Some Physical and Chemical Characteristics of Bottom Sediments in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia

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ABSTRACT

Investigations on horizontal and vertical distribution in levels of total organic matter contents (TOM), acid volatile sulfides contents (AVS), and water contents (WC) of bottom sediments from the eastern and western parts of the Gulf of Thailand and the eastern part of the Peninsular Malaysia have been carried out during 5-28 September 1995 and 24 April to 17 May 1996 by M.V. SEAFDEC. The overall results indicated comparatively low amount of organic matters and sulfides deposited in the sediments. Considering on the vertical profiles, coupled efforts of low rate of sedimentation of the organic matters and high rate of their decomposition should play an important role providing fast diagenesis of their organic substances. Nevertheless, the particulate matters which had settled onto the sea bed and formed the sediments can be remarkably observed to accumulate in two major zones in the Gulf of Thailand; one in the central part of the upper gulf (around Station 7) and another one in the western part of the gulf, near Samui Island (around Station 23). Such an accumulation pattern was considered to be directly controlled by the bottom topography and current effort. The accumulation of organic materials there also implied the mode of biological fishery resources. High abundant of organisms in the benthic community should be observed. Moreover, according to biogeochemical interaction between the sediment-water interface, phytoplankton production in the overlying water column should be enhanced and, consequently, a congregation of organisms in the upper trophic levels especially those of fish species were accordingly expected. Future assessment for development of the fishery resources in the Gulf of Thailand and the eastern part of Peninsular Malaysia has been discussed.

Introduction

Sediments are known to be the key to ancient and historical environments. A sequence of sedimentary layers can tell us about environmental changes over time (Hallberg, 1992). The recent sedimentary record can reveal cultural impacts on the environments during the industrial era. During formation and diagenesis, the sediments also take an active part in the biogeochemical cycles of the elements which affect the overlying water column.

Studies on bottom sediments of the Gulf of Thailand have been carried out by a number of scientists (eg. Brown et al., 1951, Emery and Niino, 1963, Windom et al., 1982, Takahashi et al., 1984, Kasemsupaya, 1986, Dharmvanij, 1987, and Snidvongs, 1993). Almost of researches in the former time had concentrated in the area closed to the river mouths or in the upper Gulf of Thailand. Studies on discharge of suspended particles from major rivers and geological composition of sediments were firstly carried out. Brown et al. (1951) and Windom et al. (1982) suggested that suspended particles from the rivers were mostly settled within the upper gulf. Sediments there were mostly reported to be clay to clayed sand (Umnuay, 1984) with some silt with apparent brown color discharged from the rivers (Yamamoto and Yada, 1982, Yada et al., 1982). In the upper gulf, organic carbon contents of sediments had been examined to be higher in the sediments with finer grains, and range in the levels of 0.3-1.6 % (Umnuay, 1982). Attempt to determine vertical gradients of organic carbon and carbonate contents in sediments was done by Snidvongs (1993). Accodingly, a high degree of organic decomposition was suggested although the profiles illustrated remarkedly variations. Few research studies of bottom sediment had been conducted in the middle part (Takahashi et al., 1984), the eastern part (Kasemsupaya, 1986, Sanguansin, 1989), and the western part (Sompongchaiyakul, 1989) of the Gulf of Thaland. Levels of organic carbon contents in these whole area were reported to be in the wide range of 0.5-2.5 %.

This research study of sediment was the first attempt which covered largest surveyed areas from the upper to the lower part of the Gulf of Thailand. It was carried as one subproject under the Collaborative Research Project between SEAFDEC'-s Training Department (TD) in Thailand and the Marine Fisheries Resource Development and Management Department (MFRDMD) in Malaysia. Objective of this research was to collect up-to-date sediment information concerning on the marine fishery resources and the present oceanographic conditions in the sea area for suitable development of fishery resource scheme of the South China Sea.

Investigations on some physical and chemical characteristics of bottom sediments have been throroughly carried out in the sea areas around the East and the West Coasts of the Gulf of Thailand and in the East Coast of the Peninsular Malaysia. In this study, distribution patterns, both in horizontal and vertical aspects, of water contents, acid volatile sulfides contents, and total organic contents of core sediments have been illustrated. Information obtained from these sediment modes have been consequently discussed in view points of fishery resources and related environmental situations for further application purpose in promotion of the fishery resources in the sea area.

Materials and Methods

Collection of sediment samples

The sediment samples were collected from 81 stations in the Gulf of Thailand and the East Coast of Peninsular Malaysia during 5-28 September 1995 and 24 April to 17 May 1996 by M.V. SEAFDEC. The map of the sampling locations has been illustrated in Figure 1. Since the purpose of collecting the samples was to obtain an accurate presentation of the nature of the bottom sediment in the study area, the sampler used in this project was thus a gravity corer which can collect a cross section of sediments, thereby providing materials for determination of both horizontal and vertical distributions of parameters.

The corer consists of a hollow metal with ca 100 cm in length and ca 6 cm in diameter in which contains easily removable plastic liners (core tubes; 85 cm long and 5.2 cm inner diameter) which fit into a core barrel and retains the sediment sample. The piston mounted on the top of the core barrel was opened and allows water to flow through the barrel during descent, but shut upon penetration of the corer into the sediment. The tip was a core cutter for better penetration of the sampler and the stabilizing fins situated in the upper part to assure vertical descent of the corer.

During application, the gravity corer was lowered to the depth of about 2 m above the sediment surface. From that depth, it was let to sink freely to penetrate the bottom. At least two sedimental cores were sampled from each sampling station. In addition, sediment grab was applied in stead of the corer in few stations in which the bottom was mainly composed of sand and gravels that was unable to retrieve by the corer.

Subsampling of sedimental cores

Prior to subsampling, measurement of sediment surface temperature was immediately conducted. Then the appearances of the sediment core were recorded for the length of the core, the consistency (for example described as soupy, soft, medium firm, firm, stiff, loose, packed), the texture (for example described as gravel, sand, silt, clay, silt clay or sandy clay), the presence of organic matter, shells and coarse fragments with description of their size and type, the sediment odor (for example odorless or chemical odor such as chlorine, petroleum, sulfurous, or decaying organic odor), the appearance of oil, coal dust, or ash, the presence of carbonate and the occurrence of fauna. The cores was subsampled as soon as possible after retrieval of the core. After the overlying water was calmly suctioned off, the sediment core was extruded out of the liner and subsampled into 2-cm sections for the upper 10 cm depth and 3-cm sections for the depth of more than 10 cm. The sectioned sediment samples were packed tightly in prepared containers and immediately frozen under -60 °-C until further analysis.

Analysis of sediment samples

Laboratory analyses were performed in the Laboratory of Aquatic Environments and Biochemistry, Department of Fishery Biology, Faculty of Fisheries, Kasetsart University. Determination of total organic matters (TOM) in the sediments was performed by measuring the weight loss of dry sediment after ignition in the furnace heater at 750 °-C for 3 hours.

The levels of acid volatile sulfides (AVS; $H_2S+FeS+FeS_2$) contents of the sediments and the percentages of water contents of each sediment sample had been examined simultaneously. After the sediment was defrozen, the levels of AVS contents had been immediately measured on the sediments by acidifying with 18 N H_2SO_4. Evaporated H_2S gas was consequently trapped in the H_2S-absorbent column (Gastec Model 201L, Kagawa Science Ltd., Japan) as the procedure according to Tsutsumi and Kikuchi (1983). The levels of AVS were expressed in the unit of milligram AVS per gram (dry weight) of the analyzed sediments. The model of AVS test columns that had been used can provide a minimum significant value of 0.001 mg AVS per gram dry weight of the test samples.

The percentages of water content of the sediment samples had been determined from weight reduction by drying wet sediments in heater oven under 60 °-C for at least 3 days.

Results

The sedimental cores had been collected from 81 stations with various water depths (Fig. 2). Depths of the cores obtained from the gravity core sampler were varied upon types of deposits in each location. The bottom sediments in which consisted of particles with large grain size e.g. sand and gravel usually provided short sedimental cores with sometimes less than 10 cm, whereas those of fine grain provided comparatively longer cores of more than 30 cm. Preliminary observation of core structure indicated that coarse material, such as sand and gravels, settled almost in the nearshore zone of the Peninsular, and fine-grained particles, such as silt and clay, usually deposited in waters with restricted current in the central part of the gulf and in the locations near Samui Island. The colors of sediment were depended on the type of deposits. Sandy sediments commonly appeared to be yellowish brown, whereas the muddy deposits appeared to be greenish gray to dull gray. Oxidized layer of the sediment surface can be distinguishably observed from almost all stations. Many fragments of sea shells were also found in the sediment cores from almost all stations as well.

The contour graphs of total organic matter contents (TOM), acid volatile sulfide contents (AVS), and water contents (WC) illustrating horizontal distributions of physical and chemical characteristics of surface sediments were showed in Figs. 3-7, respectively.

The levels of TOM were determined only for the sediments collected during April 1996. Generally, TOM levels were lower than 10 % on the basis of dry weight. The maximum TOM of 15.4 % was found at the sediment surface (0-2 cm) of Station 17. The levels in the surface of Station 23 was also in comparatively high level of 14.5 %, whereas those in Station 1 indicated the lowest value of 3.1 %. The contours graphs of TOM (Fig. 3) clearly depicted the pattern of organic accumulation in which the organic particles settled down to form the sediments were majorily observed in the two zones of the Gulf of Thailand; one in the central part of the upper gulf and another one in the western part, near Samui Island.

The levels of AVS contents in the surface (0-2 cm) sediments from the Gulf of Thailand and the eastern part of Peninsular Malaysia were almost in extremely low to non-detectable values of less than 0.001 mg/g (Fig. 4-5). Comparatively high levels of AVS were found from the sediments located around Samui Island and adjacent areas (Stations 23, 24 and 30). Some stations closed to the

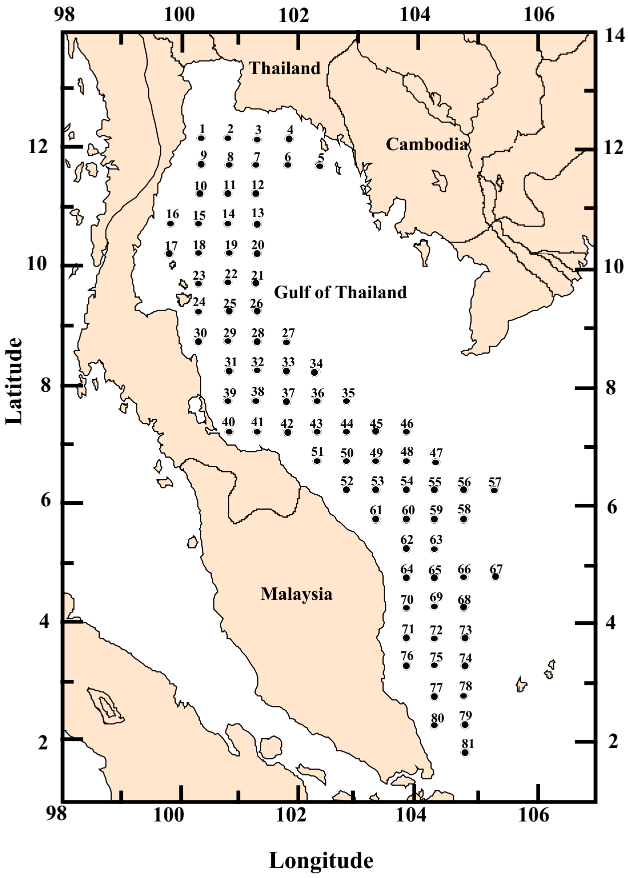

Fig. 1. Sampling stations located in the western part of the Gulf of Thailand and the eastern part of the Penisular Malaysia

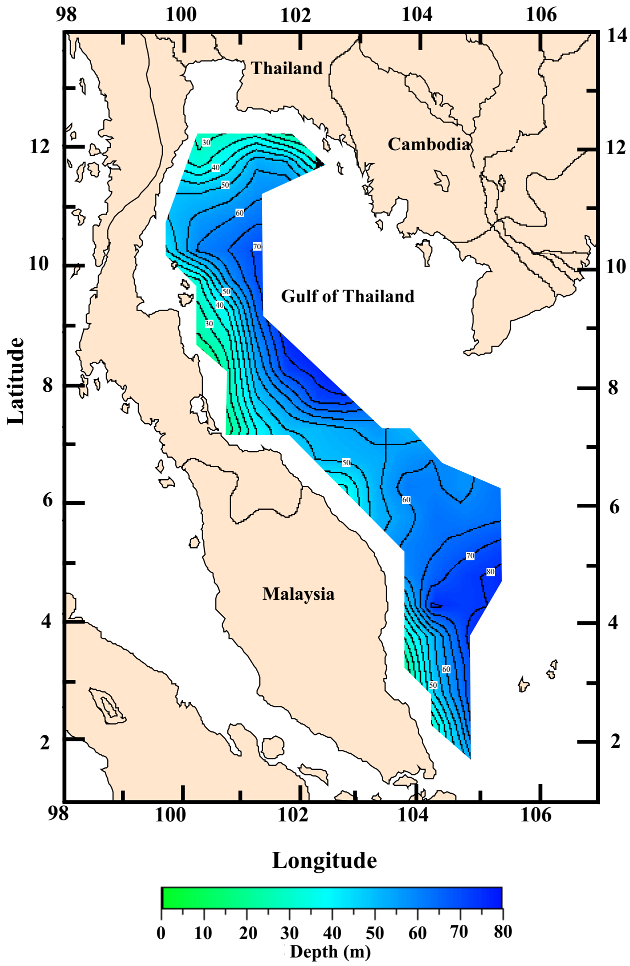

Fig. 2. Contour graph illustrating the depths of seawater in the study area

shore line (e.g. Station 40, near Songkhla Province) also showed comparatively higher levels of AVS when compared to those located in the central part of the gulf. In these stations, main compositions of the bottom deposits are mud with quite fine particles. The highest levels of AVS contents in the sediment (0.228 mg/g) were found from Station 23. In this station, the sediment had distinguish smell of rotten gas (hydrogen sulfides) even when the corer had been retrieved from the sea. The levels of AVS in the sediments of the stations situated in the eastern part of Peninsular Malaysia were extremely low in which almost of them were below the levels of 0.001 mg/g to zero mg/g. These characteristics corresponded with the TOM data and reflected the comparatively low levels of organic compositions in the sediments.

Horizontal distribution of the levels of WC contents in the surface (0-2 cm) sediments from the Gulf of Thailand and the eastern part of Peninsular Malaysia were depicted as contour graphs in various sediment depths (Fig. 6-7). The pattern of WC distribution corresponded to those of the TOM. Comparatively high WC levels were found from the two zones of organic accumulation. From the observation of the sediment types, we found that mean WC in each group of different sediments were quite separated. In three types of the deposits the are mud, sandy mud to muddy sand, and sand, mean WC were gradually decreased from 58.73 %, to 44.06 %, and 33.04 %, respectively, for the first survey data, and from 59.02 %, to 44.63 %, and 39.04 %, respectively, for the second survey data. The bottom deposits containing great compositions of fine grain like mud deposits showed distinguish higher levels of WC than those containing the sandy particles. Therefore, the levels of WC can be possibly utilized as a parameter determination the granulometric components of the sea bed. Overview from the whole WC data also reflected the typical bottom characteristics that were mainly composed of the muddy deposits in the upper half and the sandy deposits in the lower half of the gulf. This meant that finer particles were accumulated much more in the Gulf of Thailand (Stations 1-44) and larger particles were found commonly in the eastern part of the Peninsular Malaysia. Such pattern of deposition had revealed that their environment of deposition were different.

Data on WC in the surface sediments reflected that the two major zones of locations in which the decreases in WC of their sediments (0-2 cm) had been apparently occurred during the temporal change of the sampling tenure from September 1995 to the period during April 1996. The first major zone was composed of the sediments in Stations 7 and adjacent stations which situated in the inner part of the Gulf of Thailand. These observed stations somewhat lied on a "-circular pattern"- in the middle of the gulf. The second major zone was composed of stations which situated just near the shore line along the east coast of lower part of Thailand, downwards to some areas in the eastern part of the Peninsular Malaysia. Among these groups of stations, the WC in surface sediments had been decreased more than ca 10 % from the first record data in September 1995. On the contrary, there were three distinguish stations (Stations 2, 24, and 80) in which the WC of the surface sediments had increased more than 7 % after the Northeast monsoon had passed the areas. Station 2 situated in the innermost part of the Gulf of Thailand, whereas Station 24 situated near Samui Island in the Southern part, and Station 80 was a near shore station at the end part of the Peninsular Malaysia. Such a decrease or increase in the levels of WC of the surface sediments here might reveal that there had somewhat monsoon effort on the bottom deposits.

Vertical distribution of the sediment characteristics

From the first survey of the Gulf of Thailand and the Western Peninsular Malaysia in September 1995, two sedimental cores had been collected from each station. In total of 80 stations, each duplicate of cores obtained were almost the same. We found some apparent differences of the obtained cores only from Stations 10 and 20. In those cores, the one was muddy clay deposit which was quite homogeneously throughout the column, whereas the other one was composed of sandy mud deposits in the upper ca 10 cm depth and turned to be harder clay deposit in the lower part. Since the differences of two cores from one station had been found only from 2 surveyed stations, percentage of confidence for the obtained core from each station was thus estimated to be about 98%. This meant that the sedimental core obtained from each station can be an appropriate representative of the bottom deposit in the designated area.

The levels of TOM in various depths were slightly fluctuated. A few decreases of TOM as the sediment depth had been found in Stations 5, 6 (Figs. 9), and 37 (Fig. 10) which constituted less than 5 % of the investigated sedimental cores from the whole area. However, such decreases were not apparent. More than 75% of analyzed sediments depicted nearly constant values in each layer throughout the sedimental column. The vertcial profiles of TOM from some stations, such as Stations 3, 8, 39, and 42 (Figs. 8-11), indicated comparatively high levels of TOM in the depth of more than ca 10 cm. This occurrence corresponded to the types of deposits in which the upper 10 cm layer was medium to coarse grain of sands but the lower part immediately turned to be fine and hard clayed sediments. Such pattern of deposits covered ca 17 % of the investigated area in the Gulf of Thailand.

Vertical profiles of the AVS contents commonly indicated a comparatively high values in the upper 2-4 cm layers. The AVS levels were somewhat gradually decreased with the increase in depth. However, fluctuation of the levels were possibly observed such as in those of Stations 23 and 30 (Figs. 12-13). Since these stations are situated just near the Island and closed to the shore line, fisherman activities (e.g. fish trawling etc.) were considered to cause such phenomena. Frequent disturbances of the bottom deposit together with comparatively high organic loading from the overlying water column should thus be major cause of such fluctuations.

The contents of water in sediment should indicated the physical properties and mineralogical composition of the bottom deposits. The vertical profiles of the WC in almost cores obtained indicated gradual decrease in the levels as the depth increases. This characteristic is quite normal for

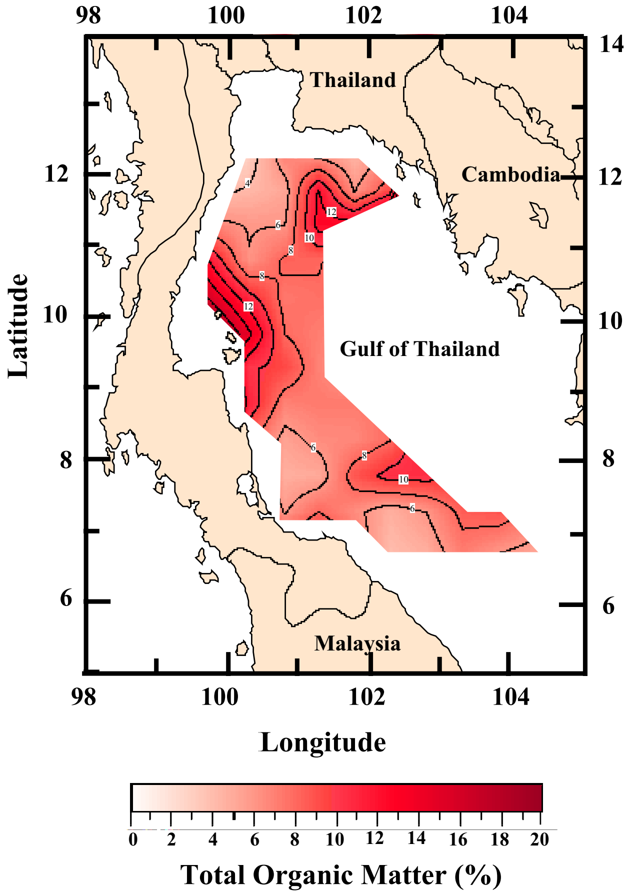

Fig. 3. Holizontal distribution of the levels of total organic matter (TOM) contents of the 0-2 cm sediments collected during April 1996.

well-sorted sedimental deposit. The uppermost 1- to 2-cm layer of the sediment cores often consisted of soft material with a comparatively high WC. The quantity of the sediment in a core tube below the topmost 2-cm layer gradually increased due to the lowered water content and sediment compaction. In fine-grained material, the WC reaches about 70-80 % at 10 cm sediment depth, 60 % at about 20 cm sediment depth, and about 40-50 % at 30 cm depth. The sediment in deeper layer usually became more compacted and their is little change in WC. Almost of the mud deposits to sandy mud deposit showed homogeneous characteristics throughout the column. The WC was thus reduced by the compaction with the depth increase together with the gradual changes in sediment compositions. Anyway, some variations in the profiles of water contents of the sediment, especially from the survey in September 1995 (e.g. Station 10; Fig. 14) could be caused by a mixture of the duplicate cores in which the levels of WC in each sectioned layer had a few differences. Incidentally high water contents in deeper layer also caused by some deposit of wood fragments (e.g. Station 26 from the cruise of September 1995; Fig. 15). Some vertical profiles of WC e.g. from Stations 69, 72 and 78 (Figs. 16-17) showed distinguish characteristics in which the WC become higher in the depth lower than ca 10 cm. In this aspects, the observation of obvious core texture on board have revealed that those cores are composed of two major separate layers of the deposits, the upper layer of above 10 cm depth normally consisted with sandy mud to muddy sand part, while the lower layer turned to be quite sticky clay deposit with finer grain of particles. Such deposits in the lower parts were thus suggested to have comparatively higher ability to retain more water among their grains and the interstitial spaces.

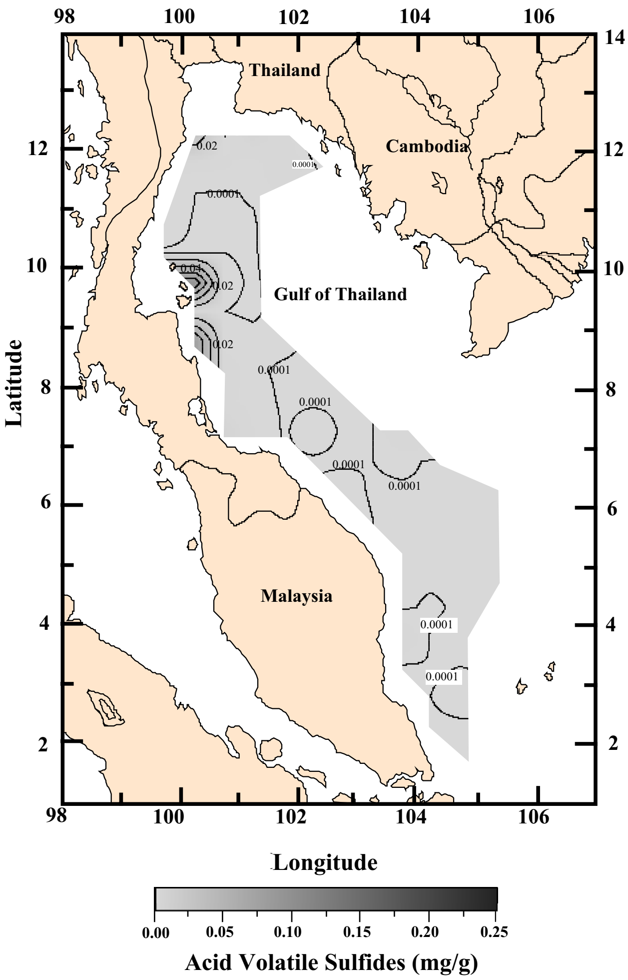

Fig. 4. Horizontal distribution of the levels of acid volatile sulfides (AVS) contents of the 0-2 cm sediments collected during September 1995.

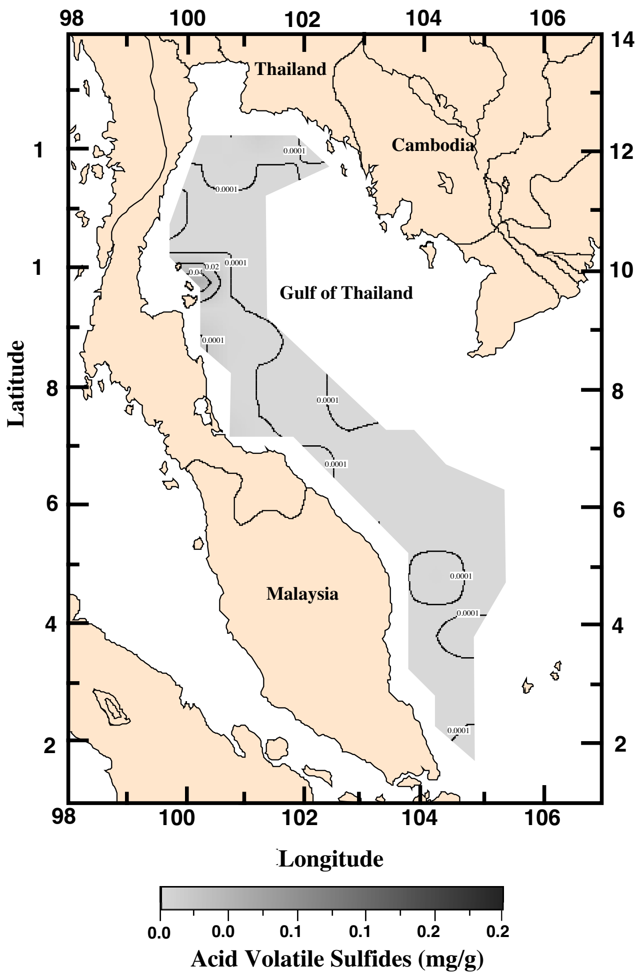

Fig. 5. Horizontal distribution of the levels of acid volatile sulfides (AVS) content of the 0-2 cm sediments collected during April 1996.

Discussion

Evaluation for sediment sources and accumulation

Generally, the natural processes responsible for the formation of bottom sediments in such shallow waters are distinguishably altered by human activities. The erosion of soils is accelerated by the construction of buildings and roadways in nearshore zones. Many man-made compounds in gases, liquid, and solid forms with complex chemical composition and physical properties, have entered the water through atmospheric deposition runoff from the drainage basin or direct discharge into the water. Most hydrophobic organic contaminants, metal compounds, and the nutrients entering water bodies become associated with particulate matter. This particulate matter is carried by currents into quiet areas where it settles and accumulates in bottom sediments (Mudroch and MacKnight, 1994). The sediment particles with differences in sizes, shape, and chemical composition, therefore, were formerly transported by water, or air from the site of their origin in a terrestrial environment and have been deposited on the sea floor. In addition to these sources, bottom sediments also contained materials precipitated from chemical and biological processes in sea water. Accordingly, bottom sediments are thus said to be a sink, as well as a source of substances in aquatic environments.

Previous echo profile study of the bottom topography in the central gulf of Thailand indicated

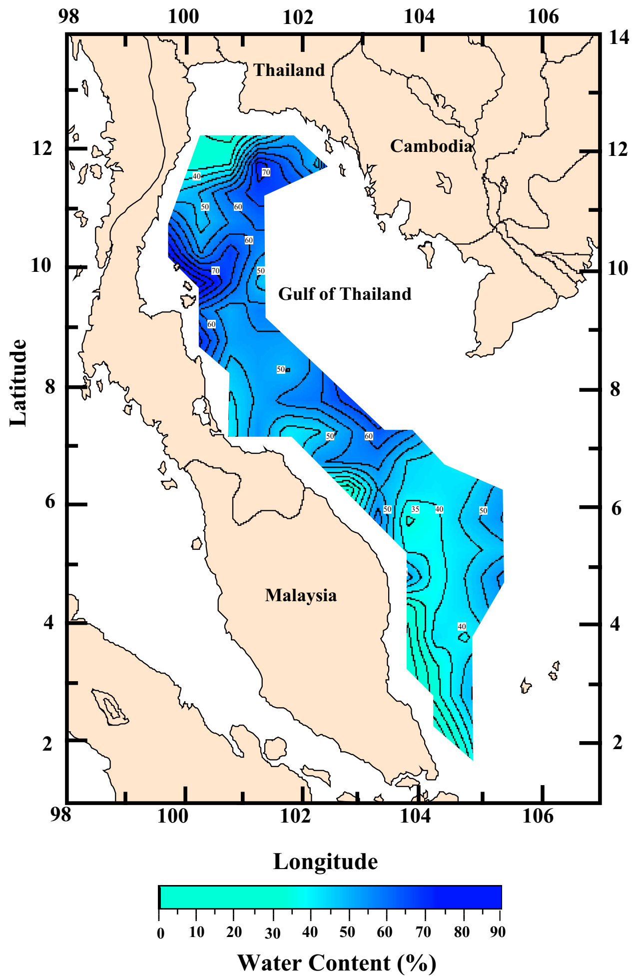

Fig. 6. Horizontal distribution of the levels of water contents (WC) of the 0-2 cm sediments collected during September 1995.

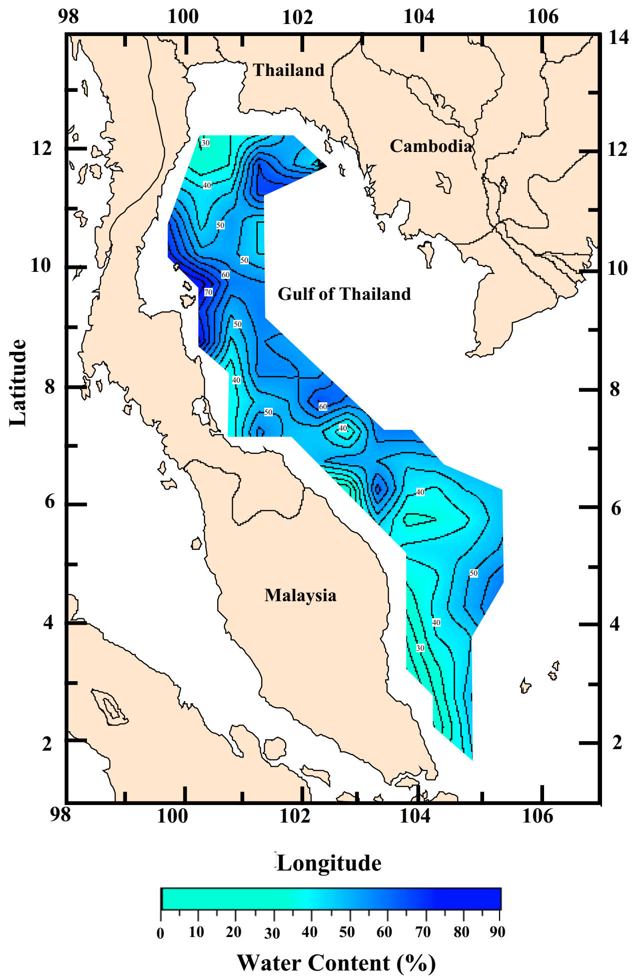

Fig. 7. Horizontal distribution of the levels of water contents (WC) of the 0-2 cm sediments collected during April 1996.

that the sea bed was very irregular (Takashashi et al., 1984). The sediment in the gulf, nevertheless, had been investigated mainly by grab collecting. In the central gulf, the sediments consist with abundant calcareous biogenic remains. Former granolometric study of the sediment indicates that the sediment can be roughly divided into two composition; the sandy clay and the clayed sand. Each type of sediment is characterized by its environmental of deposition which is depended on the distribution of different velocity of water masses and currents. However, there have some studies indicating that the particulate materials loaded from land through the runoff of main rivers were deposited in the inner gulf (Windom et al., 1982). Watanabe et al. (1997) had determined the fate of terrestrial organic matter in the Chao Praya estuary by the use of 13C stable isotope. The results have also revealed that the materials loaded from the river were settled entirely around the river mouth.

In this study, the particulate matters which are settling to the sea bed are remarkably accumulated in two major zones of the Gulf of Thailand; one in the central part of the gulf (around Station 7) and another one in the western part of the gulf, near Samui Island (around Station 23). The sedimental materials in these areas are thus considered to be mostly composed of autochthonous organic matters such as dead phytoplankton which has been produced in the water column and settled onto the sea bed. Allochthonous organic particles originated from other sources such as river runoff and nearshore man-made activity should be entirely settled in the areas just close to the shore line. A study of Meksumpun et al., 1997 (personal communication) on the carbon and nitrogen stable isotope ratios of

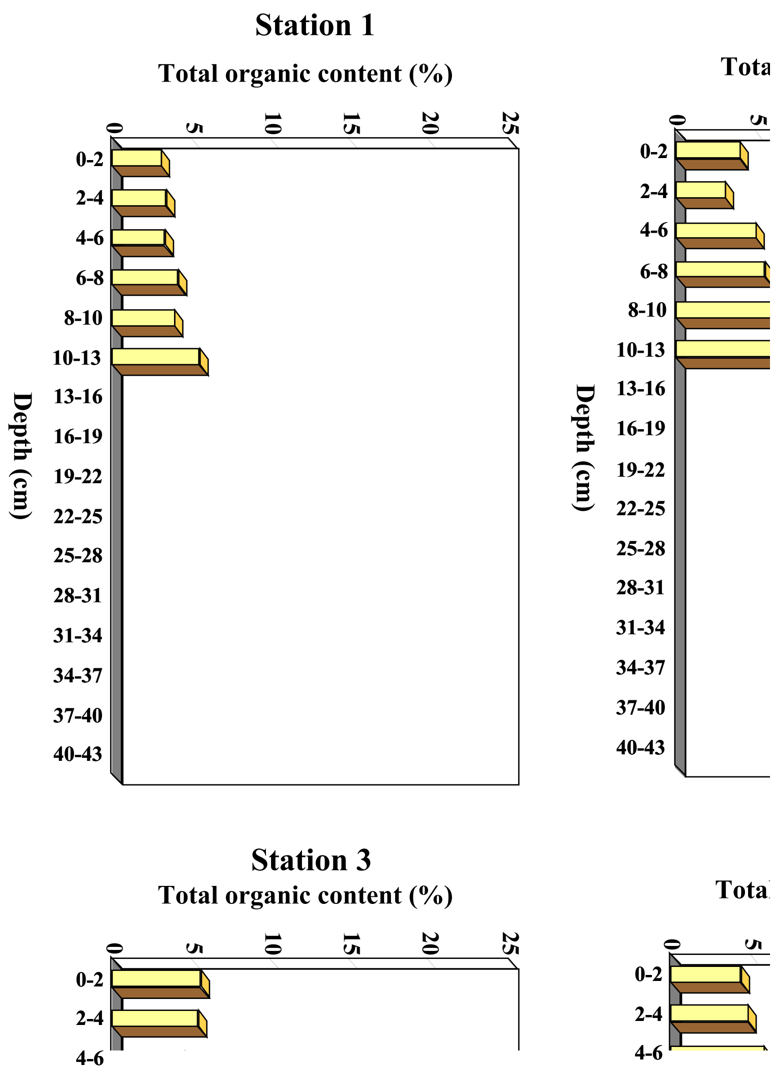

Fig. 8. Vertical profiles of total organic matter (TOM) contents of the sediments from Stations 1-4.

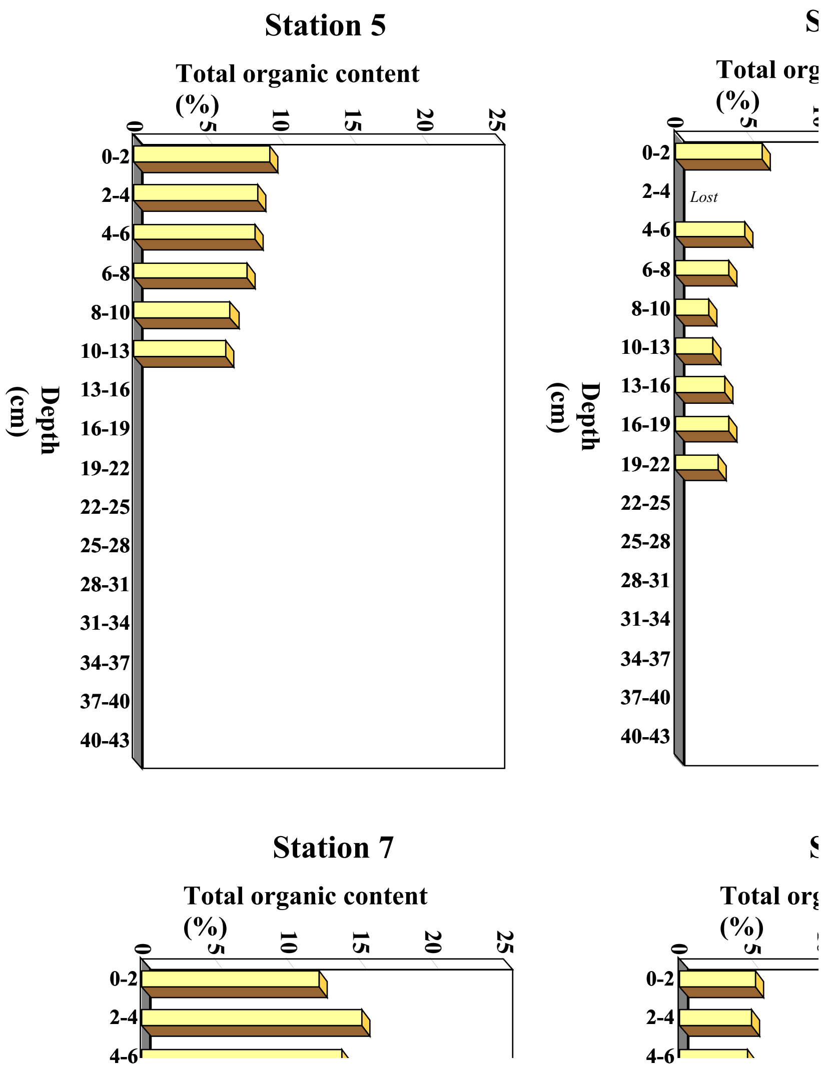

Fig. 9. Vertical profiles of total organic matter (TOM) contents of the sediments from Stations 5-8.

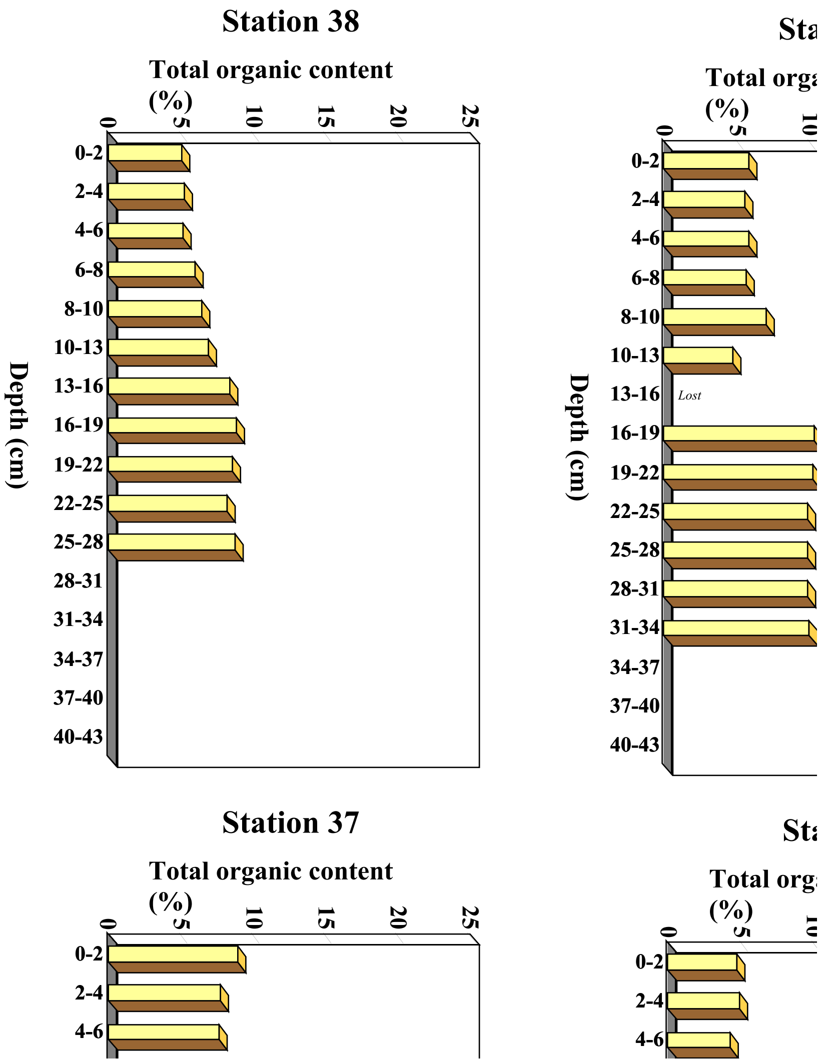

Fig. 10. Vertical profiles of total organic matter (TOM) contents of the sediments from Stations 37-40.

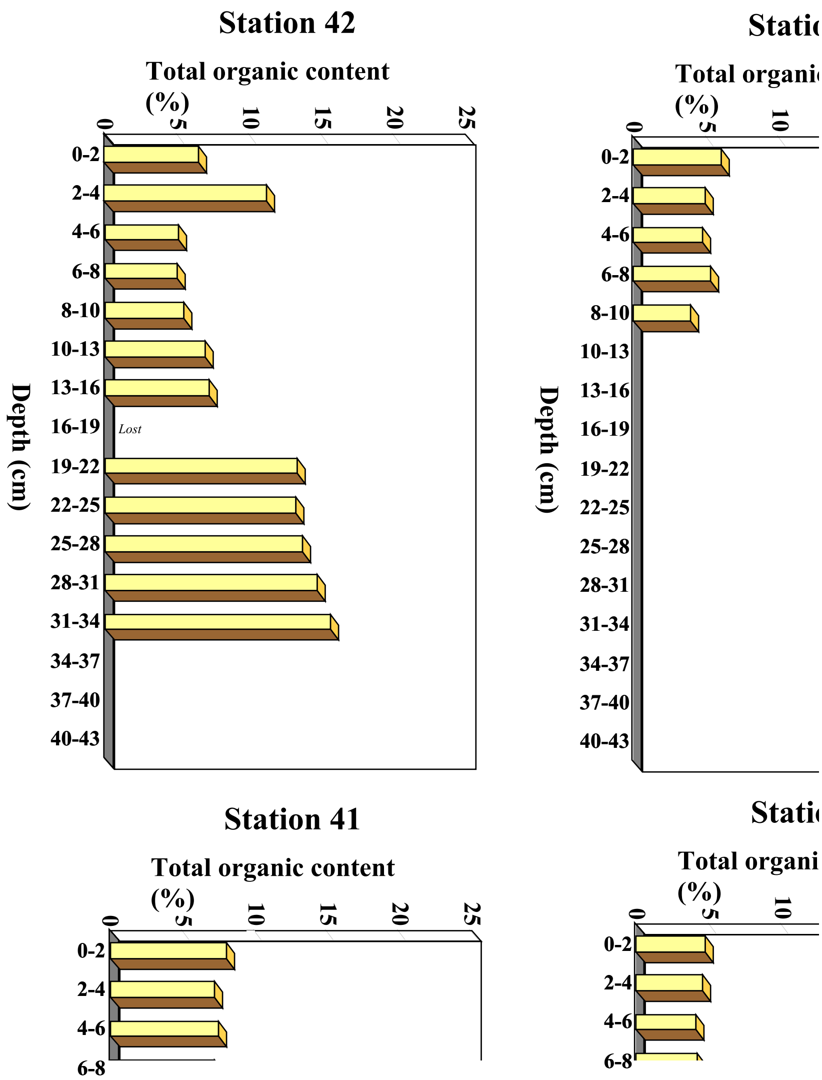

Fig. 11. Vertical profiles of total organic matter (TOM) contents of the sediments from Stations 41-44.

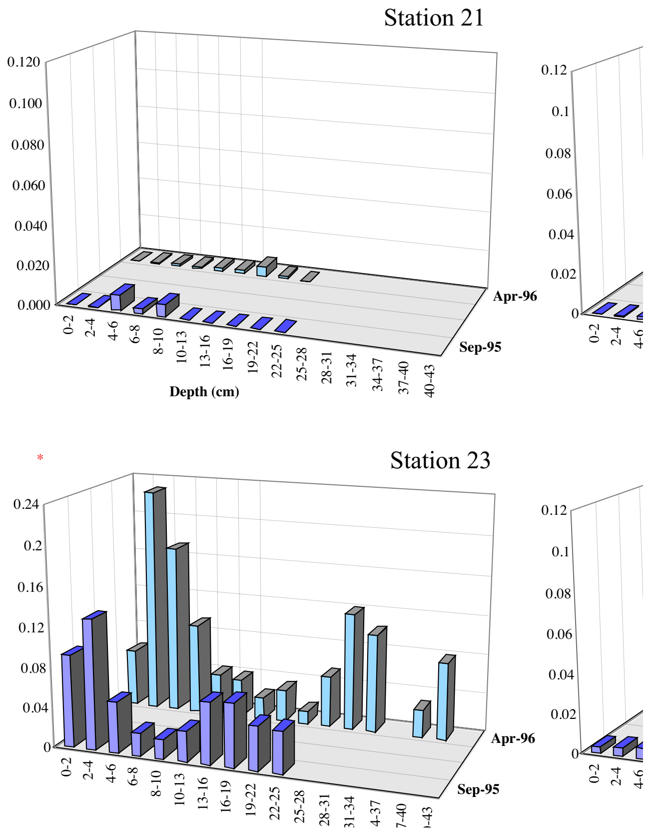

Fig. 12. Vertical profiles of acid volatile sulfides (AVS) contents of the sediments from Stations 21-24.

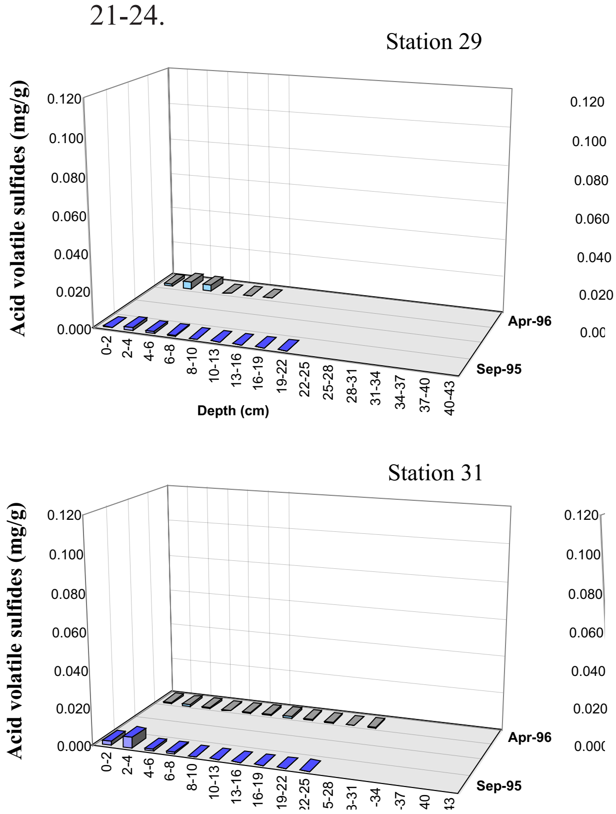

Fig. 13. Vertical profiles of acid volatile sulfides (AVS) contents of the sediments from Stations 27-30.

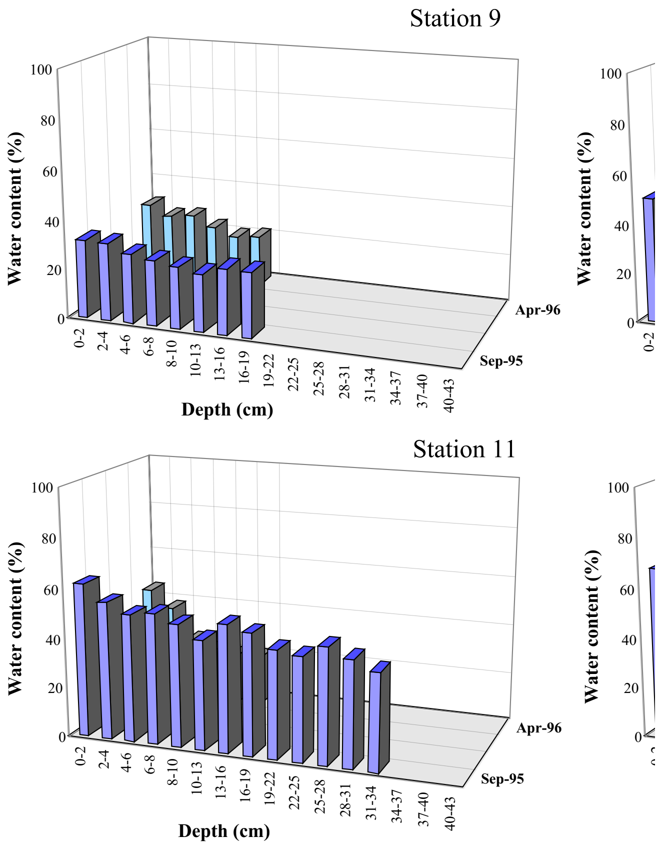

Fig. 14. Vertical profiles of water contents (WC) contents of the sediments from Stations 9-12.

the sediments from the Gulf of Thailand have correspondingly revealed that the sediment in the gulf had nearly similar stable isotope ratios to those of the phytoplankton found in the water column.

Influences of current and geological topography

Distribution of sediment deposits was suggested to be depended upon the distribution of different velocity of water masses and currents (Takahashi et al., 1984) which had preliminary influenced by wind velocity and direction and the topography of the areas. Surface current speed and direction in the Gulf of Thailand and east coast of the Peninsular Malaysia are remarkably influenced by the monsoon. In winter or dry season, the northeastern monsoon from the continent of Asia blows over the sea and correspondingly creates an anti-clockwise monsoon current. In summer or raining season, the Southwestern monsoon blows towards and over the continent so as to initialize the clockwise current.

From the interpretation of WC horizontal distribution data in this study, finer particles were accumulated more in the Gulf of Thailand in which the current velocities were comparatively lower than the areas outside the gulf. Such an accumulation pattern of sedimental materials is considered to be directly controlled by the bottom topography and monsoon-induced current effort in the whole study area. Some former studies show that the velocity of water movement in the central gulf seems to be weak even during the monsoon season. Some illustrated the oceanic fronts of two different water masses occurring in the water off Samui Island. These phenomena are well responded for the pattern of organic accumulation in those areas.

Alternations of bottom deposits should also be depended on the nature of bottom deposits themselves. The bottom deposits have been sorted naturally by the influences of environmental factors and their size together with the kind of the materials. In the nearshore or shallow water areas

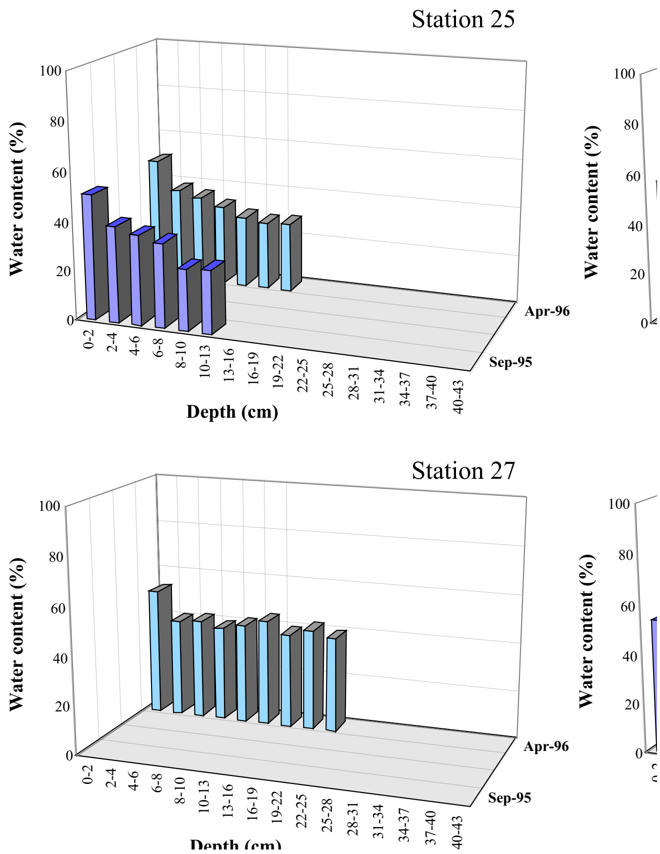

Fig. 15. Vertical profiles of water contents (WC) contents of the sediments from Stations 25-28.

in which there has some effects of wave action, muddy deposits are generally difficult to be alternated or move than the sandy deposits. These are because of the coagulation force among each mud particles. Consequently, sandy bottom with diameter of particles that are easier to be moved should have more apparently alternated than the confirm mud deposits.

Thus, the decrease or increase of the WC found in the first and second surveys should also be created by other several processes. The influences from factors such as subtidal wave, current velocity and direction must be considered both in the way of the wave that induced turbulence resuspension of bottom deposit and the wave that acted onto or removed the suspended material outward. Material with small diameter settling from the overlying water column may be moved off by subtidal wave and current action which comparatively higher during the monsoon season. Thus, during the time past, the sediment column had been naturally sorted so as only heavier particle could be settled. Other possible way is that comparatively fine particles within the sediment surface may be resuspended and migrated away from the former position by the wave action and current. Accordingly, the WC of the surface sediment became decreased. On the contrary, the possible processes that caused the increases of WC observed from some typical stations was considered because of more finer particles had been enhanced to settle down in such areas. Here the environmental factors which were influencing on such an occurrence should mainly be water current as well. Around the settling points, the current velocity should be comparatively slow so as the softer particles can be settled down to the sea bottom easily. A typical current phenomena e.g. vortex movement which lead particles to move circularly into its center part should somewhat be other possible effort.

In addition, when we considered on the effect of current on bottom deposit, the “-critical velocity”- of bottom current (less than 1 m above the sediment surface) should be further clarified. The critical velocity means the current velocity which have enough power to resuspended the bottom

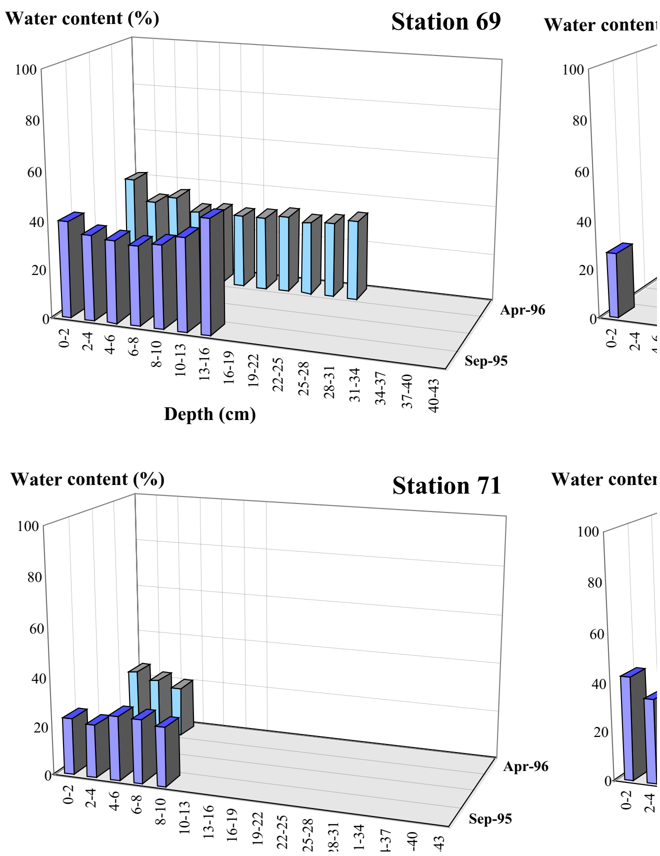

Fig. 16. Vertical profiles of water contents (WC) contents of the sediments from Stations 69-72.

deposits upward. This velocity is generally higher than that to flow the resuspended material horizontally. Generally , the critical velocity for mud deposit (mud with high levels of water content) is about 14 cm/s and for those with low water content is about 20 cm/s, respectively. That is to say, these velocities change upon the kind of bottom deposit and the diameters of particles which are moved. Thus, the gradient of current velocity from the surface water downward to above the bottom layer should be examined to answer the question whether the monsoon had effected on the bottom deposits or not.

Geological topography, water depth and the stratification of water column are quite influencing on the alternation of current velocity and direction. Considering the geological features of the gulf, the movement of the current seems to be very complicated compared with the main current in the South China Sea. There are not wind current but tidal current that can affect the bottom topography in the gulf. Generally, wind-induced wave of about 1-2 m/s has an effort to turbulence suspended material within the depth of less than 10 m. Accordingly, bottom deposits in the stations which the depth are deep are quite protected from the wave action more than those in the near-shore, shallower areas. The stratification of water column is one factor that should not be neglected. The apparent of thermocline layer usually acts as a border separating the upper water mass and the lower water mass apart. Thus the wave or current action from surface water can be extremely depressed by their effort. However, the surveyed data on vertical changes of water temperature and salinity from most stations in the Gulf of Thailand and almost of them in the eastern part of Peninsular Malaysia indicated no significant stratification of the water column (Snidvongs et al., 1995). Exceptionally in some deep stations in the lowest part of Peninsular Malaysia, however, there had some signs of ther-

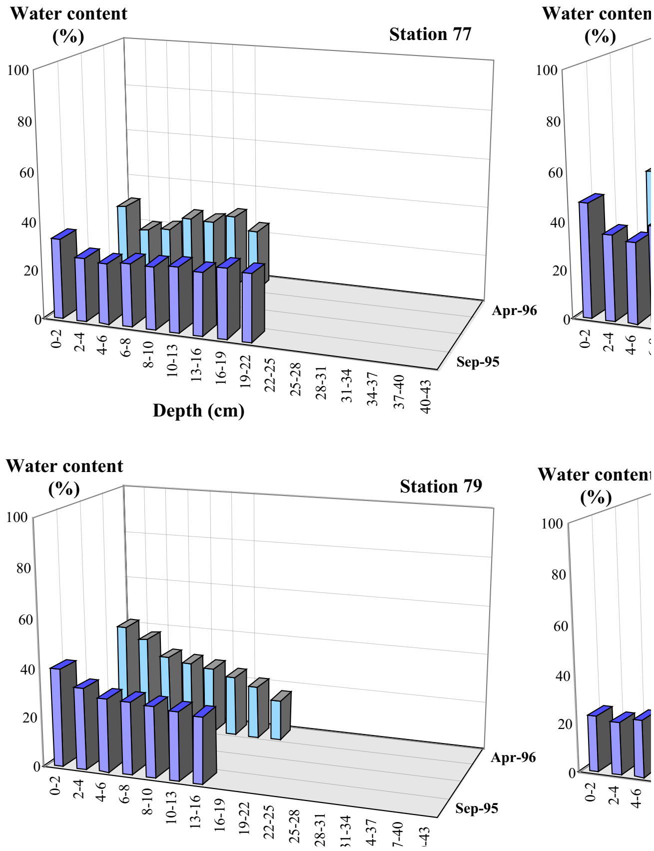

Fig. 17. Vertical profiles of water contents (WC) contents of the sediments from Stations 9-12.

mocline occurred in which the water temperature alternated around 4-5 °-C in the depth of about 50 m. The bottom deposit in those stations was accordingly suggested to be well protected from the surface wave action, because of the depth and their nature of deposits which are heavier material (e.g. sand and gravels) themselves.

Sediment organic matter : Evaluation for environmental situation

In general, particulate organic matter in sediments is measured as the percentage weight loss on combustion or by elemental analysis of carbon after removal of inorganic carbonates. Organic matter can constitute up to 30 % of sediment weight in salt marshed or coastal areas where upwelling occurs and organic carbon can account for 50 % of this amount. Open-ocean sediments, however, usually contain less than 1 % organic carbon (Bezrukov et al., 1977). According to the former method, the levels of total organic matter content in the study area were determined. These levels were very low when compared to those from the other nearshore organically enriched areas. TOM the sediments from central gulf was found in an average value of about 6 %. This levels reflected a comparatively oxidized conditions of the sea bed and implied a type of water area with comparatively low primary productivity. Study on the vertical profiles of total organic carbon contents of core sediments from the inner gulf indicated somewhat fluctuation of the levels. Nevertheless, chemical composition of of pore water nutrients had correspondingly revealed a comparatively high degree of aerobic oxidation of the organic materials occurring in the sediment surface (Snidvongs, 1993).

Organic carbon content in the surface sediments indicated comparatively high value in the stations located in the central gulf and in some near Samui Island. An average value of about 1.5 %

had been determined by Kasemsupaya (1986). An average calcium carbonate contents of the sediments were reported to be about 13-34 % on the basis of dry weight (Emery and Niino, 1963, Takashashi et al., 1984, Dharmvanij, 1987). An average COD level was less than 20 mg/g (Takashashi et al., 1984).

In addition, an inverse relation was often observed between sediment particle size and organic content which reflect the high surface area for organic adsorption on fine-grained deposits. This characteristic had been discussed by Dale (1974). In this study, fine-grained sediments with high WC usually accumulated in the two major zones of depositional areas to forms sediment rich in organic matter.

Organic matter - sulfide relation

The amount of organic matter deposited in sediments depends upon the rate of sedimentation, bio-productivity and the input of organic matter. High sedimentation rates tend to dilute the organic matter with inorganic sediment, where low sedimentation rates allow the organic matter to be oxidized either while it is settling through the water column (Kaplan and Rittenberg, 1963) or at the sediment interface (Emery, 1960). In nearshore sediments in which the newly settled particulate materials are high in organic content, the decomposition of organic matter is high and consequently anoxic condition are produced. The reductions of nitrates and sulfates occur. Jø-rgensen and Fenchel (1974) and Jø-rgensen (1977) found that 50 % of total mineralization of organic matter in organically enriched sand microcosms and sediments of a Danish fjord was due to sulfate reduction. Initially most sulfide was precipitated as FeS but with time and increasing fraction remained in solution and diffused to the sediment surface. Iron sulfides may be transformed by biological and inorganic processes to pyrite which is the major end product of sulfate reduction in reduced sediments (Howarth and Teal, 1979). These sulfide substances are known to be harmful for an extent of degree to several benthic organisms. All forms of sulfides in the bottom sediments had been examined as AVS in this study.

The levels of total sulfides in the sediment had been reported to be below the limit of detection, except for the sediment from the station near Samui Island (Takashashi et al., 1984). Such pattern apparently corresponded to our study. AVS levels should reflect a comparative high degree of organic decomposition and also a comparatively low abundant of organic loading around the areas. The levels of primary productions in such areas should be corresponding with these results. Almost all surveyed stations especially those in the eastern part of Peninsular Malaysia indicated very low to non-detectable levels of AVS in the surface sediments. Observation of the sediment textures (e.g. type of deposits, grain size, compactness, etc.) indicated that almost of the bottom deposits in that part were sandy sediments. These characters of deposits leaded fast decomposition of the organic loaded onto the sediment surface (Gray, 1981). In the same time, tidal current and wind induced current should enhance a better water movement than the areas in the central of the gulf.

Evaluation on the levels of AVS accumulated in the surface (0-2 cm) sediments has revealed the correspondingly high accumulation of organic materials especially in Stations 23 and 30. Thus, the results implied that AVS usually accumulated around nearshore zones in which organic loading from human activities may comparatively higher than those of the central gulf. Nevertheless, other factors such as current, which may relative stagnant so as to let the finer particle with high organic matter sink down easily, should be significantly concerned.

The Sediments : Evaluation for benthic organisms

Since the benthic organisms are affected by the chemical composition of the bottom deposits, it is useful to briefly consider the chemical characteristics of marine sediments as they relate to biological processes within benthic community. In this study, remarkable relationship among the sediment parameters e.g. TOM, AVS and WC had been revealed. Such as interrelationship should have promising effort in controlling the distribution of kind and abundance of benthic organisms. Comparative high levels of organic materials in sediments of the two zones may favor several benthic organisms and, consequently, the fishery production in the benthic community can be distinguishably enhanced. The levels of WC can reflect the granulometric aspect of the sea bed habitat that have been emphasized to play an important role on the distribution of benthic fauna. Nevertheless, simultaneously increase in sulfide levels according to sulfate reduction in anaerobic layer of the sediments may be a possible limiting factor limiting the biomass of some benthic organisms.

The sediments : Evaluation for nutrient dynamic and primary production

The nonequilibrium assemblage of minerals, organic matter, and sea water deposited together in marine sediments brings about chemical reactions which appreciably change the composition of near-surface interstitial waters from the typical sea water values present at the time of deposition (Berner, 1976). In shallow water ecosystem there is good evidence that sediments play an important role in supplying up to 100 % of the nutrients requirements for phytoplankton primary productivity (Zeitzschel, 1980). On the continental shelf and off the Spanish Sahara, over 35 % of nitrogen estimated to be required for phytoplankton production was suggested to be supplied from flux out of the sediments (Rowe et al., 1975, Smith, 1978, Smith et al., 1979). Nixon et al., (1980) indicated that about 50 % of the phosphorus required for phytoplankton production in Narragansett Bay had been released from sediments.

In well-flushed coarse sediments, concentrations of biologically important nutrients increase with depth to levels which are high relative to those in the overlying water. The major transport process for exchange across the sediment surface is though to be diffusion (Berner, 1980). This diffusion may control flux into the layer where turbulent mixing occurs (Caldwell and Chriss, 1979). In addition to the diffusion, there are several processes (e.g. turbulence and resuspension, density-driven displacement, and bioturbation by animals etc.) that transport soluble nutrients and gases out of the sediment. Whatever the mechanism of release, where vertical transport is sufficient and regenerated nutrients enter the euphotic zone, they may be utilized for phytoplankton production.

According to high accumulation of the organic materials in the two zones in the Gulf of Thailand, the sediments there should have comparatively high nutrient regeneration rate. Due to the interaction between the sea water and the sediments and the suitable of geological topography and current effort, regenerated nutrients from the sea bed can be further utilized by phytoplankton in the water column. Correspondingly to those previous studies, primary production in the water column may be consequently enhanced. Distribution of the regenerated nutrients from the sea bed, however, may be restricted in limited area due to the mode of current.

The sediments : Evaluation for further application approach

An apparent accumulation of current-induced materials on the sea bed in the two zones has also reflected a comparatively high amounts of particles in the water column. In those areas, comparatively high densities of suspended particles, together with phytoplankton, zooplankton or small fish larvae etc. could be reasonably observed in the water column. Accordingly, several kinds of phytoplankton feeding fish may aggregate due to comparatively high density of living phytolankton. In this aspect, Takahashi et al. (1984) has revealed that the planktonic organisms and fishes apparently congregated in the zone near Samui Island at the optimum temperature and salinity. Hence the water areas there are potentially good fishing ground for marlin, mackerel, little tuna, and other fishes. The fishing grounds for black marlin, Makaira indica CUVIER, which were caught by longline locate at the boundary of a high salinity water mass extension from the South China Sea with the highest density in the vicinity of Samui Island. Such a distribution pattern of black marlin was roughly coincide with those of mackerel. The pelagic fishes migrating for feeding purpose are, therefore, have revealed to attach to the zones of densely concentrated marine organisms around there. In addition, the aggregation of fishes has long been determined also by pattern of water flow. Fishes, particularly demersal species, are attracted to areas of weak movement of water and they avoid place where strong currents prevail. Therefore, such typical pattern of particle accumulation in the bottom sediment in such stagnant area can illustrate the mode of biological fishery resource in the water column as well.

In conclusion, the physical and chemical characteristics of bottom sediments and the sea water in the two zones of organic accumulation have revealed to provide appropriate aquatic conditions which are able to promote the growth and succession development of several kinds of organisms from the primary producers to those in the upper trophic levels. Therefore, future assessment of the fishery resources in the Gulf of Thailand and the eastern part of the Peninsular Malaysia should concern the proper way to manage and develop these zones as major fishery resources. An establishment of fish apartments so as to develop the nursery ground and thus increase the fishery production around there may be one of possible approaches to be carried out. Moreover, because of the fact that very low levels of dissolved inorganic nutrients in the water column were found from almost sampling stations including those from the two zones with high particulate accumulation, the nutrient sources for primary production are thus considered to be insufficient. Therefore, an increase of nutrient loading from terrestrial sources to the gulf should still provide a positive effort in enhancement of the biological fishery resources of the whole area.

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