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Subaqueous Sedimentary Processes Around the Mangrove Habitats in Khlong Thom and Satun Areas, South Thailand

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ABSTRACT Subaqueous sedimentological studies were carried out in the Khlong Thom and Satun areas, South Thailand where mangrove habitats are widely distributed, for the purpose to illustrate present subaqueous sedimentary processes around the habitats. Water areas in both are sedimen-tologically defined as tidal current dominated estuarine environments. Fifty-six subaqueous sediments from the Khlong Thom area and 53 from the Satun area were obtained and sedimentologically analysed to comprehend their textural and compositional features, and their spatial distributions. Water depth and surface water chemical properties of measurements were conduced in both areas to grasp subaqueous topographies and saline/fresh water mixing processes, respectively. A clear decrease of salinity is recognized from the Straits of Malacca area to the innermost parts in both areas, and no marked trend of it is detected between surface and bottom waters. Sandy sediments mostly cover the bottom surface of the Khlong Thom area, while muddy sediments dominate in the Satun area. The difference between them are resulted mainly from the difference of their geological settings. Sandy terrigeneous sediments consisting mainly of quartz in the bottom sediments from both areas are derived mainly from the consolidated strata cropping mainly out in the inner parts in both areas, but such micro-organic remains as benthic foraminifers and marine ostracodes are originated in the area of the Straits of Malacca. Further, charcoals derived only from villages and kilns in and around the mangrove habitats are dominant in the sediments from the inner parts. Because of these sediments are traceable wholly or partly in the bottom sediments and they indicate certain and relative source areas, course ways of subaqueous sediment transportation by tidal currents in both areas are inferred on the basis mainly of their spatial distribution of grain-sizes and relative amounts.

Key Words: mangrove habitat / subaqueous sedimentation / tidal current dominated estuary / sediment transportation / South Thailand / depositional environment

Dense mangrove habitats are widely distributed in the Khlong Thom and Satun areas in the western coast of the Malay Peninsula, South Thailand (Fig. 1). However, no systematic geological and sedimentological studies have been carried out in the water areas around the habitats in both areas, in spite of importance of understanding upon relationship between subaqueous sedimentary processes and mangrove habitat dynamics has been pointed out (*e. g.* Allen, 1965). A field research project "Mangrove Habitat Dynamics and Sea-level Change" was carried out in both areas in 1996 and 1997 (Miyagi & Woodroffe, 1998). As a part of the project, detailed subaqueous sedimentological studies

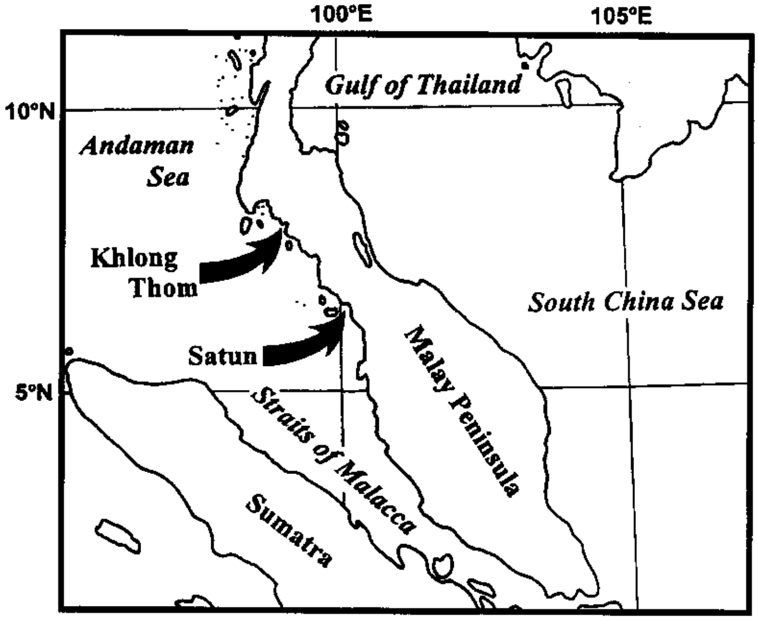

Fig. 1: Locations of the Khlong Thom and Satun areas in the western coast of the Malay Peninsula, South Thailand.

were investigated in and around the mangrove habitats in both areas to comprehend present subaqueous sedimentary processes, particularly sediment transportation around the habitats. Further, water depth and chemical properties of surface water measurements were conduced to grasp subaqueous topographies and salt-water/fresh-water mixing processes, respectively.

The sites for subaqueous sediment samplings, and water depth and chemical properties measurements were selected uniformly in both the Khlong Thom and Satun areas for the purposes of the following scientific searchings; (1) recognition of present subaqueous topographies, (2) spatial distribution of subaqueous sediments, (3) spatial distribution of such benthic micro-organisms as benthic foraminifers and ostracodes, and (4) spatial distribution of chemical properties of surface waters properties. Fifty-six and 53 subaqueous sediments were successfully obtained from the Khlong Thom and Satun areas, respectively. The preliminary results of the above-mentioned searchings were reported (Tsukawaki & Kamiya, 1998). Thus, taking the results of the previous searchings with new data, obtained mainly from the results of textural and compositional investigations of subaqueous sediments into account, present subaqueous sedimentary processes of both areas are illustrated in this article.

TOPOGRAPHY AND GEOLOGY OF KHLONG THOM AND SATUN AREAS

Khlong Thom Area

Figure 2 shows topographic features and present distribution of the mangrove habitats in the Khlong Thom area in the western coast of South Thailand. The water areas can be divided

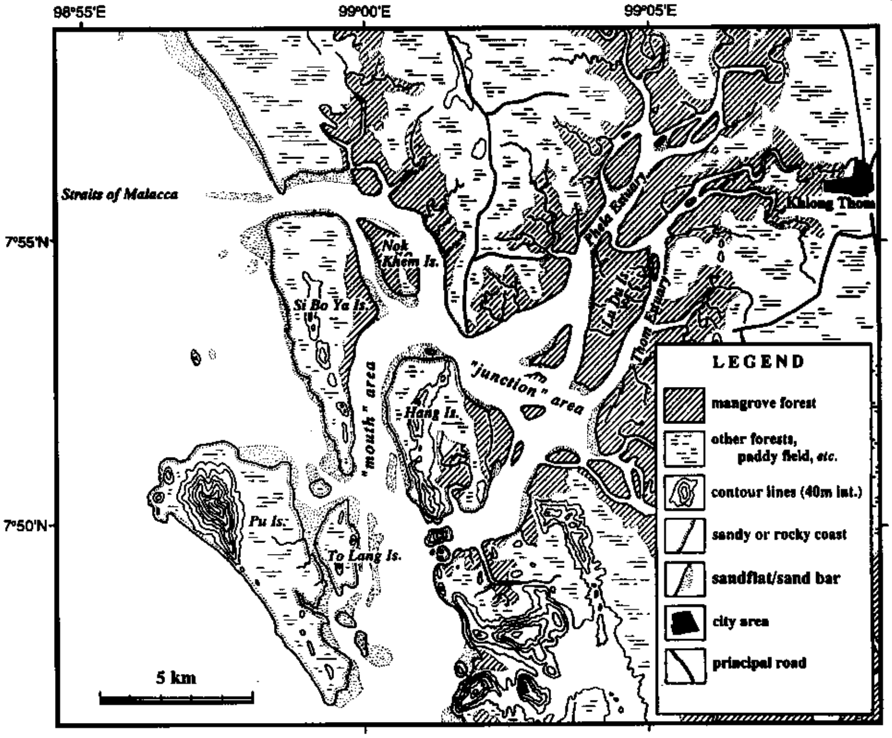

Fig. 2: Topographic features and distribution of mangrove habitats in the Khlong Thom area, South Thailand.

geomorphologically into the estuarine area in the east, the junction area in the centre, the mouth area west of the Hang Island, and the area of the Straits of Malacca.

The estuarine area is composed of two narrow and long estuaries, the southern Thom and northern Phela Estuaries. The former, about 700 m in width, and the latter, about one kilometre in width, are connected by a tidal channel on the north of the Lu Du Island. The junction area where these estuaries run together east of the Hang Island is about seven kilometres in width and six kilometres in depth. Several islands, such as the Lu Du Island having NE-SW to E-W longitudinal axes are distributed from the lower courses of two estuaries to the junction area, and these islands seem to be composed mainly of sandflats. Lateral current bars are recognized on the banks of two estuaries, and point bars are developed mainly on the southwestern margins of the islands in the junction area. The mangrove habitats are widely distributed along the two estuaries, on these islands in the junction area and in the eastern coast of the Hang Island composed mainly of the undifferentiated Jurassic to Cretaceous sedimentary rocks composed mainly of sandstones, shales and conglomerates with a small amount of limestones (Department of Mineral Resources, 1987). A limited number of meandered tidal channels is distributed in the habitats. Lateritic rocks crop out in part in and around the junction area. The town of Khlong Thom is located in the uppermost course of the Thom Estuary, and several small villages and charcoal kilns are distributed mainly along both estuaries and coastal part of the junction area.

The junction area is connected with the mouth area, more than 15 km in width and about five kilometres in depth, by a comparatively wide, about one kilometre in width, channel on the north and a few narrow, less than 200 m in width, channels on the south of the Hang Island. Sandy or muddy coasts are distributed on both sides of the wide northern channel. On the other hand, consolidated strata are exposed on both sides of the southern narrow channels. The mouth area is sheltered from the Straits of Malacca by several comparatively large islands such as the Si Bo Ya, To Lung, Nok Khem and Pu Islands having N-S to NNW-SSE longitudinal axes. These islands consist mainly of the undifferentiated Jurassic to Cretaceous sedimentary rocks composed mainly of sandstones, shales and conglomerates with a small amount of limestones (Department of Mineral Resources, 1987), and the highest point is recognized in the west of the Pu Island at the altitude of about 400 m. Several hills at altitudes of less than 200 m at the peaks, situating southeast of the mouth area are composed probably of the same strata. Lateritic rocks crop out in part on the coastal and water areas. Lateral current bars or longitudinal sand bars are developed on the northwestern coast of the Hang Island and on the east of To Lang Island. Point bars are also recognized on the south of Nok Khem Island. Sandflats appear widely on the west of the Hang Island, and between the Pu and To Lang Islands. The mangrove habitats are limitedly distributed in the northern coast of the area, on the Nok Khem Island and in the eastern coast of the Si Bo Ya Island. Several small villages are located in part on the islands and coastal part of the mainland in the area.

The mouth area is connected with the Straits of Malacca by three channels on the north and south of Si Bo Ya Island, and on the south of Pu Island. The comparatively long and narrow northern channel, about one kilometre in the maximum width and seven kilometres long, situated between the Si Bo Ya Island and the mainland, and the channel is divided into two narrow channels in the southeast by existence of the Nok Khem Island. Sandflats or lateral current bars are developed on the northern bank of the channel, on the north of the Nok Khem Island, and between the Si Bo Ya and Nok Khem Islands. Linear tidal shoals and swash bars are distributed west of the channel. The central channels situated among the Si Bo Ya, Pu and To Lang Islands are short and narrow less than one kilometre in width. Swash bars and sandflats mostly cover the channel. The southern channel between the Pu Island and the mainland is the largest channel in the area about four kilometres in width. Sandflats are developed on the south of the island. Mangrove habitats are limitedly distributed in part in the coastal areas of these islands and the mainland.

Satun Area

Topographic features of the Satun area in the western coast of South Thailand are shown in Fig. 3. The water areas can be divided geomorphologically into the Tam Ma Lung Bay area, the Ta Chin Estuary area extending northeastwards from the bay, and the area of the Straits of Malacca where small islands are situated. These islands, such as the Yao, Khamin and Karap Islands, are composed mainly of such Ordovician sedimentary rocks as limestones, shales and sandstones of the Thung Song Group (Department of Mineral Resources, 1987).

The Tam Ma Lung Bay opens south-southwestwards to the Strait of Malacca. The bay, about three kilometres in width and six kilometres in depth, has a western straight and an eastern concaved coastal lines. Several low hills, a few tens of metres high, are situated on the southeastern coastal area of the bay. The sandflats appear narrowly on the eastern coast of the bay mouth area and on the south of the Tam Ma Lung Island, but they develop widely on the eastern coast of the Straits of Malacca and

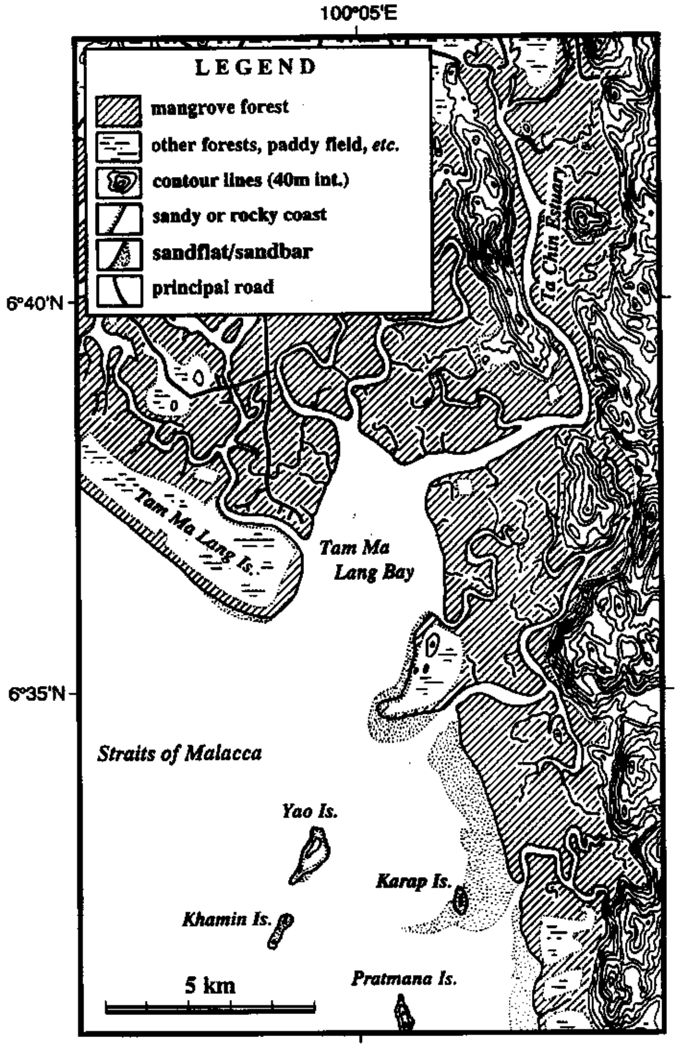

Fig. 3: Topographic features and distribution of mangrove habitats in the Satun area, South Thailand.

around the Karup Island. The long and narrow Ta Chin Estuary starts east-northeastwards from the northeastern marginal part of the Tam Ma Lung Bay. It turns north-northwestwards at about four kilomtres from the bay where is on the west of a mountain chain at the highest altitude of about 500 m, composed mainly of limestones, shales and sandstones of the Ordovician Thung Song Group (Department of Mineral Resources, 1987). The estuary extends about eight kilometres north-northwestwards between the mountain chain and a long and narrow hill that consists same strata as the mountain chain. The width of the estuary is about few hundreds metres in the south but it decreases to about 100 m in the northernmost. The city of Satun, the capital city of the Satun Province in South Thailand, is located about five kilometres north of the head of the bay, and many villages are distributed wholly in the mangrove habitat area. Some large charcoal kilns are located mainly in the coastal part around the bay.

The mangrove habitats are widely distributed around the Tam Ma Lung Bay, on the both sides of

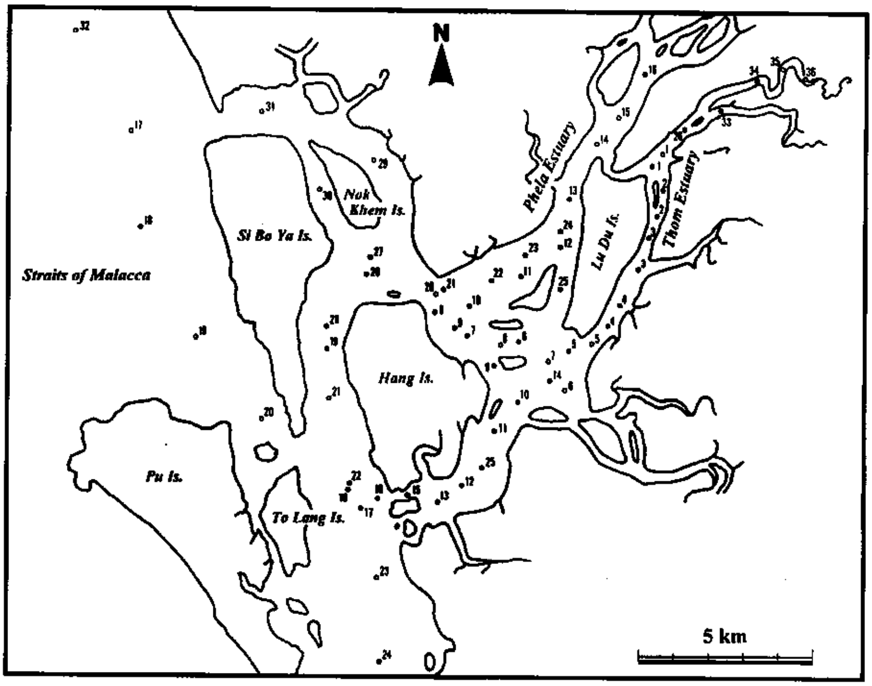

Fig. 4. Sediment sampling and water chemical properties measurement sites in Khlong Thom area, South Thailand (solid circle: site in 1996, open circle: site in 1997).

the Ta Chin Estuary, and the eastern coastal area of the Straits of Malacca. The habitats are cut by a dense tidal channel network.

SAMPLING METHODS AND SAMPLE TREATMENT PROCEDURES

The subaqueous sediment samples used for the present study were collected in December 1996 and August 1997 in both Khlong Thom and Satun areas (Figs. 3 and 4; Tables 1 and 2). The sediment samplings in 1996 were mainly carried out in the Thom and Phela Estuaries, junction and mouth areas in the Khlong Thom area, and mainly within the Tam Ma Lung Bay in the Satun area. Further, on the basis of the results of sediment samplings in 1996, the samples were collected uniformly in whole water areas in both in 1997.

Sampling devices were a Seki-type grab surface sampler, about 500 ml in volume, in 1996 and a Tamura-type grab surface sampler, about 3,000 ml in volume, in 1997, respectively. Salinity, temperature, hydrogen ion exponent value (pH) and dissolved oxygen amount (DO) measurements for mainly surface waters were conduced in both areas in August 1997. The site survey was always carried out with a water depth measurement by an about 20-metres-long nylon rope with an about two kilogrammes weight. Latitude and longitude of each sampling site were generally confirmed by using a SONY type IPS-360 GPS receiver, but several sampling sites in the Satun area in 1996 were determined by using conspicuous topographic features around the water area.

Table 1. Results of surface sediment sampling in Khlong Thom area, South Thailand.

Site No.	Date (D/M/Y)	Time Hit	Lat. (N)	Long. (E)	Depth (m)	Sediment Type
KT96-1	06/12/96	12:49	7°54'44"	99°05'00"	2.5	granule gravelly mud with f. sand
KT96-2	"	13:05	7°54'54"	99°04'55"	2.2	plant debris rich gravelly f.sand
KT96-3	"	13:15	7°54'19"	99°04'44"	3.2	plant debris rich f.sand
KT96-4	"	13:26	7°52'46"	99°04'23"	3.7	plant debris rich f. sand
KT96-5	'	13:36	7°52'21"	99°04'01"	1.0	plant debris rich f. sand, stained in dark grey in lower part
KT96-6	"	13:46	-	-	4.2	plant debris rich gravelly f. sand
KT96-7	"	13:56	7°52'24"	99°02'21"	3.8	dark grey shelly f.sand
KT96-8	"	14:08	7°52'47"	99°01'47"	14.8	dark grey shelly f.sand
KT96-9	"	14:26	7°51'51"	99°02'38"	1.4	shell fragments and plant debris bering f. sand
KT96-10	"	14:41	7°51'20"	99°02'51"	3.5	plant debris rich dark grey sandy mud
KT96-11	"	14:49	7°50'53"	99°02'30"	3.6	shell rich darkgreysandy mud
KT96-12	"	14:58	7°50'15"	99°02'13"	8.2	shell rich sandy mud with mud balls
KT96-13	"	15:15	7°50'06"	99°01'47"	14.2	shell fragments rich f.-m. sand
KT96-14	07/12/96	12:58	7°51'36"	99°03'25"	3.5	shell rich f. sand
KT96-15	"	13:15	7°50'01"	99°01'19"	20+	*no recovery*
KT96-16	"	13:22	7°49'56"	99°00'53"	20+	*no recovery*
KT96-17	"	13:25	7°49'54"	99°01'40"	14.0	organic matter rich dark grey massive mud with reddish brown surface
KT96-18	"	13:39	7°50'43"	99°00'21"	1.2	shell rich f.sand
KT96-19	"	13:53	7°52'35"	99°00'18"	3.6	lateritic gravel bering f. sand with shell fragments
KT96-20	"	14:13	7°53'10"	99°00'57"	16	shell bering gravelly f. sand
KT96-21	"	14:29	7°53'10"	99°02'02"	4.8	lateritic gravel rich f. sand
KT96-22	"	14:53	7°53'25"	99°02'30"	3.2	gravelly muddy f. sand with shells and plant debris
KT96-23	"	15:05	7°53'43"	99°03'00"	3.8	shell fragments bering gravelly f. sand
KT96-24	"	15:28	7°54'13"	99°03'46"	8.5	plant debris rich f. sand
KT96-25	"	15:42	7°53'09"	99°03'41"	3.6	plant debris rich dark grey sandy mud with a little shell fragments
KT96-26	"	17:01	7°55'34"	99°05'44"	4.5	plantdebris rich reddish brown muddy sand
KT97-1	08/08/97	07:57	7°55'13"	99°05'12"	4.6	plant debris rich pale brown muddy sand
KT97-2	"	08:07	7°54'32"	99°05'11"	2.4	plant debris and shell bearing f. sand
KT97-3	"	08:14	7°54'00"	99°05'02"	4.7	plant debris rich f. sand
KT97-4	"	08:28	7°53'03"	99°04'38"	2.5	shell fragments bearing f. -m. sand
KT97-5	"	08:43	7°52'26"	99°04'09"	7.3	gravel bearing f. sand with a small amount of shell
KT97-6	"	09:00	7°51'21"	99°03'48"	4.0	brownish grey sandy mud, brown and layer in surface
KT97-7	"	09:21	7°52'02"	99°03'28"	2.3	plant debris rich muddy f. sand
KT97-8	"	09:42	7°52'23"	99°02'50"	4.9	shell and gravel bearing muddy f. sand
KT97-9	"	09:57	7°52'30"	99°02'20"	1.1	shell bearing f. sand
KT97-10	"	10:08	7°52'49"	99°02'38"	1.8	shell bearing f. sand
KT97-11	"	10:22	7°53'23"	99°03'09"	5.8	shell and gravel bearing f. sand
KT97-12	"	10:34	7°53'46"	99°03'38"	6.0	plant debris and shell bearing f. -m. sand
KT97-13	"	10:46	7°54'30"	99°03'54"	8.9	dark bluish grey mud. muddy f. -m. sand in surface
KT97-14	"	11:00	7°55'16"	99°04'16"	13.0	plant debris rich shell bearing f. sand
KT97-15	"	11:11	7°55'45"	99°04'44"	9.0	pebble-cobble gravel bearing f. sand
KT97-16	"	11:22	7°56'27"	99°05'10"	9.0	pebble-cobble gravel bearing f. sand
KT97-17	09/08/97	09:45	7°55'54"	98°57'24"	1.7	shell and plant debris bearing olive grey f. sand
KT97-18	"	10:06	7°54'35"	98°57'40"	2.6	shell and plant debris bearing olive grey f. sand
KT97-19	"	10:31	7°52'23"	98°58'11"	4.2	calcareous rich olive grey f.-m sand with mud balls
KT97-20	"	10:50	7°50'53"	98°59'13"	1.2	calcareous rich muddy olive grey f. sand
KT97-21	"	11:15	7°51'14"	99°00'05"	9.0	shell and laterite gravel bearing reddish brown f. -m. sand
KT97-22	"	11:24	7°50'10"	99°00'21"	3.0	shellfragmentbearingolivegrey f. sand
KT97-23	"	11:44	7°46'42"	99°00'35"	9.2	shell bearing muddy f. -m. sand with mud balls
KT97-24	"	12:00	7°47'23"	99°00'44"	7.4	gravel bearing muddy m. sand with mud balls
KT97-25	'	12:32	7°50'30"	99°02'20"	6.4	shell and plant debris rich dark olive grey muddy f. sand
KT97-26	"	13:09	7°52'55"	99°02'00"	12.0	shell bearing brown f. m. sand
KT97-27	"	13:30	7°53'33"	99°00'59"	10.5	shell and fragments rich muddy f. -m.sand
KT97-28	"	13:51	7°52'34"	99°00'16"	60	gravel and shell bearing muddy f. -m. sand
KT97-29	"	14:15	7°54'56"	99°01'01"	7.7	lateraite gravel and shell rich olive grey f. sand
KT97-30	"	14:32	7°55'12"	98°59'55"	6.7	shell and fragments bearing olive grey f. sand
KT97-31	"	14:54	7°55'49"	98°58'51"	11.7	shell yolive grey f. sand
KT97-32	"	15:14	7°56'47"	98°57'47"	4.0	shell fragment bearing olive grey f. sand
KT97-33	10/08/97	08:16	7°55'47"	99°06'00"	2.7	plant debris rich brownish grey muddy sand
KT97-34	"	08:50	7°56'16"	99°06'41"	2.5	gravel bearing m. -c. sand
KT97-35	"	09:07	7°56'13"	99°07'01"	2.4	plant debris rich m.-vc. sand
KT97-36	"	09:40	7°56'11"	99°07'22"	2.6	laterite gravels with a small amount of f. sand

Table 2. Results of surface sediment sampling in Satun area, South Thailand.

Site No.	Date (D/M/Y)	Time Hit	Lat. (N)	Long. (E)	Depth (m)	Sediment Type
ST96- 1	30/11/96	13 05	-	-	7.0	shell bering muddy c.-vc. sand
ST96- 2	"	13:15	-	-	7.5	plant bering grey muddy c.-vc. sand
ST96- 3	"	13:30	-	-	8.0	bluish grey massive mud
ST96- 4	"	13:37	-	-	6.5	shell and plant debris bering bluish grey massive mud
ST96- 5	"	13:49	-	-	3.0	shell fragments and plant debris bering bluish grey massive mud
ST96- 6	"	14:00	-	-	4.5	shell and plant debris rich bluish grey mud
ST96- 7	"	14:10	-	-	5.0	fragmented plant debris rich bluish grey mud
ST96- 8	"	14:22	-	-	2.0	plant debris rich shell bering dark bluish grey mud
ST96- 9	"	14:26	-	-	1.5	plant debris rich shell bering dark bluish grey mud
ST96-10	"	14:55	-	-	1.2	plant debris rich dark bluish grey mud
ST96-11	"	15:05	-	-	4.5	plant debris rich dark bluish grey mud
ST96-12	"	15:15	-	-	7.5	shell rich bluish grey mud with large plant debris
ST96-13	"	15:24	-	-	4.5	shell and plant debris bering bluish grey mud
ST96-14	"	15:35	-	-	2.5	shell fragments bering bluish grey mud
ST96-15	"	15:45	-	-	5.5	bluish grey massive mud covered by a thin c. sand layer
ST96-16	"	15:51	-	-	1.5	bluish grey mud covered by a brow mud layer
ST96-17	"	16:01	-	-	4.5	plant debris rich shell bering bluish grey mud
ST96-18	"	16:12	-	-	2.5	plant debris rich shell bering bluish grey mud
ST96-19	"	16:29	-	-	1.0	plant debris rich bluish grey mud
ST96-20	"	16:21	-	-	8.5	plant debris rich bluish grey mud
ST96-21	01/12/96	10:00	-	-	5.0	plant debris and shell bering bluish grey muddy c. sand
ST96-22	"	10:10	-	-	5.0	plant debris and shell bering bluish grey muddy c. sand
ST96-23	"	10:25	-	-	5.5	plant debris bering bluish grey mud with reddish brown surface
ST96-24	02/12/96	09:55	6°29'48"	100°04'51"	5.0	shell and plant debris rich dark blue massive mud
ST96-25	"	10:10	6°28'46"	100°04'51"	4.8	shell rich plant debris bering bluish grey massive mud
ST96-26	"	10:20	-	-	3.5	bluish grey massive mud with fine organic matter
ST97- 1	14/08/97	09:25	6°30'32"	100°03'21"	2.0	plant debris and shell bearing bluish grey mud, brown mud layer in surface
ST97- 2	"	09:42	6°29'59"	100°04'11"	2.5	plant debris rich bluish grey mud with a small amount of shell
ST97- 3	"	10:00	6°29'43"	100°04'59"	4.4	shell rich bluish grey sandy mud, brown mud ayer in surface
ST97- 4	"	10:16	6°30'40"	100°05'19"	2.7	plant debris rich bluish grey sandy mud, brown mud layer in surface
ST97- 5	"	10:37	6°30'42"	100°04'19"	4.5	plant debris rich bluish grey mud, brown mud layer in surface
ST97- 6	"	10:53	6°31'22"	100°04'29"	4.6	plant debris bearing brownish grey mud
ST97- 7	"	11:07	6°31'22"	100°05'00"	1.3	plant debris and shell bearing olive grey mud, brown mud layer in surface
ST97- 8	"	11:17	6°31'23"	100°05'41"	3.0	molluscan shell rich olive grey sandy mud
ST97- 9	"	11:32	6°31'59"	100°05'38"	3.6	plant debris and shell rich olive grey sandy mud
ST97-10	"	11:45	6°31'59"	100°05'00"	1.3	plant debris and shell bearing olive grey soupy mud
ST97-11	"	12:12	6°32'32"	100°05'03"	1.1	olive grey mud with vc. quartz sand
ST97-12	"	12:30	6°32'39"	100°05'35"	3.4	molluscan shell rich olive grey sandy mud
ST97-13	"	12:40	6°32'49"	100°06'24"	5.3	plant debris, vc. quartz sand and shell bearing, olive grey sandy mud
ST97-14	"	12:56	6°33'16"	100°07'32"	6.0	olive grey mud, brown layer in surface
ST97-15	"	13:17	6°34'37"	100°07'26"	11.9	slightlymuddy c.-vc. quartz sand
ST97-16	"	13:34	6°36'01"	100°07'20"	?	plant debris rich muddy c.-vc. quartz sand
ST97-17	"	13:50	6°37'13"	100°06'54"	?	plant debris rich muddy c.-vc.quartz sand
ST97-18	15/08/97	09:04	6°28'59"	100°05'03"	3.2	plant debris and shell rich muddy f. sand
ST97-19	"	09:17	6°28'59"	100°03'59"	3.0	oyster shell fragments with a small amount of f. sand
ST97-20	"	09:36	6°29'07"	100°02'59"	4.2	shell fragments bearing bluish grey sandy mud
ST97-21	"	09:49	6°29'01"	100°02'00"	4.2	shell rich bluish greysandy mud
ST97-22	"	10:35	6°27'58"	100°02'53"	3.5	oyster shell fragments rich f. sand
ST97-23	"	10:48	6°28'08"	100°04'02"	1.9	shelly f. sand
ST97-24	"	11:02	6°27'59"	100°05'00"	2.8	shelly bluish grey mud
ST97-25	"	11:14	6°27'00"	100°05'03"	2.4	shell and plant debris bering bluish grey mud
ST97-26	"	11:26	6°26'57"	100°04'18"	2.5	shell fragments bearing black f. sand
ST97-27	"	11:45	6°27'01"	100°03'00"	3.5	molluscan shells with a small amount of f. sand

In the laboratory, smear slides were prepared first and examined under a microscope for compositional description of muddy sediments. For sandy sediments, the entire sample was heated over 24 hours at about 50°C, and its dry weight was measured. Then, it was washed over a screen with opening of 63 μm to remove muddy sediments, and dried and weight again to obtain proportional mud contents. The remained sandy sediments were sieved over screens with openings of 90, 125, 180,

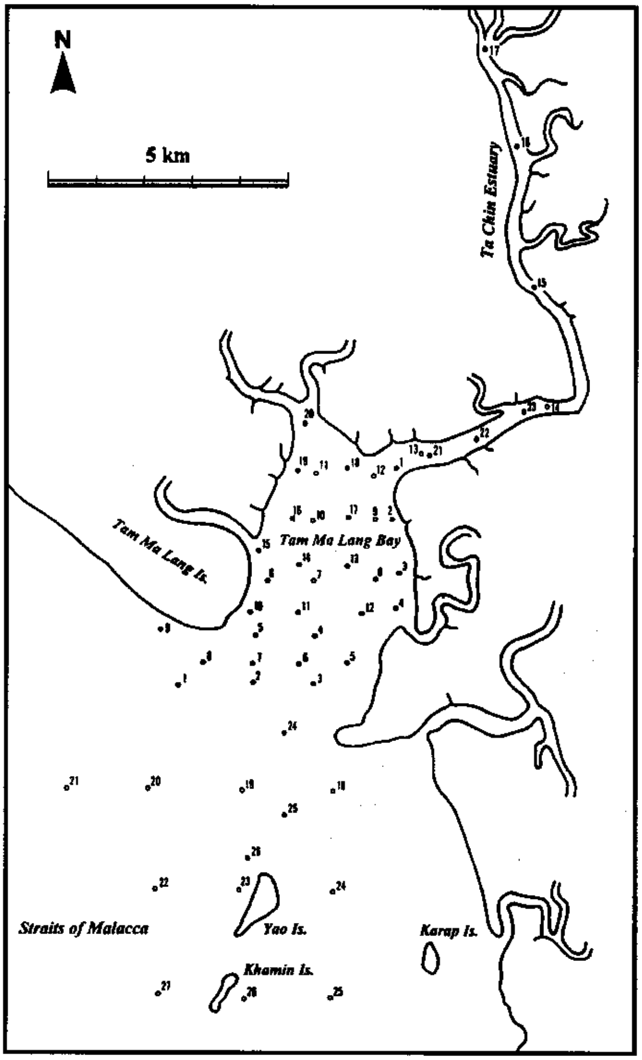

Fig. 5. Sediment sampling and water chemical properties measurment sites in Satun area, South Thailand. (solid circle: site in 1996, open circle: site in 1997)

250, 355, 500, 710, 1,000, 1,400, 2,000, 2,800 and 4,000 μ m. Then, dry weights of remains on each screen were measured to obtain proportional grain-size distribution for sandy sediments. Further, microscopic observations for each remain were conduced to the textural and compositional description for sandy sediments.

PROPERTIES OF WATER OF KHLONG THOM AND SATUN AREAS

Such chemical properties measurements as salinity, temperature, hydrogen ion exponents value and dissolved oxygen amount were carried out for surface waters in both Khlong Thom and Satun areas in

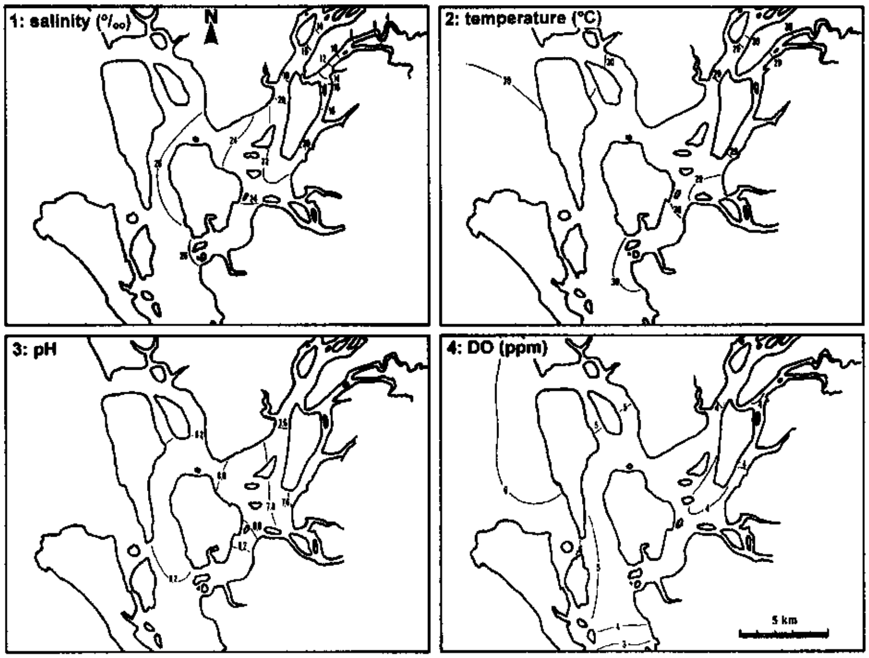

Fig. 6. Spatial distributions of Chemical properties of surface water properties in Khlong Thom area, South Thailand. (1: salinity, 2: temperature, 3: hydrogen ion exponent, 4: dissolved oxygen amount)

August 1997 during mainly the low tide periods, and the summarized results are shown in Figs. 6 and 7, respectively. Salinity measurement was conduced for bottom waters at several sites in the Khlong Thom area to recognize its vertical differences. The salinity measured in the area of the Straits of Malacca in this study was comparatively low rather than the average salinity in the open sea water, but it seems to be resulted by a certain effect of strong rainfalls during the survey.

Khlong Thom Area

Salinity of the surface water shows a clear gradient from the area of the Straits of Malacca to the areas of both Thom and Phela Estuaries. It is more than 25 ‰ in the Straits of Malacca and the mouth areas, between 20 and 25 ‰ in the junction area, and less than 20 ‰ in the areas of both estuaries. It particularly shows a marked decrease in the Thom Estuary from 20.5 ‰ in the lower course near the junction area to 1.7 ‰ in the uppermost course near the town of Khlong Thom. On the other hand, surface water temperatures are constant wholly between 28 and 31 ℃ Hydrogen ion exponent value also shows a gradual decrease from the straits to the estuarine areas. It is more than 8.1 in the areas of the straits and the mouth, between 8.3 and 7.6 in the junction area, and generally less than 7.7 in the areas of both estuaries. Dissolved oxygen amount is around 6 ppm in the area of the straits, between 4.5 and 5.7 ppm in the mouth area with an exception of the site KT97-24 where it is very low 2.83 ppm located in the southernmost part of the survey area, between 4.0 and 4.5 ppm in the junction area, and less than 4.0 ppm in the areas of the two estuarines with an exception of the site KT97-4 where it

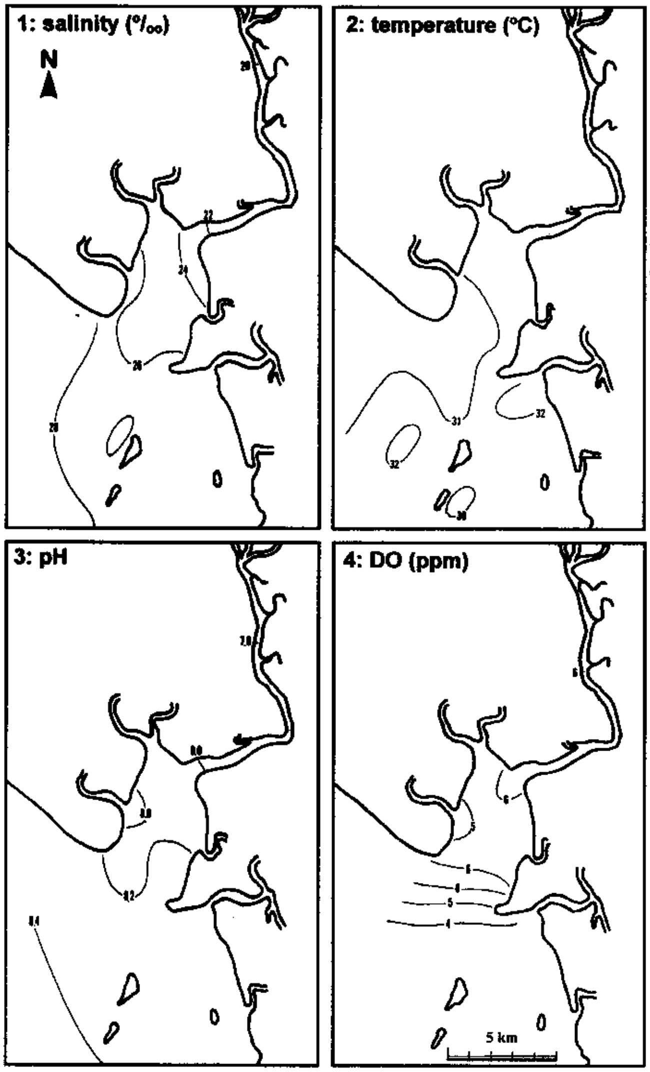

Fig. 7. Spatial distributions of Chemical properties of surface water in Satun area, South Thailand. (1: salinity, 2: temperature, 3: hydrogen ion exponent, 4: dissolved oxygen amount)

is comparatively high 4.49 ppm. Salinity of the bottom water was slightly (1 to 2 ‰) higher than that of the surface water at several sites in the junction area and the lower courses of the both estuaries, but no marked differences of salinity between them were distinguished in other areas.

Satun Area

Salinity of the surface water in the Satun area is more than 25 ‰ in the area of the Straits of Malacca, between 23 and 26 ‰ in the Tam Ma Lung Bay area, and between 19 and 22 ‰ in the Ta Chin Estuary area where the salinity shows a gradual decrease from 21.8 ‰ near the bay to 19.1 ‰ at the northernmost part of the estuary. In this manner, the salinity of the surface water in the Satun area shows a gradient from the straits to the estuary areas, but it is not remarkable as compared with that in the Khlong Thom area. On the other hand, surface water temperatures are constantly high between 30

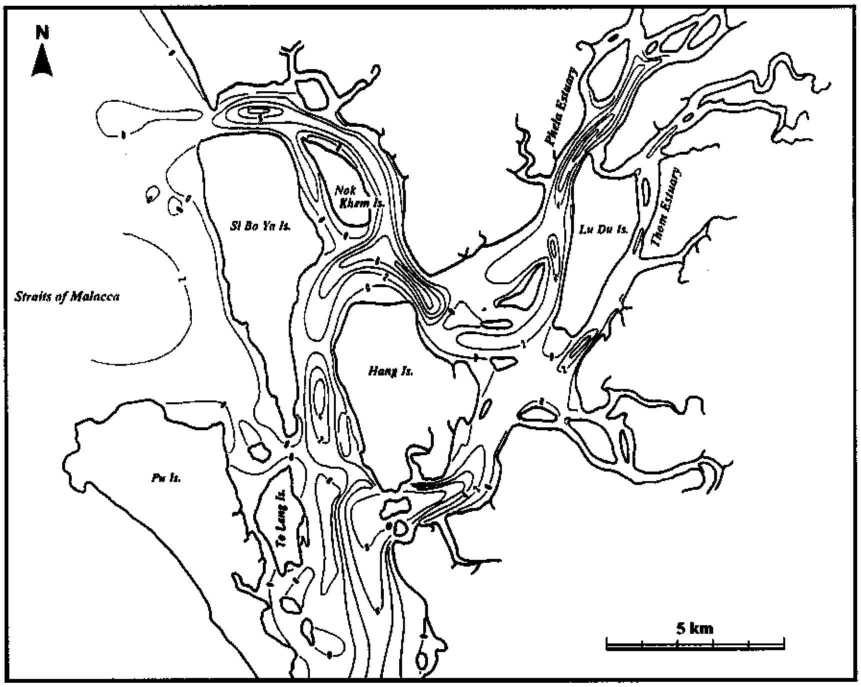

Fig. 8. Bathymetric chart of Khlong Thom area, South Thailand. Contour lines indicate water depths at the lowest low tide period.

and 32 ℃ in whole area. Hydrogen ion exponent value also shows a clear decrease from the straits to estuary areas. It is more than 8.2 in the area of the straits, between 7.8 and 8.2 in the bay area, and less than 8.0 in the areas of the estuary. Dissolved oxygen amount in the area of the straits is markedly low between 3.1 and 3.6 ppm. On the other hand, it is markedly high between 4.7 and 6.8 ppm, and between 5.6 and 6.3 ppm in the area of the estuary. It is notable that the high DO area is recognized in the mouth area of the Tam Ma Lung Bay.

BATHYMETRY OF KHLONG THOM AND SATUN AREAS

Taking onshore topographies and geological features into account, bathymetric chart of the Khlong Thom and Satun areas are drawn based on the results from water depth measurements carried out in both areas in 1996 and 1997 (Figs. 8 and 9). Water depths indicated as contour lines in the figures are revised into the water depths at the lowest low tide period.

Khlong Thom Area

Water depths of the Thom Estuary are shallow less than three metres in whole, but it becomes deeper, around seven metres, near the junction area. On the other hand, they in the Phela Estuaries are generally deeper than them in the Thom Estuary, round four metres, and a long and narrow deepest part, about 13 m deep, is recognized north of the Lu Du Island. They in the junction area where some islands are situated are very shallow less than two metres in general, and areas composed of sandflats

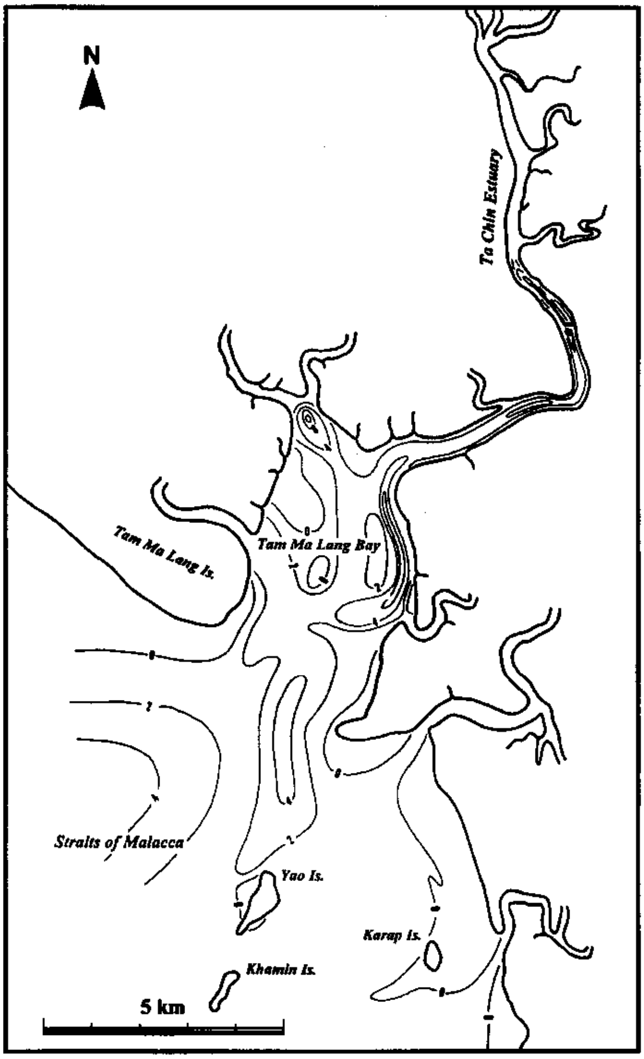

Fig. 9. Bathymetric chart of Satun area, South Thailand. Contour lines indicate water depths at the lowest low tide period.

where are shallower than zero metre are emerged during the low tide periods. The deepest parts of the Khlong Thom area are situated in the channels that connect the junction area with the mouth area. The water depths are about 12 m deep in the central part of the channel north of the Hang Island, and more than 20 m deep in the channels south of the island. On the other hand, the water depths in the mouth area are generally small less than three metres in whole with exceptions of west off the channels. Further, trough shaped deeper parts are situated within a channel north of the Si Bo Ya Island, and between the Hang and Si Bo Ya Islands where they are about 12 and nine metres, respectively. The Straits of Malacca area is about one to four metres deep, and the sea floor is rather flat.

Satun Area

Most part of the Tam Ma Lung Bay area is generally shallow less than two metres deep and the floor is rather flat. Certain areas of the bay are less than zero metre deep where are emerged during the low

Table 3. Proportional mud contents, sediment mean diameters and compositions of sandy sediments of the subaqueous sediments from the Khlong Thom area. (+++: dominant, ++: common, +: present)

Site No.	Locality	Mud contents (weight %)	Mean diam. (in phi)	Terrigeneous Sediments: fine quartz	coarse quartz	lithic fragm.	charcoal	Biogenic Sediments: foraminifer	ostracode	diatom	radioarian	sponge spicule	sponge microsc.	echinoide	plant debris	mollus. shell
KT96- 9	Junction area	4	-	++	+	+	+	+							++	+++
KT96-10	"	20	-	++	+		++	+	+	+					++	++
KT96-12	"	4	-	+++	+	++	+	+	+	+			+		++	+++
KT96-13	"	3	-	++		+	++	+	+			+		+	+	+++
KT96-17	Mouth area	85	-	+++			+	++	+	+		+	+		++	++
KT96-18	"	4	-	+++		++	+	++	+			+		+	+	+
KT96-22	Juncton area	11	-	++	++	++	+	+	+	+		+	+		+	++
KT96-25	"	22	-	++	+		+	+		+					+++	++
KT97- 1	Thom Estuary	25	2.58	++	+		++							+	+++	
KT97- 2	"	1	1.28	+	++	+	++								+++	
KT97- 3	"	2	1.33	++	+		++								+++	+
KT97- 4	"	1	1.33	+++	+	+	++								++	+
KT97- 5	"	4	1.52	++	+		++								++	+
KT97- 6	Junction area	34	3.00	+++			++	+					+	+	+++	++
KT97- 7	"	24	2.87	+++			++	+		+					++	++
KT97- 8	"	9	-0.12	+		++	+	+	+	+					++	++
KT97- 9	"	2	1.76	++	+	++	++	++	+						++	+++
KT97-10	"	4	1.98	++		+	++	++	+						+	++
KT97-11	"	2	-0.38	+	++	+++	+	+							+	++
KT97-12	Phela Estuary	2	1.25	++	+		++	+				+			+++	++
KT97-13	"	22	2.30	++	+	++	++	+					+		++	+
KT97-14	"	8	1.75	++	+		++	+		+					+++	+
KT97-15	"	1	1.38	++	+	++	++	+							+	+
KT97-16	"	0	-2.75	+	+	+++	+	+					+		+	+
KT97-17	Straits of Malacca	14	3.01	+++			+	+++	++	+		+	+	+		+++
KT97-18	"	22	2.14	+++			+	++	+++		+	+		+		+++
KT97-19	"	6	1.63	+++			+	+++	+++	+		+		+		+++
KT97-20	"	9	1.80	+++				+++	++		+	+	+	+		+++
KT97-21	Mouth area	3	-0.62	++		++		++	+	+		+	+			++
KT97-22	"	3	1.90	+++	+	+	+	+	++	+		+		+	+	+++
KT97-23	"	3	-0.05	+++		+		++	+	+		+				+++
KT97-24	"	7	-0.25	+++		++		++	+			+	+			++
KT97-25	Junction area	11	2.06	+++	+		++	++	+	+		+	+	+	+	+++
KT97-26	"	3	1.45	++		+	++	++	+			+		+	++	++
KT97-27	Mouth area	2	-0.73	++		+++	+	++	+			+	+	+		+++
KT97-28	"	3	0.35	+++	+	+++	+	++	+			+	+	+	+	++
KT97-29	"	3	0.43	+++		++	+	+	+			+	+	+		+++
KT97-30	"	3	0.68	+++	+	++	++	+++	++	+		+				++
KT97-31	"	1	0.15	+++			+	++	++	+		++		+		+++
KT97-32	Straits of Malacca	4	2.21	+++			+	+++	++			+		+		+++
KT97-33	Thom Estuary	19	2.68	+++	+		++	+							+++	+
KT97-34	"	1	0.25	++		+	++	+							+++	+
KT97-35	"	3	0.25	++	+	++	+++								+++	
KT97-36	"	48	0.63	+		+++	+++								+++	+

tide periods. However, a narrow and deep subaqueous channel where the water depths are more than six metres, is recognized along the eastern margin of the bay. Another deepest part is distinguished on the northernmost part of the bay near the northern tidal channels where the water depth is more than eight metres. In contrast with this, the water depths of the Ta Chin Estuary are much greater round eight metres. In the southern part of the estuary, they are between five and six metres, but they are more than 10 m in the northern part. The Straits of Malacca area is shallow one to four metres deep. A

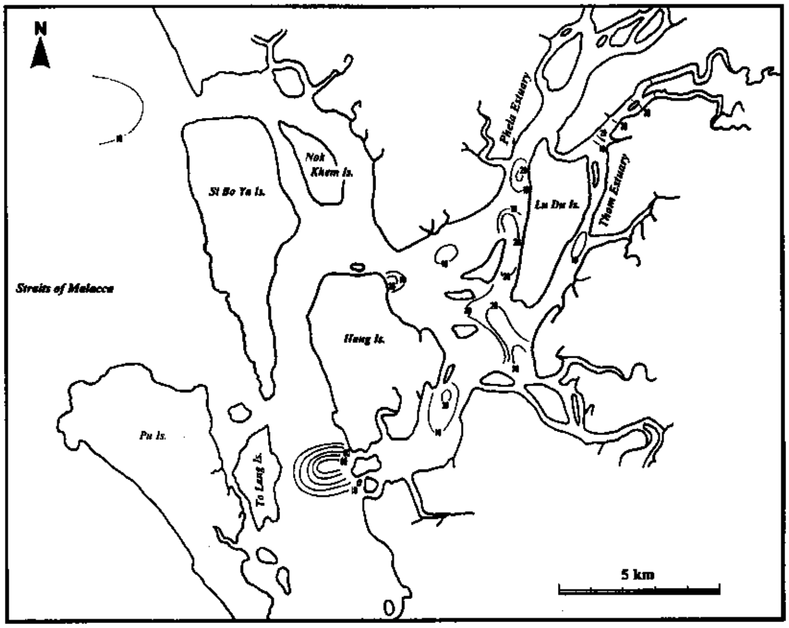

Fig. 10. Spatial distribution of proportional mud contents of entire sediments in Khlong Thom area, South Thailand.

broad subaqueous channel, about five metres deep, runs from the central part of the bay mouth area to north of the Yao Island situated in the straits area.

SUBAQUEOUS SEDIMENTS FROM KHLONG THOM AND SATUN AREAS

Khlong Thom Area

Propotional mud contents, sediment mean diameter (Inman, 1952) and compositions of sandy sediments from the Khlong Thom area are shown in Table 3. Further, Figs. 10 and 11 illustrate spatial distribution of proportional mud contents and sediment mean diameters of entire sediments from the area, respectively. Fine- to medium-grained sandy sediments that contain less than 20 % of muddy sediments in weight are mostly distributed in the bottom surface of the Khlong Thom area with the exception of the site KT96-17 west off the channel on the south of the Hang Island where muddy sediments are dominance. Terrigeneous sediments in whole area are composed mainly of fine- to medium-grained quartz with a small amount of muscovite and such heavy minerals as hornblende and zircon. A certain amount of coarse-grained quartz stained with reddish brown colour is contained in the sediments in part. Mud consists chiefly of reddish brown coloured clay minerals.

Plant debris rich muddy sand and fine- to medium-grained sand mostly cover the bottom surface in the lower course of the Thom Estuary, while plant debris bearing sandy mud, gravel bearing medium-grained sand and laterite gravels dominate in the upper course. A small amount of molluscan

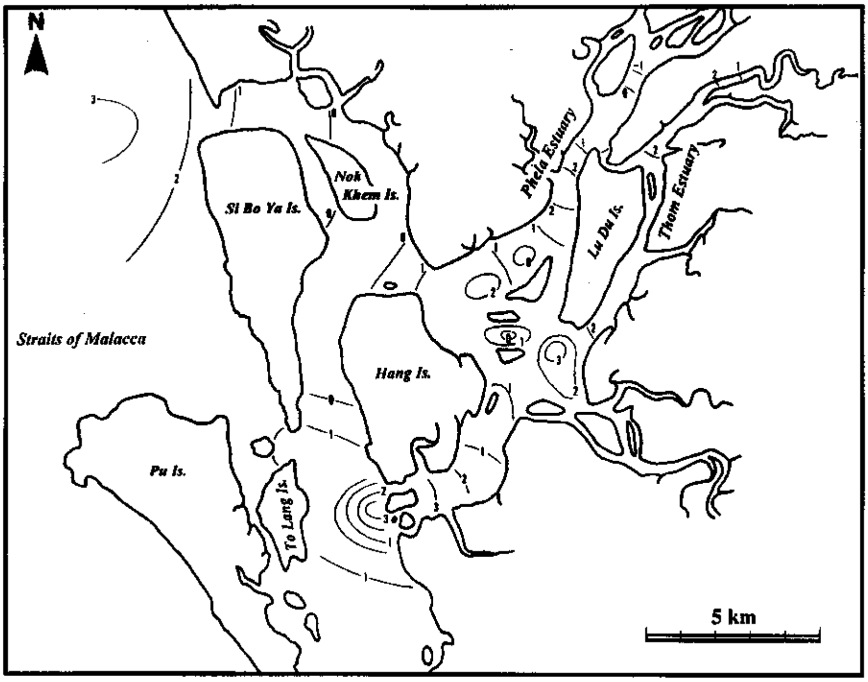

Fig. 11. Spatial distribution of sediment mean diameter (Inman, 1952) in Khlong Thom area, South Thailand.

shells and shell fragments are recognized in the sediments from the lower course. In contrast with this, plant debris and molluscan shell fragment bearing fine- to medium-grained sand, and molluscan shell and gravel bearing fine-grained sand are distributed in the lower and upper courses in the Phela Estuary. Benthic foraminifers, sponge microscleres and diatoms are occasionally recognized in the sediments. Fine- to very coarse-grained charcoals are frequently recognized in the sediments from both estuaries.

In the junction area, plant debris, molluscan shells and shell fragments bearing muddy fine-grained sand is dominated sediments in the southern part. Less than one millimetre thick reddish brown mud sometimes covers them. Benthic foraminifers, sponge microscleres and marine ostracodes are recognized in the sediments. Fine- to medium-grained charcoals are also common. On the other hand, molluscan shell and gravel bearing fine-grained sand covers the bottom surface in the northern part of the junction area. Gravels are composed mainly of lateritic rock fragments. Benthic foraminifers, ostracodes and sponge microscleres are frequently observed within the sediments. Fine- to medium-grained charcoals are also frequently contained. Bottom sediments from the channels that connect the junction area with the mouth area are composed of molluscan shell and plant debris bearing muddy sand in the southern channel and molluscan shell rich fine- to medium-grained sand around the northern channel. Benthic foraminifers, ostracodes, sponge spicules and microscleres are commonly recognized in both.

Bottom sediments in the southern part of the mouth area, south of the Pu and To Lang Islands, consist mainly of molluscan shell and shell fragment rich fine- to medium-grained sand. Benthic

Table 4. Proportional mud contents, sediment mean diameters and compositions of sandy sediments of the subaqueous sediments from the Satun area. (+++: dominant, +: common, +: present)

Station	Locality	Mud contents (weight %)	Mean diam. (in phi)	Terrigeneous Sediments: fine quartz	coarse quartz	lithic fragm.	charcoal	Biogenic Sediments: foram-inifer	ostra code	diatom	radio-larian	sponge spicule	sponge microsc.	echi-noide	plant debris	mollus. shell
ST97- 1	Straits of Malacca	94	3.80	++			+	+++	++						+++	+++
ST97- 2	Tam Ma Lung Bay	83	3.70	++		+	++	++	++	++		+	+	+	+++	+
ST97- 3	"	62	0.98	+++	+		+	++	+	+			+	+	++	+++
ST97- 4	"	92	3.90	++	+		++	++			+	+	+	+	+++	+
ST97- 5	"	97	3.95	++	+		++	++	+				+		++	+
ST97- 6	"	99	4.00<	++			++	+					+			
ST97- 7	"	91	3.83	++	+		++	+	+	+	+	+	+	+	++	++
ST97- 8	"	89	3.88	++	++	+	+	+	+			++	+	+	+++	+++
ST97- 9	"	41	2.25	++	++	+	+++	+	+		+	+			+++	+++
ST97-10	"	87	3.88	++	+		++	++	+					+	+++	+++
ST97-11	"	30	1.55	+++	+		+++	+							++	+
ST97-12	"	90	3.88	++	+		++	++	+				+	+	+++	+++
ST97-13	Ta Chin Estuary	50	1.45	+++	+	+	++	+				+	+		++	++
ST97-14	"	10	4.00<	++			+	+					+		++	+
ST97-15	"	2	0.13	++	+++	+	+	+					+		+	+
ST97-16	"	2	-0.25	+	+++		+	+				+			++	+
ST97-17	"	0	-0.25	+	+++			+							++	+
ST97-18	Straits of Malacca	33	2.75	+++		+	++	++	+					+	+	+++
ST97-19	"	7	-0.48	++	+	+	+	++	+			+		+	+	+++
ST97-20	"	73	3.75	++			+	++	++		+		+	+	+	+++
ST97-21	"	86	3.75	++			+	++	+				+		++	++
ST97-22	"	11	-1.14	+			++	++	++				+	+	+	+++
ST97-23	"	5	-0.25	+	+		+	++	++			+		+	+	+++
ST97-24	"	74	2.38	++		+	+	++	+					+	+	+++
ST97-25	"	32	3.00	++		+	++	++	+				+		++	+++
ST97-26	"	23	1.75	++		+	+	++	++				+	+	+	+++
ST97-27	"	7	-0.25	++			+	++	++			+		+	+	+++

foraminifers, ostracodes and sponge spicules are common in these sediments. Fine-grained and well rounded charcoal grains are commonly recognized. Lateritic rock fragments and mud balls are contained in the sediments from the southernmost sites KT97-23 and 24 both southwest off the Pu Island. In the northern part of the mouth area, between the Si Bo Ya and Hang Islands, bottom sediments are composed chiefly of molluscan shell and lateritic rock fragment bearing fine- to medium-grained sand. Benthic foraminifers, ostracodes, sponge spicules and microscleres are abundant in them. Further, such biogenic materials as molluscan shell and shell fragments are rich in the sediments obtained from the northern channels, between the Si Bo Ya and Nok Khem Islands and between the Nok Khem Island and the mainland. Very fine- to fine-grained charcoal grains are present in all sediments.

Molluscan shell and shell fragment rich fine-grained sand covers the bottom surface of the Straits of Malacca. Benthic foraminifers, marine ostracodes, sponge spines and microscleres, echinoide spines and fragments of bryozoas are abundant in the sediments, and a small amount of planktonic foraminifers and radiolarians are recognized. A certain amount of plant debris are contained in the sediments off the channel between the Si Bo Ya Island and the mainland. A small quantity of very fine- to fine-grained charcoals are recognized in all sediments.

Satun Area

Propotional mud contents, sediment mean diameter (Inman, 1952) and compositions of sandy

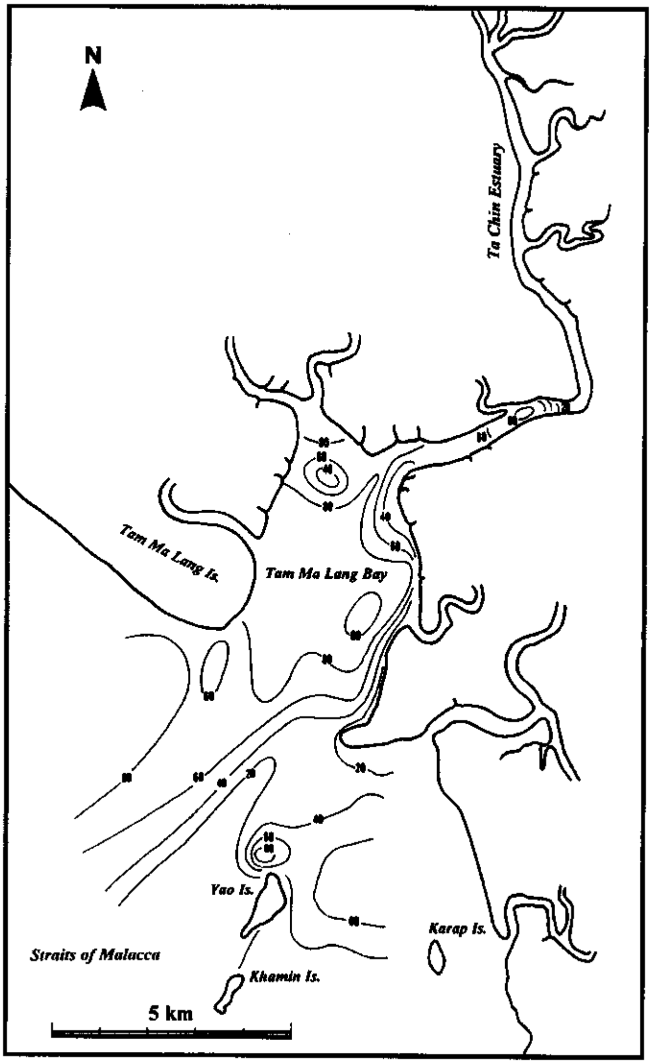

Fig. 12. Spatial distribution of proportional mud contents of entire sediments in Satun area, South Thailand.

sediments from the Satun area are shown in Table 4. Further, Figs. 12 and 13 show spatial distribution of proportional mud contents and sediment mean diameters of entire sediments from the area, respectively. In contrast with them in the Khlong Thom area, muddy sediments mostly cover the bottom surface of the Tam Ma Lung Bay and the western and eastern parts of the area of the Straits of Malacca, but coarse-grained sandy sediments are dominant in the Ta Chin Estuary, and the central part of the straits. Terrigeneous sandy sediments in whole area are composed mainly of fine-grained and/or very coarse-grained quartz with a small amount of muscovite and such heavy minerals as biotite, hornblende and zircon. Muddy sediments consist mainly of bluish grey coloured clay minerals.

Plant debris bearing bluish grey homogeneous mud mostly covers the bottom surface of the Tam Ma Lung Bay. Proportional mud contents are generally over 80 %. Plant debris and fine- to medium-grained charcoals are dominant. Molluscan shells and shell fragments, benthic foraminifers, ostracodes, and sponge spicules and microscleres are commonly recognized in the sediments.

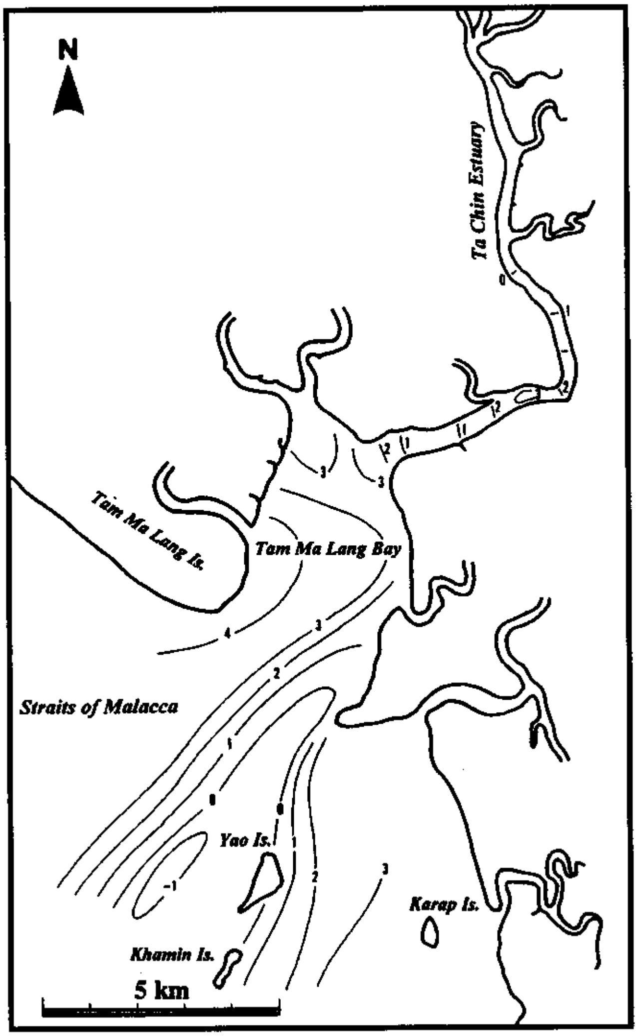

Fig. 13. Spatial distribution of sediment mean diameter (Inman, 1952) in Satun area, South Thailand.

However, the sediments distributed in a narrow subaqueous channel along the eastern margin of the bay are composed mainly of molluscan shell and shell fragment rich fine- to coarse-grained sand. Fine plant debris and comparatively large charcoals are also dominant. Benthic foraminifers, ostracodes, and sponge spicules and microscleres with a small amount of radiolarians are distinguished in the sediments from the channel. Large plant debris rich bluish grey sandy mud with a large amount of coarse-grained charcoals, up to a few centimetres long, is distributed in the northernmost of the bay.

In contrast with the bottom sediments in the Tam Ma Lung Bay, coarse-grained sandy sediments are distributed mostly in the Ta Chin Estuary area. Mud contents are generally less than 20 %. Sandy sediments are composed mainly of coarse- to very coarse-grained and angular-shaped quartz. Plant debris and fine- to medium-grained charcoals are frequently contained in the sediments, and molluscan shell fragments, benthic foraminifers and sponge spicules and microscleres are occationally recognized.

Bluish grey muddy sediments cover the bottom surface of the western and eastern parts of the

Straits of Malacca area within the survey area. Mud contents are generally more than 60 %. Molluscan shells and shell fragments, benthic foraminifers, ostracodes, sponge spicules and microscleres are commonly contained in the sediments. Further, a small amount of radiolarians and planktonic foraminifers are recognized. On the other hand, on the bottom surface of the central part of the straits area, around the Yao and Khamin Islands, mud contents are low less than 40 % in general, and sediment mean diameter is more than 2 ϕ (= 0.25 mm), because the sediments contain a great amount of molluscan shells and shell fragments. The composition of the terrigeneous sediments from the central part of the straits are same as that of the western and eastern marginal parts described in above. Fine- to medium-grained charcoals are frequently recognized in the sediments from whole area of the straits.

DISCUSSION

Depositional Setting of the Khlong Thom and Satun Areas

Topographic features of the Khlong Thom and Satun areas, South Thailand indicate that the depositional setting of their water areas are undoubtedly defined as estuarine environments. Water and sediment dynamics in estuaries are closely dependent upon the relative magnitude of tidal, river and wave processes (Prentice *et al.*, 1968; Prichard & Carter, 1971; Allen *et al.*, 1976; Leeder, 1982; Elliott, 1986). Prichard & Carter (1971) divided the water and sediment dynamics in estuaries into four such end members as; Type A: river-dominated estuaries where tidal and wave mixing processes are at a minimum, Type B: 'partially mixed' because of the effects of tidal turbulence which destroy the upper salt wedge interface and produce a more gradual salinity gradient from bed to surface water by both advectional and diffusional mechanisms, Type C: vertically homogeneous because strong tidal currents completely destroy the salt-water/fresh-water interface over the entire estuarine cross section, and Type D: theoretical end members of the estuarine continuum and they show both lateral and vertical homogeneity of salinity.

Both Khlong Thom and Satun areas are situated in the western coast of the central part of the Malay Peninsula where the width of the peninsula is narrow, less than 150 km, and undulations of the land areas are comparatively small. Accordingly, it is inferred that river water supply is generally small in both areas because drainage systems are undeveloped behind them. On the other hand, both areas open to the Andaman Sea and the Straits of Malacca where marked wave processes take place due to seasonal generation of cyclones in the northern part of the Indian Ocean. However, since the Khlong Thom area is situated in the southeastern mouth area of the Phang Nga Bay in where numerous small islands composed mainly of limestones (Department of Mineral Resouces, 1987) are distributed, the effect of waves from the Indian Ocean is reduced due to the existence of these islands. Further, the Si Bo Ya and Pu Islands situating between the mouth area and the Straits of Malacca shelter the inner parts of the water area from the waves of the open sea. The Satun area is also sheltered from the waves of the Indian Ocean by such large islands as the Ta Lu Tao and Langkawi Islands situating closely to the west of the area. Consequently, river water supply and wave processes can be disregarded to consider the sedimentary processes in both areas.

It is known that tidal ranges of both areas are wide three to four metres in maximum. Strong tidal currents at the maximum stages in both flooding and ebbing tides were observed in both areas, particularly in the mouth and junction areas in the Khlong Thom area, and the mouth area of the Tam Ma Lung Bay in the Satun area during the sediment samplings in the present study. Thus, it is concluded that tidal process gives the most dominant effect to the water and sediment dynamics in both areas.

Spatial distribution of salinity of the surface water shows a clear decrease from 27 ‰ in the Straits of Malacca area to 1.7 ‰ in the western end of the Thom Estuary in the Khlong Thom area. It also shows a certain amount of decrease from 28 ‰ in the straits area to 19 ‰ in the northern end of the Ta Chin Estuary within the Satun area. Spatial distribution of hydrogen ion exponent value of the surface water develops a tendency to that of salinity in both areas. Further, any marked differences in salinity are not recognized between the surface and bottom waters in the Khlong Thom area. Taking all these factors into consideration, the sedimentary environments around the mangrove habitats in the Khlong Thom and Satun areas are defined as 'Type C' estuary of Prichard & Carter (1971) that is the tidal currents dominated estuaries.

Subaqueous Sedimentary Processes around the Mangrove Habitats in Khlong Thom and Satun Areas : Estimation from Origin and Spatial Distribution of Terrigeneous, Biogenic and Artificial Sediments

Taking all the discussions on the above-stated depositional settings of the Khlong Thom and Satun areas, and the following discussions on the origin and spatial distribution of terrigeneous, biogenic and artificial materials in the bottom sediments into consideration, estimated current course ways of flooding and ebbing tides in the Khlong Thom and Satun areas are illustrated in Figs. 14 and 15, respectively. Further, on the basis of the following discussions, it is concluded that the sedimentary processes, particularly sediment transportation in the water areas around the mangrove habitats in both areas are subjected mainly by the directions and magnitudes of flooding and ebbing tidal currents controlled by the onshore and subaqueous topographic properties.

Sandy sediments mostly cover the bottom surface of the Khlong Thom area, while muddy sediments dominate in the Satun area. As already described, the undifferentiated Jurassic to Cretaceous sedimentary rocks consisting mainly of consolidated sandstones, shales and conglomerates with a small amount of limestones are widely distributed within and behind the Khlong Thom area (Department of Mineral Resouces, 1987). It is inferred that these strata produce a large amount of sandy sediments due to heavy weathering in the tropical regions and the sediments are transported directly into the water area. This idea is supported by the dominance of fine-grained quartz in the subaqueous sediments from the most sites. On the other hand, the Ordovician Thung Song Group composed chiefly of limestones with a small amount of shales and sandstones is distributed in the northeastern and eastern parts of the Satun area (Department of Mineral Resouces, 1987), and the group forms long and narrow hills on both sides of the Ta Chin Estuary. Since these strata comprise mainly of limestones that provide markedly less quantity of sandy sediments, it is undoubted that sandy sediment production rate in the Satun area is conspicuously low in compare with that in the Khlong Thom area. Accordingly, it is concluded that the differences of subaqueous sediment composition between the Khlong Thom and Satun areas is resulted by their differences of the geological settings.

In spite of the surface sediment properties are completely different between the Khlong Thom and

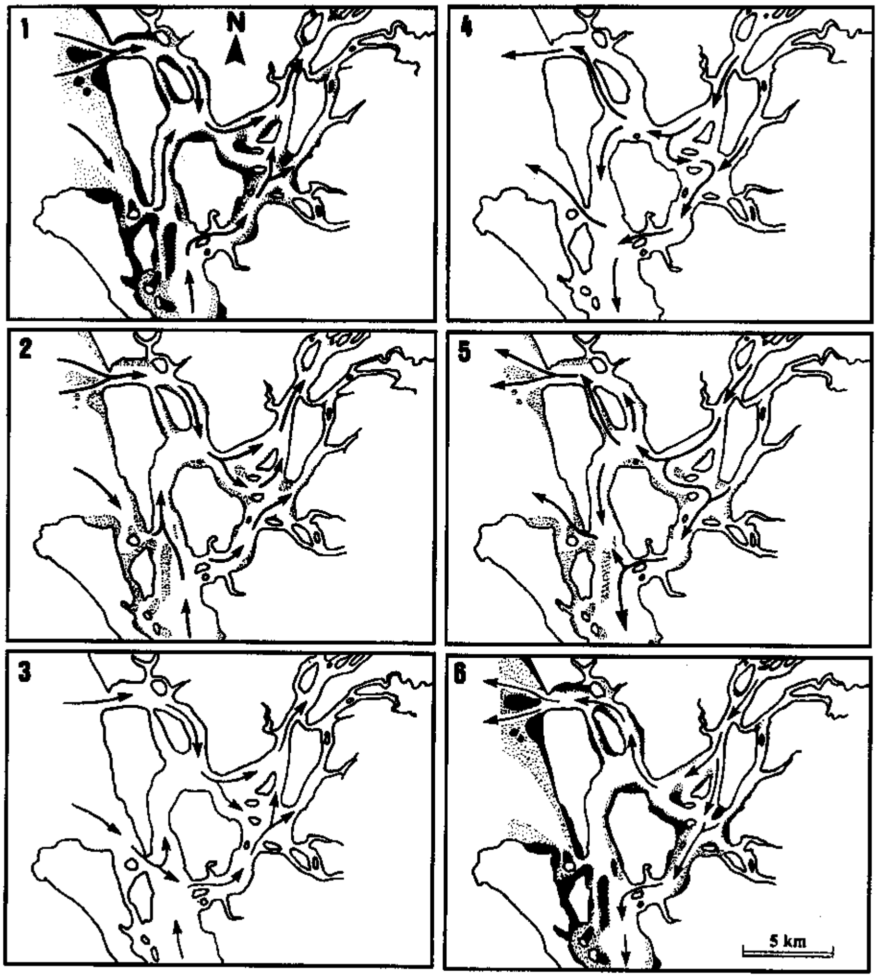

Fig. 14: Inferred course ways of flooding and ebbing tidal currents around the mangrove habitats in the Khlong Thom area, South Thailand. (1: beginning stage of flooding, 2: maximum stage of flooding, 3: final stage of flooding, 4: beginning stage of ebbing, 5: maximum stage of ebbing, 6: final stage of ebbing, dotted part: area where water depth shallower than 1 metre, black part: emerged sandflats, thickness of lines indicate the magnitude of tidal currents)

Satun areas as described and discussed in above, certain trends on grain-size distributions of terrigeneous sediments are recognized in both areas. Since sandy sediments are dominated wholly in the subaqueous sediments from the Khlong Thom area, the sandy sediments distributed in the Straits of Malacca area are distinguished clearly from them in the Thom and Phela Estuarine areas. The former is composed mainly of well sorted very fine- to fine-grained quartz with a small amount of heavy minerals, the latter consists of poorly sorted fine- to medium-grained and angular-shaped quartz and lateritic rock fragments. The sandy terrigeneous sediments distributed in the junction and mouth areas are mixtures of them, but the contents of coarse- to very coarse-grained quartz in entire

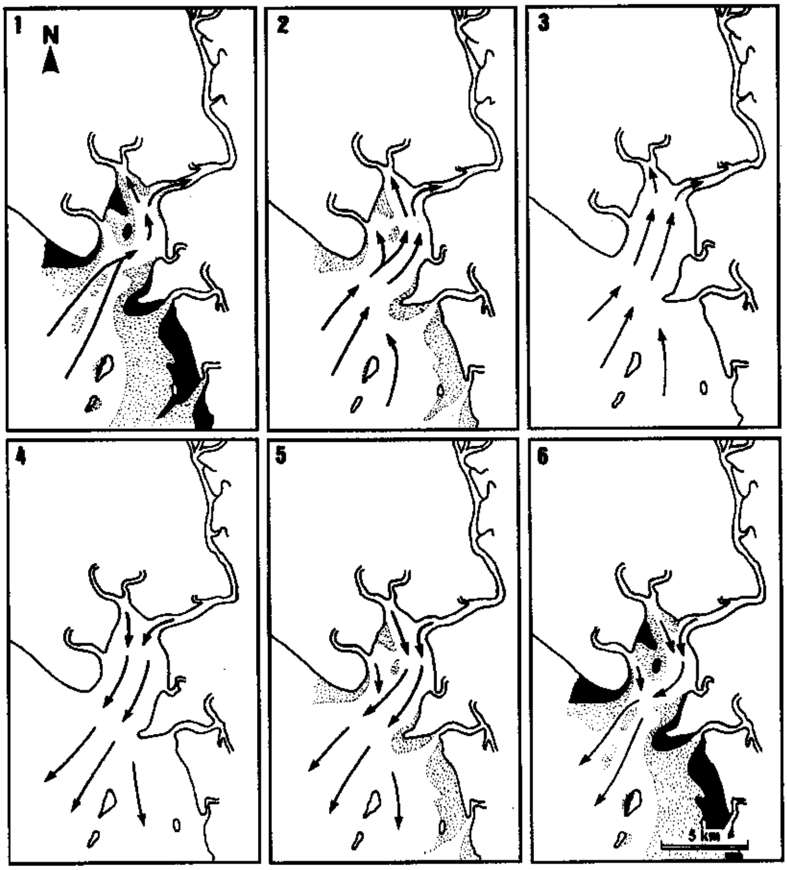

Fig. 15: Inferred course ways of flooding and ebbing tidal currents around the mangrove habitats in the Satun area, South Thailand. (1: beginning stage of flooding, 2: maximum stage of flooding, 3: final stage of flooding, 4: beginning stage of ebbing, 5: maximum stage of ebbing, 6: final stage of ebbing, dotted part: area where water depth shallower than 1 metre, black part: emerged sandflats, thickness of lines indicating the magnitude of tidal currents)

sediments decrease from the inner to outer parts within the areas. Accordingly, it is inferred that a certain amount of sediment exchange takes place uniformly by flooding and ebbing tidal currents between the inner and outer parts of the water areas in the Khlong Thom area.

On the other hand, in the Satun area where muddy sediments are distributed in most bottom surface in the Tam Ma Lung Bay area, coarse- to very coarse-grained and angular-shaped quartz is dominant in the Ta Chin Estuary area. The coarse quartz grains are undoubtedly derived from the mountains and hills situated along both sides of the estuary, and they are traceable in the sediments from a narrow subaqueous channel recognized along the eastern margin of the bay. The channel is extended southwestwardly into the area of the Straits of Malacca where coarse-grained biogenic sediments consisting mainly of molluscan shells and shell fragments are distributed. These coarse-grained biogenic sediments are particularly dominant in the bottom sediments from the channel but the coarse-grained quartz are very rare. These biogenic sediments are commonly recognized in the sediments from the eastern marginal subaqueous channel in the bay to the southern part of the Ta Chin Estuary. Consequently, it is inferred that the coarse quartz grains originated from the area around the Ta Chin Estuary are transported by strong ebbing tidal currents into the subaqueous channel in the bay, but most of them do not reach to the straits area due to probably by a sudden decline of the current velocity at the bay mouth. In contrast of this, coarse biogenic sediments in the straits area are transported into the bay area by strong flooding tidal currents, and some of them reach to the southern part of the estuary.

Such remains of benthic micro-organisms as benthic foraminifers and marine ostracodes are dominant in the subaqueous sediments from the Straits of Malacca area in both Khlong Thom and Satun areas, and they are undoubtedly principal marine forms living on the sea floor in the straits. A certain number of these remains are also recognized in the bottom sediments from the inner parts of both water areas. There are two possibilities that these remains detected in the inner parts of the water areas are either transported physically from the straits area or survived due to a certain amount of saline water supply both by flooding tidal currents. Such quantitative analysis of these micro-organic remains as properties of their assemblages and separation of living species/dead tests have been still under the investigation. However, it is roughly assumpted that existence of above-mentioned remains in the bottom sediments from the inner parts of the water areas indicates a certain effect of flooding tides from the straits. Accordingly, there is a high possibility that these remains can be used as traceable sediments originated in the saline water region.

In the Khlong Thom area, both benthic foraminifers and marine ostracodes are dominant in the sediments from the mouth and the northern part of the junction areas. They are traceable in the sediments from the innermost part of the Phela Estuary. However, since the bottom sediments from the southern part of the junction area contain a certain amount of these remains, they are rare or absent in the sediments from the southern Thom Estuary. Thus, on the basis of the above-stated assumption, it is inferred that the mouth area is always under the condition of saline waters. The main flooding tides flow into the junction area through the channel on the north of the Hang Island, then the tides flow straight up into the northern Phela Estuary. The supplementary tides also flow into the junction area through the narrow channels on the south of the island, but only a limited amount of saline water flows into the southern Thom Estuary. On the other hand, the remains of marine micro-organisms are still abundant in the sediments from the bay mouth and eastern part of the Tam Ma Lung Bay in the Satun area. They are also recognized commonly in the sediments from the western and the head areas of the bay. In spite of number and variety of the remains are clearly decreased, they are still detected in the sediments from the northernmost part of the Ta Chin Estuary. Consequently, it is inferred that the whole area of the bay is under the condition of saline waters, and the flooding tides flow into the Ta Chin Estuary and they reach to its northernmost part.

Charcoal grains in various sizes are frequently distinguished within the bottom sediments in both Khlong Thom and Satun areas. They are particularly dominant in the sediments from the innermost parts or near the villages and/or charcoal kilns of the areas. Thus, it is no doubt that they are derived only from the human villages and/or kilns located in and around the areas. To put it in different terms, these charcoal grains can be used as an traceable sediments produced by human activities. These charcoal grains are dominant in the sediments from the areas in both Thom and Phela Estuaries and the junction area in the Khlong Thom area. They are commonly recognized in the sediments from the mouth area, but rare in the area of the Straits of Malacca. A clear decrease of both their grain size and grain surface roughness from the inner estuarine head to outer straits areas are observed. Villages and charcoal kilns are mostly located around the estuarine and junction areas. Accordingly, it is concluded that the ebbing tides flow uniformly out from both estuaries to the mouth area through the junction area and the channels on the north and south of the Hang Island. They reduce the current magnitude in the mouth area, then flow out to the straits through the northern and southern channels.

In contrast of this, the charcoal grains are frequently recognized in all sediments in the Satun area. A decrease of both their grain size and grain roughness from the bay head area of the Tam Ma Lung Bay to both areas of the Straits of Malacca and the northernmost part of the Ta Chin Estuary is distinguished. There is the largest charcoal kiln on the bay head area, but no such kilns are located around the Ta Chin Estuary. Thus, the charcoal grains in the sediments from the estuarine area is inferred to be transported from the bay head area by flooding tides, and ebbing tides transport uniformly these grains from the head area to the areas of the straits probably through the subaqueous channel on the eastern margin of the bay.

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塚脇真二，浅野いずみ，神谷隆宏　南タイのクロントムならびにサトゥン地域に分布するマングローブ林周辺水域における堆積作用

南タイのクロントムならびにサトゥン両地域に分布するマングローブ林周辺水域での堆積作用の解明を目的とし，1996 年 12 月および 1997 年 8 月にクロントム地域から 56 ならびにサトゥン地域から 53 の水底堆積物をそれぞれ採取し，堆積物の組成およびその水平分布・変化を調べた。また，内部水域にへの海水の到達範囲の確認および全域にわたる水底地形の把握のため，表層水の水質調査および測深を採泥と並行して行った。クロントム地域の水底には全域にわたって砂質堆積物が卓越する。これに対してサトゥン地域ではおもに泥質堆積物が分布する。これは両地域における砕屑性堆積物の主供給源となる後背地の地質をそれぞれ反映するものと考えられる。また，両地域の堆積物に含まれる砕屑性堆積物が主として両地域の背後に分布する古～中生界に由来するのに対し，底生有孔虫や介形虫などの生物源堆積物は，おもにマラッカ海峡などの海底を起源とするものといえる。これに加え，いずれの堆積物にも豊富に含まれる炭粒子は，マングローブ林内または周辺地域の村落や炭焼窯から流出したものと判断される。このように，これらの堆積物はいずれも生産地が特定されるものであり，両調査地ともに生産地から離れるにつれて，これらの堆積物の堆積物全体に対する含有量の減少や細粒化が追跡される。したがって，これらの堆積物の粒度変化や含有量の変化に加え，両地域における陸上・水底地形の特徴にもとづき，両地域における堆積物の移動過程・経路が推定される。