Dissolved Oxygen and Carbonate-Carbon Dioxide in the Sea Water of the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia

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ABSTRACT

Dissolved oxygen and carbonate system in seawater in the Gulf of Thailand and the east coast of Peninsular Malaysiain September 1995 and April-May 1996 were determined. It was found that surface water was well in equilibrium with the atmosphere. The sub-pycnocline water in the Gulf had the chemistry that was distinctly different from the mixed layer as well as from sub-pycnocline water in the South China Sea near the mouth of the Gulf, even with the same depth. There were some evidences that intermediate water in the South China Sea might flow into the Gulf along the central axis and the coast of Vietnam and Cambodia, and exited the Gulf along the Thai-Malay Peninsular coast. The chemistry of deep water in the South China Sea off the coast of Western Malaysia varied its chemistry by a great deal among seasons which might be due to the prevailing monsoon. Seawater in the Gulf of Thailand and South China Sea was supersaturated with respected to the mineral calcite.

Key words: dissolved oxygen, carbonate system, mineral calcite, Gulf of Thailand, Peninsular Malaysia, South China Sea

Introduction

Oxygen and carbon dioxide play very important roles in the metabolism of the ecosystem. The concentrations of these two gases in the water are the net results of all processes, namely biological activities, the air-sea exchange, the lateral transport to and from the area under interest, and reactions with solid phases such as calcium carbonate.

Measurement of dissolved oxygen in seawater in the Gulf of Thailand has been done for a long time as one of the routine activities. However, the measurement of dissolved carbon dioxide and carbonate system in the water has been rarely performed since the work by Rao (1964) who pointed out that the total CO_2 in the Gulf of Thailand water was clearly lower than oceanic water with the same temperature and salinity. This could had been due to high primary production. Subsequent work by Snidvongs (1993) in the Upper Gulf of Thailand further confirmed that the total dissolved inorganic carbon (that is mainly bicarbonate plus carbonate) in the water is low (usually about 2.0 mmol/l) but the partial pressure of CO_2 in surface water is usually higher than the partial pressure of CO_2 in the atmosphere of about 360 matm, especially in the area with high terrestrial input of organic material. This was an evidence that led Snidvongs (1993) to conclude that the nearshore water, less than 15 kilometer from shore, of the Gulf of Thailand was heterotrophic, i.e. total respiration exceeded primary production of the ecosystem.

For further understanding of the Gulf of Thailand as a source or sink of atmospheric carbon dioxide, an important anthropogenic greenhouse gas, the carbonate system and its interaction with biological activities, indicated by oxygen production or consumption, have been determined during the SEAFDEC Collaborative Research Cruises.

Methods

The continuous oxygen profile at each station was obtained using the Beckman Polarographic Oxygen electrode connected to the Falmouth Integrated CTD unit on board the M.V. SEAFDEC. The raw data was averaged at every 1 dbar pressure interval. During the first cruise in September 1995, the obtained profiles were calibrated by assuming surface water was at saturation with atmospheric oxygen. However, during the second cruise in April-May 1996, actual calibration was performed at every station by analyzing 4-8 samples of water collected by the rosette at different depths by Winkler Titration. The profile were adjusted to the calibrated value by using regression.

The dissolved carbonate system in seawater was calculated from pH and total alkalinity. Due to the malfunction of *in situ* pH sensor attached to the CTD in both cruises, pH of seawater collected by rosette sampler was measured in the laboratory on board the vessel soon after it was collected. Water samples for total alkalinity determination were filtered to remove suspended carbonate minerals, mainly calcium carbonate skeletons of some plankton and resuspended sediments. Known amount of hydrochloric acid was added to each sample and the final pH was measured. The concentration of excess proton was calculated from the final pH using the activity coefficients given by Parsons *et al.* (1987). The total alkalinity, which is the capacity of the water to neutralize strong acid, was calculated from the total proton added minus those remain the final solution.

The carbonate alkalinity is calculated by subtracting borate alkalinity from total alkalinity assuming total boron concentration of 0.4 mmol/l. The concentration of each species in the carbonate system, which are carbon dioxide, carbonic acid, bicarbonate and carbonate, can be simply obtained by solving the equilibrium equations of these 3 chemical reactions.

$$CO_2(aq) + H_2O \iff H_2CO_3$$

$$H_2CO_3 \iff H^+ + HCO_3^-$$

$$HCO_3^- \iff H^+ + CO_3^{2-}$$

The saturation state of seawater with respect to the mineral calcite (which is a major mineral in the skeleton of many marine organisms) was calculated from the ratio between the actual carbonate concentration in the water and the concentration at equilibrium which is approximately 53 mmol/l. The ratio that is higher than 100% indicates calcite will be precipitated in that water.

Results

Surface concentration of oxygen obtained during the April-May 1996 cruise when actual calibration against Winkler Titration was performed verified the assumptions used during the September 1995 cruise that dissolved oxygen in surface water was at equilibrium with the atmosphere and the slope (or sensitivity) of the sensor was near 100%. This finding reinforce our confidence to accept the results from both cruises.

Mid depth concentration of oxygen above the pycnocline which is usually situated at about 40m are very close to the saturation of about 4.3 ml/l except two locations off Songkhla and Kota Bahru where slightly low concentration of oxygen was found in both cruises (Fig. 1b and 2b).

Oxygen concentrations in sub-pycnocline deep water of the Gulf (more than 40 m, Fig. 1 and 2) were clearly lower than surface water as well as lower than bottom water in the South China Sea near the mouth of the Gulf. This is a very important finding because it indicate the total respiration that exceed primary production in the Gulf bottom water, but the opposite might occur in the South China Sea. Organic materials net respiration in the bottom water of the Gulf could have been imported from the South China Sea as well as from the nearby land mass. Deep water along the east coast appeared to have higher concentration than the west coast for both seasons indicating new water from the South China Sea might have entered he Gulf along the northeast shore. This deep water could have left the Gulf along the Thai-Malay Peninsular in September when low oxygen deep water was found. The low oxygen water off the coast of Peninsular Malaysia occurred only in September, the month after the period when the area was protected from the Southwest monsoon but not in April-

May when the Northeast monsoon could accelerate the general circulation of the area.

Considering the precision of the determination of the carbonate system of about ±5 % we would conclude that the partial pressure of carbon dioxide gas in surface water during both cruises was not significantly different from the atmospheric partial pressure of about 360 μatm (Fig. 3 and 4). However, in September along the lower Peninsular coast, from Surat Thani to Singapore, the partial pressure of carbon dioxide in the surface water was greater than 400 matm indicating a possibility of a net evasion of carbon dioxide gas from the water to the atmosphere.

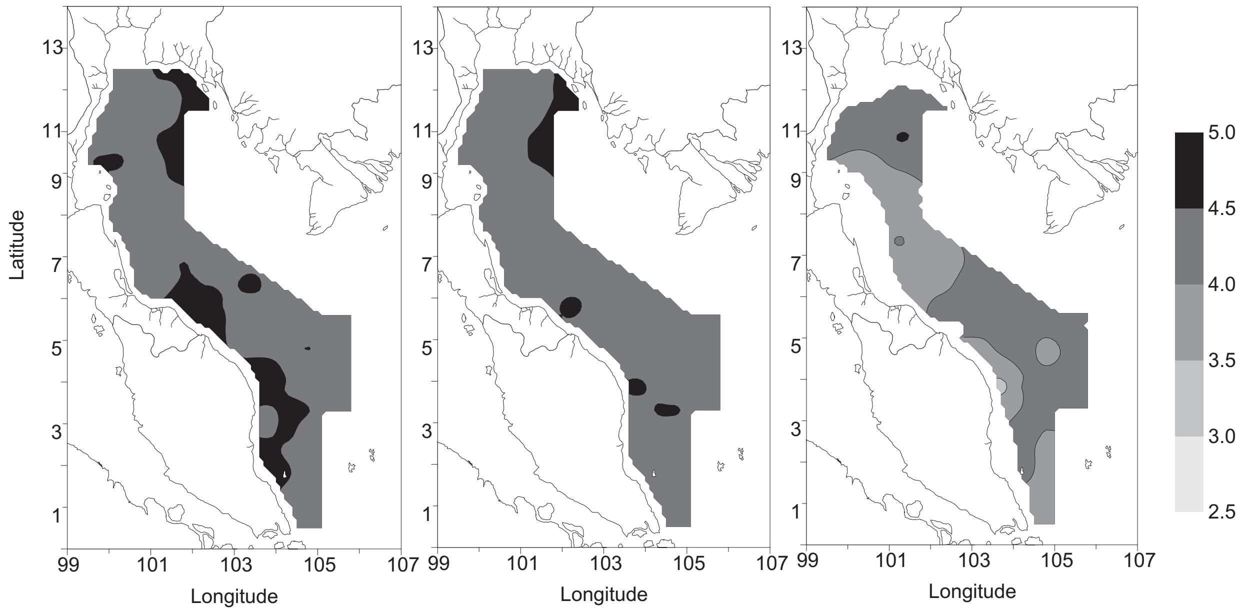

Fig. 1. Dissolved oxygen (ml/l) in the western Gulf of Thailand and eastern Peninsular Malaysia in September 1995; a) Surface level (0-10m), b) Mid-depth level (10-40m), c) Sub pycnocline level (>40m)

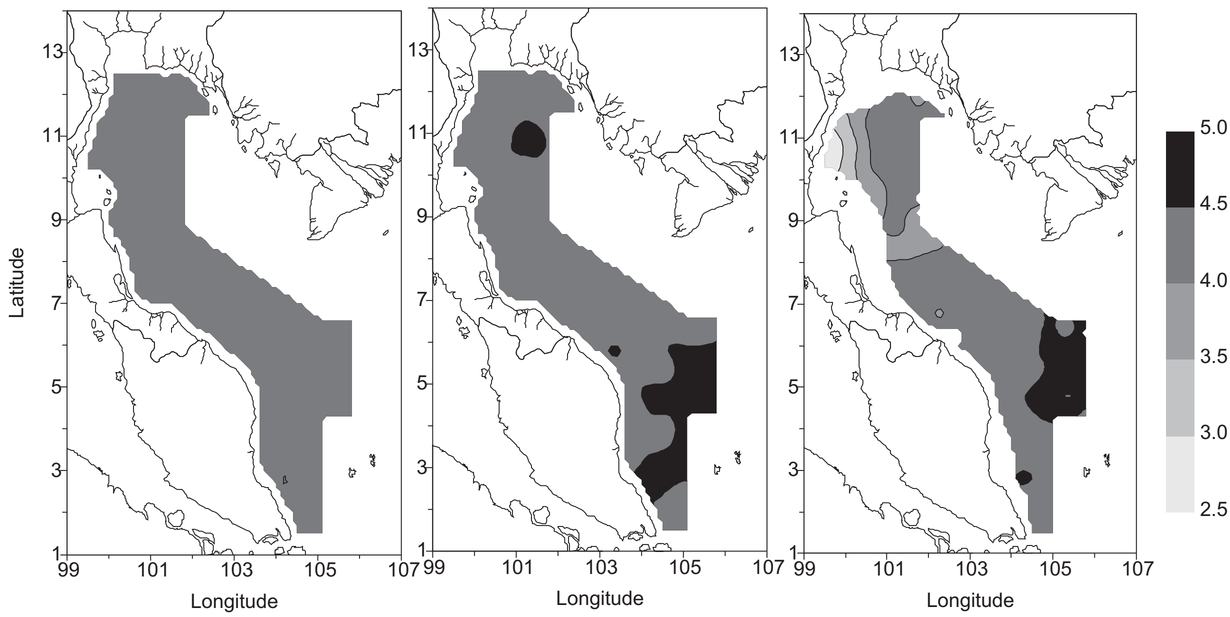

Fig. 2. Dissolved oxygen (ml/l) in the western Gulf of Thailand and eastern Peninsular Malaysia in April-May 1996; a) Surface level (0-10m), b) Mid-depth level (10-40m), c) Sub-pycnocline level (>40m)

The partial pressure of dissolved carbon dioxide in deep sub-pycnocline water showed a very similar pattern to that of dissolved oxygen. Thus confirming our previous conclusion that deep water in the Gulf derived its chemistry as it was aging inside the Gulf.

The water in this study area was supersaturated with respect to calcite throughout the year and at all depths (Fig. 5 and 6). However surface water was more supersaturate (up to 500%) than mid-depth and deep water. Calcite dissolution will not take place in the water column of the Gulf of Thailand.

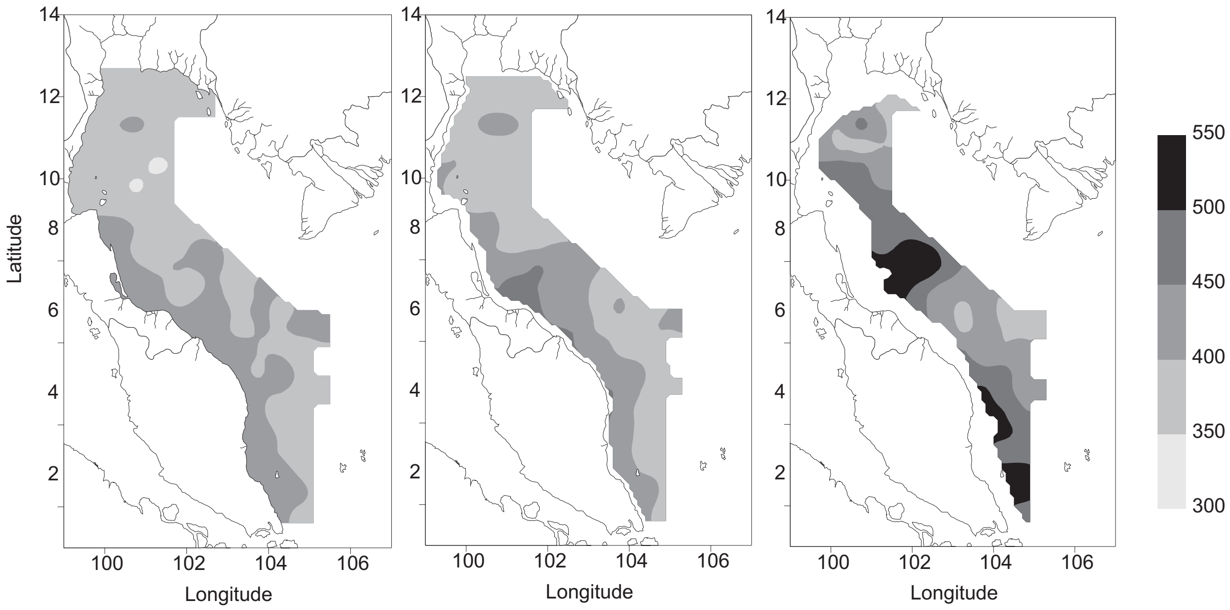

Fig. 3. Partial pressure of dissolved carbon dioxide (μatm) in the western Gulf of Thailand and eastern Peninsular Malaysia in September 1995; a) Surface level (0-10m), b) Mid-depth level (10-40m) and c) Sub-pycnocline level (>40m)

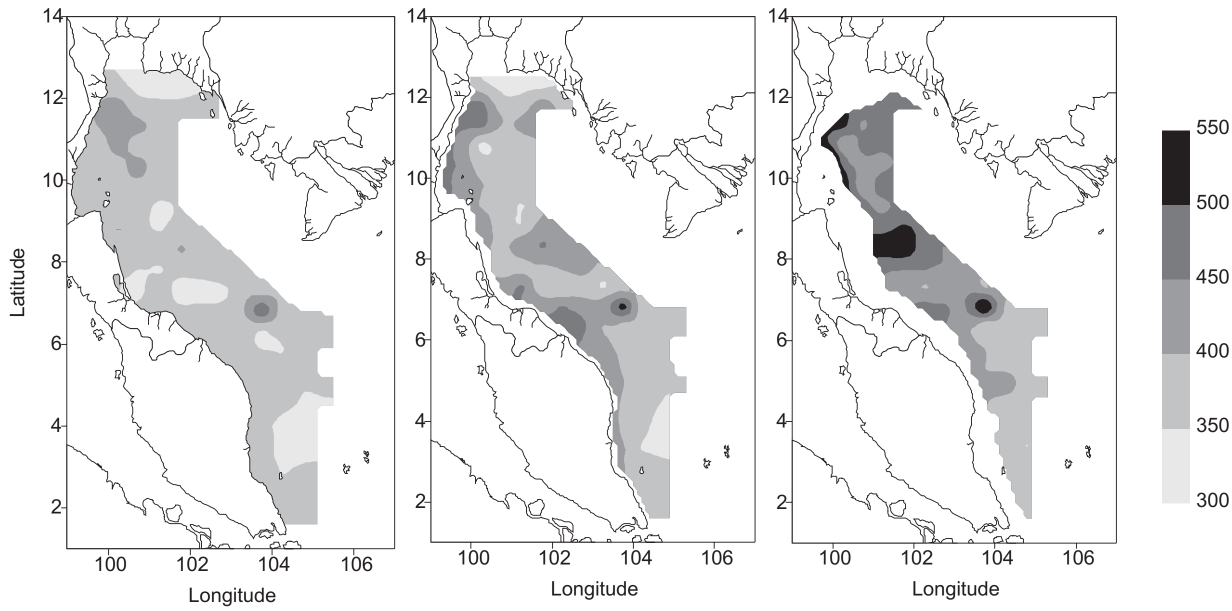

Fig. 4. Partial pressure of dissolved carbon dioxide (μatm) in the western Gulf ofThailand and eastern Peninsular Malaysia in April-May 1996; Surface level (0-10m) Mid-depth level (10-40m) Sub-pycnocline level (>40m)

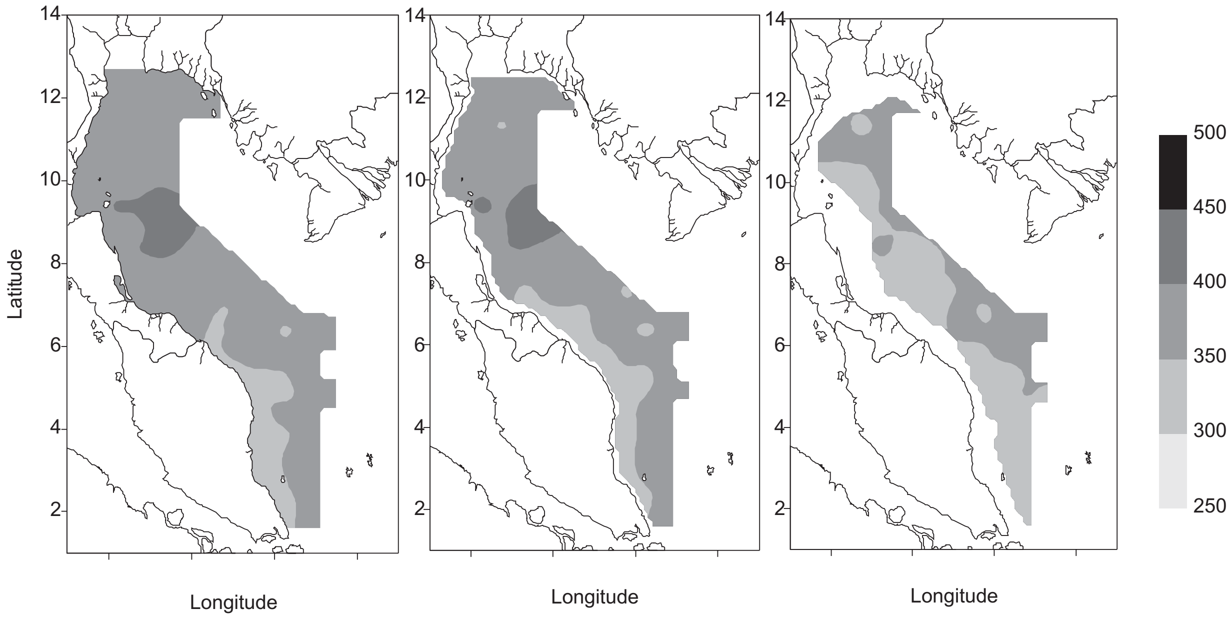

Fig. 5. Saturation state of seawater with respect to calcite in the western Gulf of Thailand and eastern Peninsular Malaysia in September 1995; a) Surface level (0-10m), b) Mid-depth level (10-40m) and c) Sub-pycnocline level (>40m)

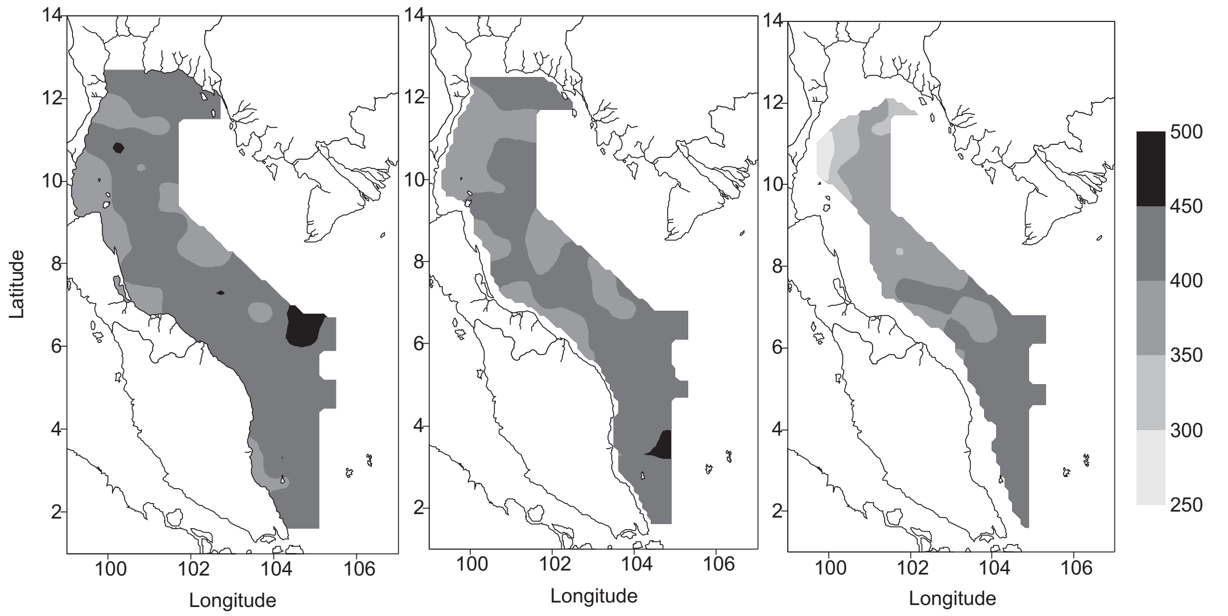

Fig. 6. Saturation state of seawater with respect to calcite in the western Gulf of Thailand and eastern Peninsular Malaysia in April-May 1996; a) Surface level (0-10m), b) Mid-depth level (10-40m) and c) Sub-pycnocline level (>40m).

Conclusions

1) With respect to dissolved oxygen and carbon dioxide gases, surface water in the Gulf of Thailandand the east coast of Peninsular Malaysia was in equilibrium with the atmosphere.
2) Sub-pycnocline water in the Gulf had the chemistry that was modified by the net respiration of organic matters.
3) Apparently deep water exited the Gulf via a near shore along the Thai-Malay Peninsular at least during the Southwest monsoon Period.
4) Sub-pycnocline water in the South China Sea off the east coast of Peninsular Malaysia varied its chemistry by a great deal between seasons which might be due to the prevailing monsoon.
5) Seawater in the study area was supersaturated up to 500% with respect to mineral calcite throughout the year.

References

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