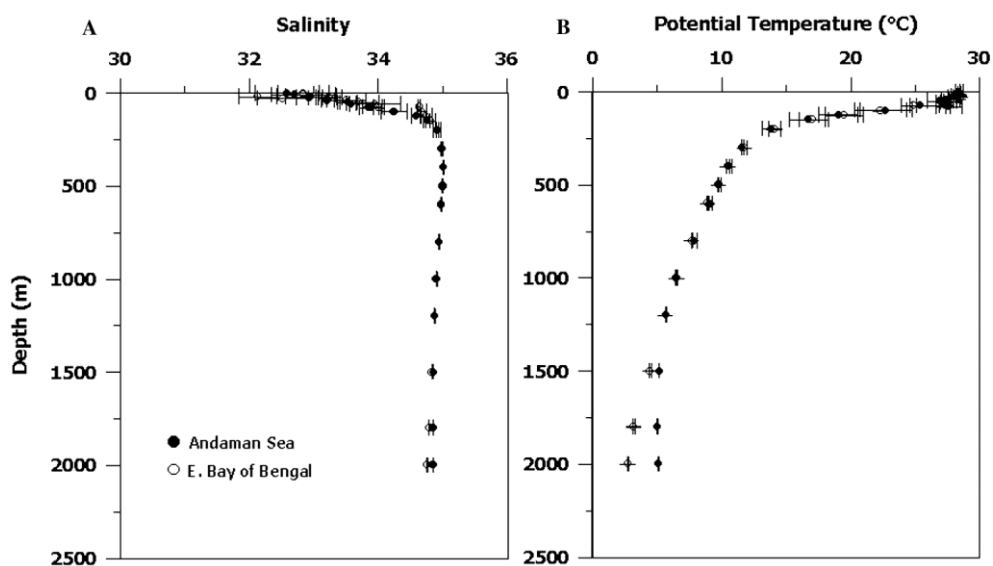


Figure 2. Depthwise averaged vertical distribution of salinity (a) and potential temperature (b) in the eastern Bay of Bengal and Andaman Sea. The variations in data points at each depth are shown as horizontal bars.

masses. Lower oxygen concentrations in 100–400 m depth range in the Andaman Sea compared to Bay of Bengal (*figure 3a*) could be due to higher rates of regeneration in the former (Mathew and Pillai, 1990). However, in subsurface waters, the oxygen concentrations were higher than in the central Arabian Sea (near zero to $10 \mu\text{mol}$) and the central Bay of Bengal ($10\text{--}20 \mu\text{mol}$; de Souza et al., 1996; George et al., 1994; Naqvi et al., 1994; Sarma, 1999). The vertical distribution of oxygen in the Andaman Sea up to a depth 1200 m is comparable to that in the Bay of Bengal, but the water below this depth showed no significant variability and had similar oxygen levels as the waters at 1000 m. In the deeper parts of the Bay of Bengal these concentrations increased from $70 \mu\text{mol kg}^{-1}$ at 1200 m to $120 \mu\text{mol kg}^{-1}$ at 2000 m. This may be due to central basin of the Andaman Sea is cut off from its northern and southern regions by shallow sills that restrict the exchange of deep waters effectively. This has resulted in relatively stagnant waters with low oxygen concentrations in the deep Andaman Sea. In addition, higher temperatures of deep waters could also have contributed to this by decreasing the solubility of gas.

Figure 3b depicts vertical distribution of nitrate in the Bay of Bengal and Andaman Sea. Nitrate concentrations were below detection limits in surface waters that appeared from a depth of 50 m, indicating the possible formation of secondary chlorophyll maxima. Gomes et al. (1992) observed that low but uniform chlorophyll con-

centration (0.1 to 0.5 mg m^{-3}) were observed in the upper 35 m whereas these were 0.24 to 1.8 mg m^{-3} below this depth. This type of distribution was attributed to poor vertical mixing caused by permanent stratification in the Andaman Sea leading to severe depletion of nitrate and phosphate in the mixed layer (Sen Gupta and Naqvi, 1984).

Unlike in the Arabian Sea, nitrate increased with depth up to 2000 m with no subsurface minima (*figure 3b*). Moreover, no denitrification was observed, as evidenced by the absence of secondary nitrite. However, primary nitrite of $0.01\text{--}0.7 \mu\text{mol kg}^{-1}$ was observed at 20–50 m in the Bay of Bengal while it was $0.02\text{--}0.4 \mu\text{mol kg}^{-1}$ in the Andaman Sea in the depth range of 50–100 m. Higher nitrate concentrations ($6\text{--}8 \mu\text{mol}$) were observed throughout the water column in the Andaman Sea as compared to the eastern Bay of Bengal, which is in agreement with oxygen distribution which is comparatively lower in the former sea (*figure 3a*).

In contrast to dissolved oxygen and nitrate, vertical distribution of silicate also showed a similar kind of discrepancy in the deeper waters of the Andaman Sea (*figure 4*). Silicate is considered to be a semi-conservative property. It is low in the surface but increases with depth with no intermediate maxima or minima. This is, in general, due to dissolution of siliceous skeletal material that increases with pressure. On the other hand, silicate concentrations in the Andaman

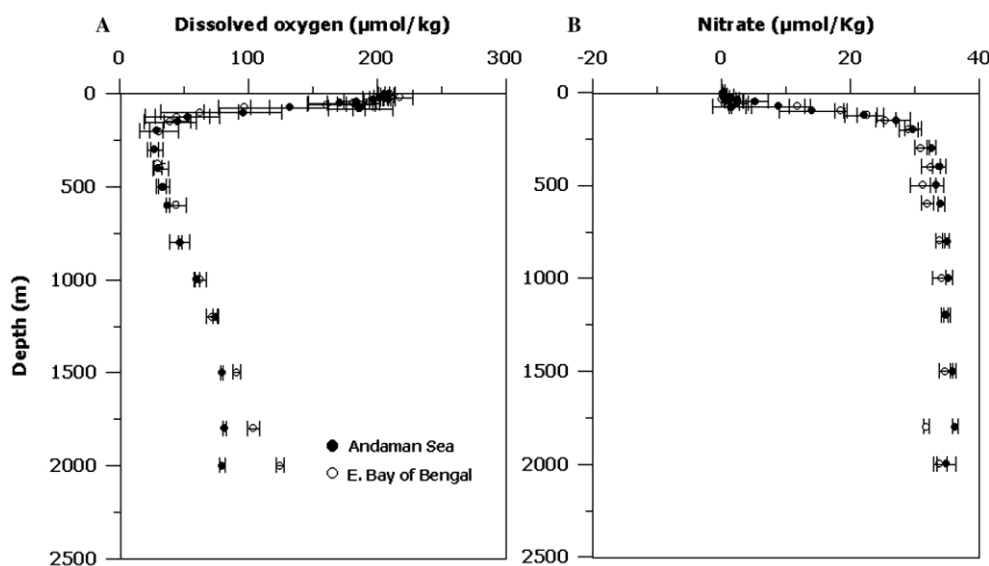


Figure 3. Depthwise averaged vertical distribution of dissolved oxygen (a) and nitrate (b) in the eastern Bay of Bengal and Andaman Sea.

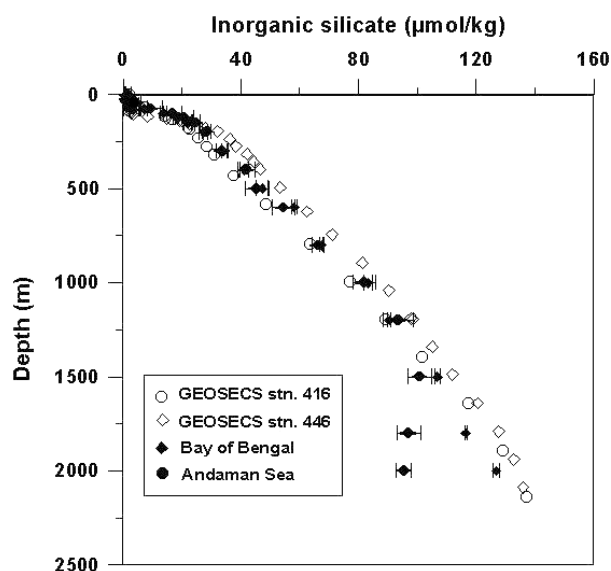


Figure 4. Depthwise averaged vertical distribution of inorganic silicate in the eastern Bay of Bengal, Andaman Sea and Geosecs stations 416 (Arabian Sea) and 446 (Bay of Bengal).

Sea increased with depth up to 1200 m and no significant variations were observed below this depth. A comparison of vertical distribution of silicate was made using Geosecs data in the Arabian Sea (station 416), Bay of Bengal (station 446) and Andaman Sea (*figure 4*). This figure shows that silicate concentrations are lower in the Ara-

bian Sea than in the Bay of Bengal and silicate distribution in the Andaman Sea is comparable with that in the Bay of Bengal only up to depth of 1200 m. The higher concentrations observed in the surface waters of the Andaman Sea might have been derived from the Irrawady–Salween system. However, the concentrations in the deeper waters of the Andaman Sea, particularly at depths below 1200 m, were lower by 40 μmol compared to those in the Arabian Sea and Bay of Bengal. This was again due to separation of the two deep basins restricting the exchange of waters through the Preparis Channel (Sen Gupta et al., 1981).

In order to understand the behaviour of carbon components under this unique setup, pH, total alkalinity, $p\text{CO}_2$, carbonates and their controlling factors were studied. *Figure 5a* shows the distribution of pH_T in the Bay of Bengal and Andaman Sea. Typical pH_T structure in the sea shows higher pH_T values at the surface, which is caused by consumption of carbon dioxide during primary production (Redfield et al., 1963). The pH_T values decreased in the subsurface layers due to release of CO_2 during decomposition of organic matter (Anderson and Dyrssen, 1994) and then increased with depth below the apparent oxygen utilization maximum. Unlike in other regions of the northern Indian Ocean, pH_T in the Andaman Sea decreased up to a depth of 2000 m which is well below the depth of apparent oxygen utilization maximum

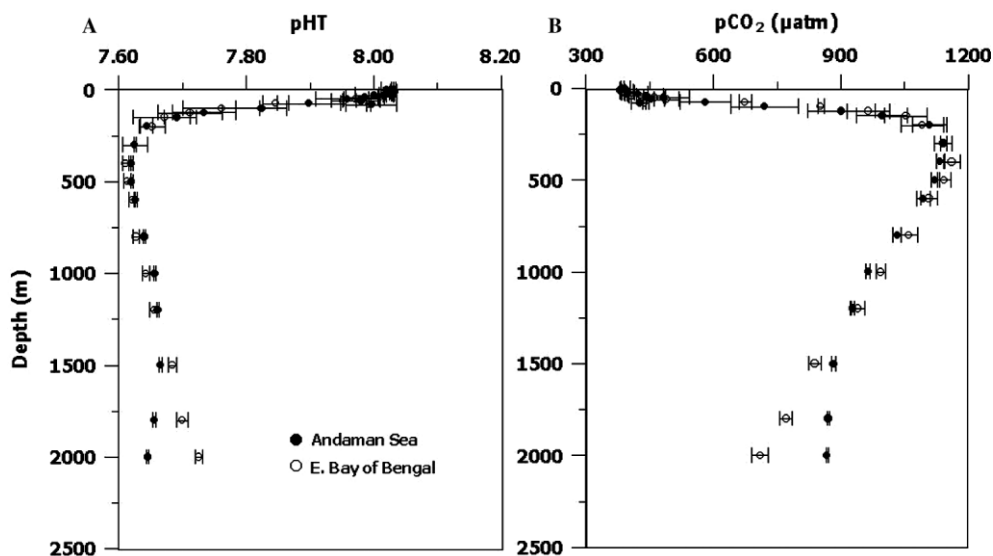


Figure 5. Depthwise averaged vertical distribution of pH_T (a) and $p\text{CO}_2$ (b) in the eastern Bay of Bengal and Andaman Sea.

(~1000 m). Surface pH_T values were > 8.00 in both the seas whereas in the subsurface layers the pH_T values were 7.65 and 7.70 in the eastern Bay of Bengal and Andaman Sea respectively (*figure 5a*). The pH_T in the Andaman Sea is comparable with Bay of Bengal waters in the depth range of 200–1200 m. However, lower pH_T values observed in the deep waters of the Andaman Sea were most likely due to the shift in the carbonate equilibria from carbonate to aqueous carbon dioxide at higher temperatures. As expected from the surface salinity distributions, lower concentrations of TA were observed in the surface layer system in both Andaman Sea and the eastern Bay of Bengal due to dilution by the Irrawady–Salween river system (*figure 6a*). The surface TA concentrations ranged between 2100–2120 $\mu\text{mol kg}^{-1}$ and 2120–2160 $\mu\text{mol kg}^{-1}$ in the Bay of Bengal and Andaman Sea, respectively. However, the TA in both these regions was much lower than in the central Bay of Bengal and Arabian Sea (Sarma, 1999), which is largely due to the influence of fresh waters. The vertical distribution of TA (*figure 6a*) shows that there is a large gradient from the surface to a depth of 200 m (2120–2300 $\mu\text{mol kg}^{-1}$), which is larger than those found in either the Arabian Sea or the Bay of Bengal. Below the gradient the increase in concentration with depth was very low ($< 20 \mu\text{mol kg}^{-1}$) due to the small salinity gradient (< 0.3). The surface waters are also depleted in TA because of the precipitation of calcium carbonate by foraminifera, pteropods, and coccolithophoridae in the euphotic zone that gives rise to carbonate

pump (Sabine et al., 1995). When these organisms die, their tests sink into waters that are under saturated with respect to the carbonate mineral phase of their skeletons. In the deep, dissolution of skeletal material takes place because of high pressures. Unlike in the Arabian Sea, no subsurface minimum in TA was observed in the Andaman Sea due to lower decomposition rates (Mathew and Pillai, 1990; Sarma, 1999). There was no difference in TA profiles up to a depth of 1200 m in Andaman Sea and Bay of Bengal. Below this depth (1200 m), however, the Andaman Sea was filled with the Bay of Bengal waters that showed total alkalinity of 2365 $\mu\text{mol kg}^{-1}$. For comparison, the increase in the Bay of Bengal was up to 2405 $\mu\text{mol kg}^{-1}$ at 2000 m. Although, carbonate dissolution decreases due to higher temperatures in the deep waters of the Andaman Sea, low TA might have resulted from low pH_T that leads to a shift in the equilibrium from carbonates to bicarbonates and to aqueous carbon dioxide. In order to eliminate the water mass effect, TA is normalized to a constant salinity of 35 and plotted against depth as shown in *figure 6b*. Normalized total alkalinity (NTA) varied within a narrow range (2280 to 2420 $\mu\text{mol kg}^{-1}$) at all depths in both the seas suggests less biological influence on TA . However, deep waters of the Andaman Sea appear to contain lower NTA than the Bay of Bengal, revealing no water mass effect on it. The lower concentrations of TA are therefore manifestation of the poor exchange of waters with the Bay of Bengal that leads to a shift in the carbonate equilibrium.

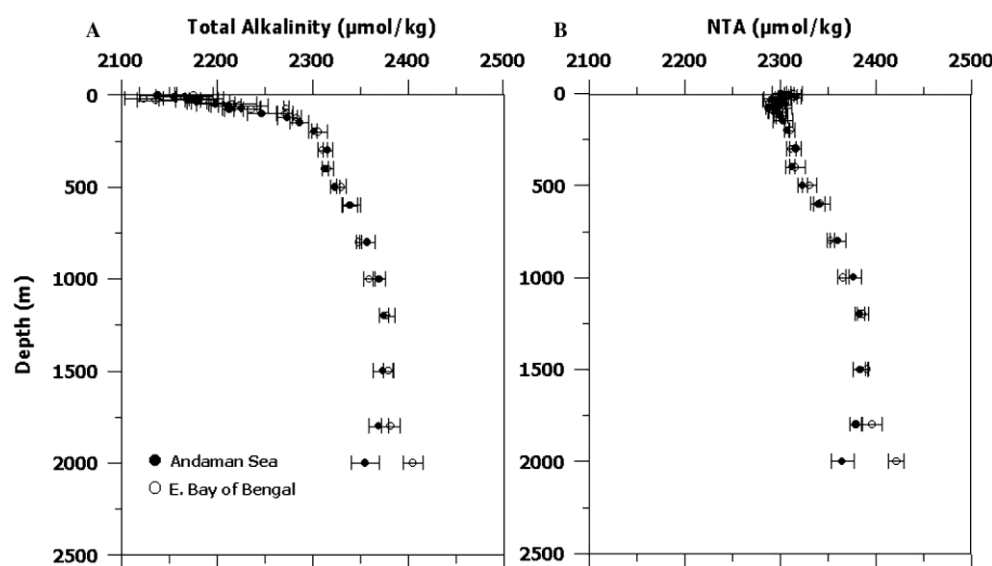


Figure 6. Depthwise averaged vertical distribution of total alkalinity (a) and normalized total alkalinity (b) in the eastern Bay of Bengal and Andaman Sea.

The pCO_2 levels computed using the TA and pH_T , were higher at the surface (362 to 479 μatm) than the atmospheric value of 356 μatm (figure 5b). Surface pCO_2 levels are almost similar in both the Andaman Sea and Bay of Bengal. Up to a depth of 1200 m, relatively higher levels of pCO_2 (by 20 μatm) were observed in the Bay of Bengal than in the Andaman Sea. In the subsurface waters, higher concentrations (1100–1180 μatm) were observed in the Bay of Bengal whereas > 1100 μatm were noticed in the Andaman Sea. This could be the result of higher rates of organic matter decomposition in the former region. Deeper waters of the Andaman Sea contained pCO_2 levels higher by ~ 200 μatm than in the Bay of Bengal. This can be attributed to the combined effect of warmer waters (by 2°C) in the deeper parts of the Andaman Sea and the effect of the Bay of Bengal intermediate waters. The former effect leads to a change in equilibrium constants resulting from high water temperatures that favours the formation of aqueous carbon dioxide. Added to this is the effect on the solubility of CO_2 that decreases with increase in temperature (Weiss, 1974). Furthermore, there is an increase in pCO_2 due to the deep Arabian Sea waters having a source in the intermediate waters of Bay of Bengal, which have higher pCO_2 levels. This effect could also be seen in the lower oxygen levels and higher temperatures of the deep Andaman Sea when compared with the Bay of Bengal waters at similar depths.

In order to understand the influence of physical and biological processes on TA distribution, the same was examined for relationships with temperature, salinity, pH and apparent oxygen utilization in the Andaman Sea and

Bay of Bengal. Despite the precipitation of calcium carbonate in surface waters and subsequent dissolution of skeletal in the deep, TA behaved in a near conservative manner (figure 7a). There is a break in the relation at a salinity of ~ 35.00 that marks the boundary for river water influence (figure 7a). The increase in TA with decrease in salinity indicates the effect of dissolution in the deep. The relations with salinity are in excellent agreement with the Bay of Bengal trends noted by Takahashi et al. (1982) based on limited data from the Geosecs expedition. The potential temperature to TA relation shows three different trends. The rapid increase in TA from 29°C to 25°C represents removal of carbonates by biological organisms in the surface layers. On the other hand, a slow increase in TA up to 10°C (this corresponds to 400 m depth) followed by a rapid increase was found (figure 7b). The slow increase in subsurface layers (200–400 m) was due to the dissolution of aragonites, which are sensitive at low pH_T . It was observed that aragonite saturation depth lies at 500 m in the Arabian Sea (Mintrop et al., 1998; Millero et al., 1998) and Bay of Bengal (George et al., 1994). The rapid increase at increased depths is attributed to dissolution of carbonates due to increase in pressure. The deeper waters of the eastern Bay of Bengal contained higher TA than the Andaman Sea (figure 7b). In order to understand the influence of biological processes on TA distribution, normalised total alkalinity was plotted against pH_T and apparent oxygen utilization (figure 8a and b). The TA relation with pH_T yields three distinct trends in the mixed layer, subsurface waters and deeper layers of the Bay of Bengal and the Andaman Sea. The NTA in the surface waters showed no correlation with

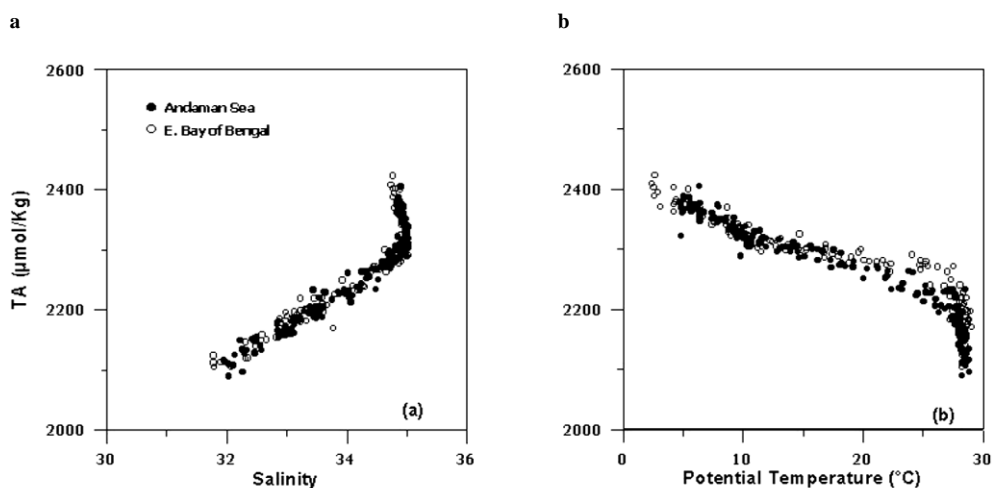


Figure 7. Relation of total alkalinity with salinity (a) and potential temperature (b).

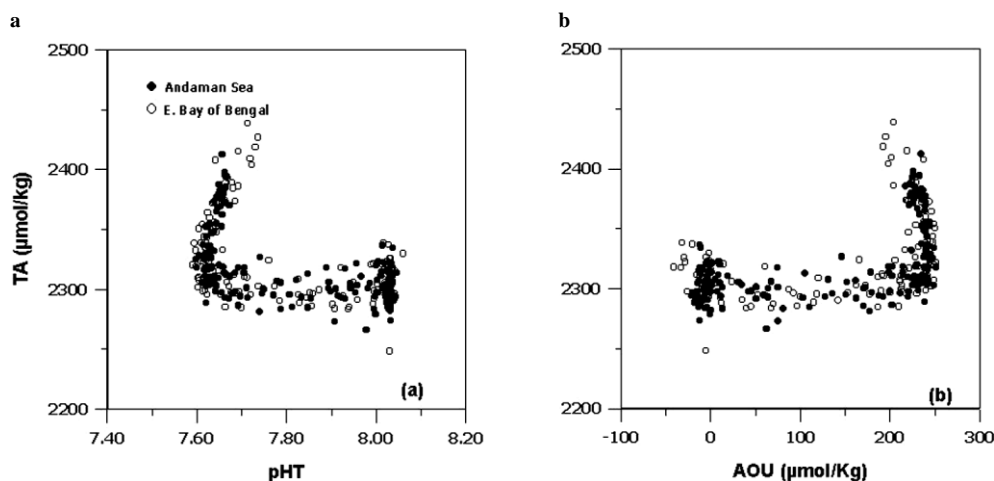


Figure 8. Relation of total alkalinity with pH_T (a) and apparent oxygen utilization (b).

pH_T , which could be due to the combined effect of dilution with fresh waters that have characteristic low pH_T , and with the biological production that leads to higher pH_T . On the contrary, very weak positive correlation is seen in the subsurface waters of both the Andaman Sea and Bay of Bengal. In spite of the expected rise in NTA due to aragonite dissolution, its decrease in sub-oxic waters was influenced by the release of protons during organic matter regeneration. As a result of competition between these two processes, the change in NTA is very small (figure 8a). The third trend is representative of deep waters with lower pH_T . Here, the pH_T variations are not so great but NTA increases due to dissolution of calcium carbonate at increased pressure. This is well supported by the relation observed between NTA and apparent oxygen utilization, which is but a mirror image of that between NTA and pH_T (figure 8b). Although, biochemical influence is significant in the subsurface waters, other relations near the surface and in the deep were largely controlled by physical processes.

3.1. Carbonate solubility

In order to evaluate the dissolution of calcite and aragonite minerals, the carbonate ion (CO_3^{2-}) concentration was plotted against depth. The saturation of carbonate ion concentrations was estimated using the equations of Mucci (1983) and Millero (1979) that take into account the effect of pressure on the solubility products of aragonite and calcite (figure 9). The surface waters of the Andaman Sea and eastern Bay of Bengal are supersatu-

rated with respect to both calcite and aragonite as in the case of Arabian Sea and Bay of Bengal (George et al., 1994). The change-over from supersaturation to undersaturation of aragonite occurred at 300 m in the eastern Bay of Bengal and Andaman Sea. It is reported that aragonite saturation depth lies around 500 m in the Arabian Sea (Mintrop et al., 1998; Millero et al., 1998) and in the central and western Bay of Bengal (George et

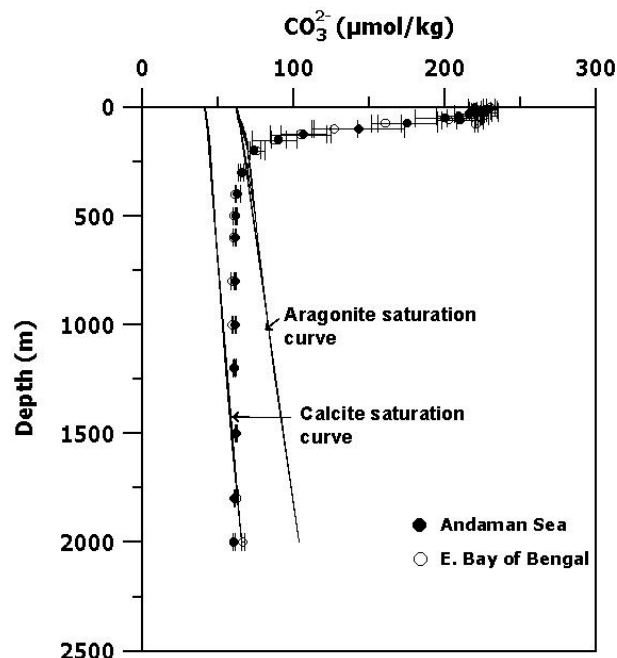


Figure 9. Depthwise averaged vertical distribution of carbonates and aragonite and calcite saturation depths.

al., 1994). However, calcite saturation depth lies at 1500 m in the northern Arabian Sea and it is much deeper in the Bay of Bengal (George et al., 1994). The deep water seems to be generally at near-equilibrium with calcite in the eastern Bay of Bengal, but Andaman Sea waters were found to be under saturated with respect to this mineral at depths exceeding 1500 m. The only explanations for this could be the higher temperature of the deep waters of Andaman Sea that leads to shifts in the carbonate equilibrium towards formation of aqueous carbon dioxide, although in turn, calcium carbonate dissolution decreases at higher temperatures.

4. CONCLUSIONS

The vertical distributions of temperature and salinity in the northeastern part of the Bay of Bengal are similar to that of in the Andaman Sea down to 700–800 m. However, at depths below 1200 m, salinity remained constant at 34.90 in the Andaman Sea and in the eastern Bay of Bengal it decreased to 34.80 and further with depth. Moreover, deep waters (> 1200 m) of the Andaman Sea are warmer than those of the Bay of Bengal by $\sim 2^\circ\text{C}$. Compared to the Andaman Sea the dissolved oxygen concentrations in the suboxic zone at mid-depths are higher in the Bay of Bengal. In the deeper waters of the Andaman Sea the dissolved oxygen concentrations are considerably lower. This decrease is because the deep Andaman Sea waters have a source in the intermediate waters of the Bay of Bengal, which have low dissolved oxygen. Although no denitrification was observed in the study region, nitrate concentrations are lower in the Bay of Bengal than in the Andaman Sea due to less intense regeneration in the former. *TA* and *NTA* distributions also conform to the effect of warm waters in the deep Andaman Sea that results in a shift in the carbonate equilibrium in favour of the formation of aqueous carbon dioxide. In addition to this, Bay of Bengal intermediate waters, as a source of the Andaman Sea deep waters, are also responsible for the increase in $p\text{CO}_2$ levels. As a result, $p\text{CO}_2$ is higher by 150–200 μatm in the deep waters of the Andaman Sea. In the Andaman Sea, aragonite saturation depth occurred at ~ 300 m whereas calcite was under saturated at 1500 m. The relations with physical and biological parameters revealed that *TA* behaved mostly conservatively in the Andaman Sea and this behaviour was controlled mainly by physical rather than biochemical processes.

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