Geomorphological evolution and mangrove habitat dynamics of the northern Mekong River delta and the Dong Nai River delta

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Chapter 7

GEOMORPHOLOGICAL EVOLUTION AND MANGROVE HABITAT DYNAMICS RELATED TO HOLOCENE SEA-LEVEL CHANGES IN THE NORTHERN MEKONG RIVER DELTA AND THE DONG NAI RIVER DELTA, SOUTHERN VIETNAM

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ABSTRACT

This study examines sea-level changes, delta evolution and mangrove habitat dynamics during the mid to late Holocene in the northern Mekong River Delta and the Dong Nai River Delta using new data from 44 boreholes and 29 radiocarbon ages, together with existing data. The sea level was -0.4 ± 0.5 m at ca.7300 cal BP and reached between +1 and +2 m around 6500 cal BP. Sea level at ca. 2000 cal BP was similar to or

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slightly lower than the present level. Between 7000 and 6000 cal BP, mangrove forests dominated by *Rhizophora* were distributed approximately 60 to 80 km inland from the present coastline on a delta formed by small rivers flowing from the north. The *Rhizophora* forests changed into other mangrove forests after 6000 cal BP with sea-level fall and sedimentation. The delta front of the Mekong River reached approximately 140 km inland from the present coastline around 4500 cal BP. Between 4500 and 2500 cal BP, the Mekong River Delta expanded rapidly. After 2100 cal BP, the mangrove forest, which stretched to about 120 km inland from the present coastline, changed to a freshwater environment during a fall in sea level. The Can Gio mangrove forests on the Dong Nai River Delta have formed during the last 2600 years from southwest to northeast with delta evolution and covered their present area by 400 cal BP.

INTRODUCTION

The Mekong River Delta, which is mainly located in southern Vietnam, is one of the largest deltas in Asia. Geological and geomorphological studies on the Mekong River Delta have been carried out since the 1960s. Gagliano and McIntire (1968) presented a morphostratigraphic classification of the deltaic successions. Fontaine (1970a, b, 1971) reported ^{14}C ages related to paleo-sea levels and the geomorphologic evolution of the Mekong River Delta, and subsequently discussed sea-level changes during the last 6000 years based on these ^{14}C ages and geomorphologic evidence, such as marine notches (Fontaine, 1974). Nguyen et al. (2000) examined delta evolution using borehole data and existing ^{14}C data. Most recently, Ta and coworkers have made several contributions to our understanding of the Mekong River Delta including, descriptions of: 1) the depositional environment of delta sediments based on diatom and foraminifera assemblages obtained from a 71 m core (Ta et al., 2001), 2) the progradation of the Mekong River Delta along the main channel during the last 5000 years (Ta et al., 2002a), 3) the sediment discharge during the last 3000 years based on data from six cores that reached Pleistocene sediments as well as delta evolution (Ta et al., 2002b).

The geological and geomorphological evolution of the Mekong River Delta in Vietnam has been clarified, especially along the main channel (Nguyen et al., 2000; Ta et al., 2001, 2002a, b). However, there is little information regarding the fringing areas where the sediment input seems to have been relatively small. Generally, mangrove forests dominated by *Rhizophora* sp. form in regions of small sediment input, and maintain their habitat by accumulating mangrove peat (Fujimoto et al., 1996, 1999). Therefore, to discuss the processes influencing delta formations in the tropics, the habitat dynamics of mangrove forests need to be examined together with sedimentation processes.

The mangrove peat layer provides direct information regarding paleo-sea level because the tidal environment in which it forms is restricted between around mean sea level and around mean high tide level (Mochida et al., 1999). Sea-level changes in the Mekong River Delta are not yet fully understood, despite earlier work by Fontaine (1974), which examined these changes using a few ^{14}C ages related with paleo-sea level.

This study has two specific aims, first, to reconstruct the relative sea-level changes during the mid to late Holocene based on the data obtained from mangrove sediments in the northern Mekong River Delta and the adjacent small delta formed in the lower reach of the Dong Nai

River. Second, the geomorphological evolution of the delta and mangrove habitat dynamics are examined in relation to these changes in sea level, focusing the distribution of mangrove peat layers through time.

STUDY AREAS

The area that was studied is located north of the Mekong River, where four small rivers, the Dong Nai, the Sai Gon, the Vam Co Dong and the Vam Co Tay, flow from the north and northwest (Figure 1). The Dong Nai River basin, with a catchment area of about 40,000 km^2, is the largest basin among these four rivers, but it is only 5 % of the Mekong River Basin. The sediment supply to the area appears to be relatively small because of the small size of the watershed and the large distance from the main channel of the Mekong River. Therefore, the marine deposits, including mangrove deposits, are shallowly buried and acid sulfate soil is widely distributed.

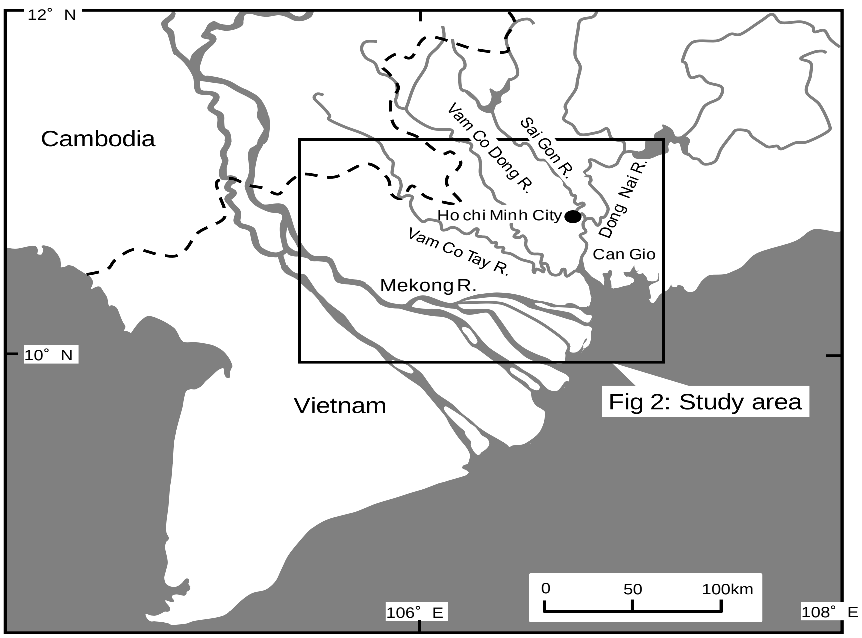

Figure 1. Map showing the study area.

At the mouth of the Dong Nai River in southeastern Ho Chi Minh City, a small delta that is covered by mangroves has formed (Figure 2). This mangrove forest is one of the largest mangrove forests of southern Vietnam, along with the forest on the Ca Mau Peninsula at the southern tip of the Mekong River Delta. The mangrove area on the Dong Nai River Delta is called the Can Gio District. Although the mangrove forests in Can Gio were almost entirely destroyed by herbicides sprayed by the U.S. military during the Vietnam War, they have mostly recovered due to aggressive replanting by the Vietnamese. About 40,000 ha of reforested mangrove forests were designated as the Mangrove Biosphere Reserve by UNESCO in 2000 (Hong, 2004).

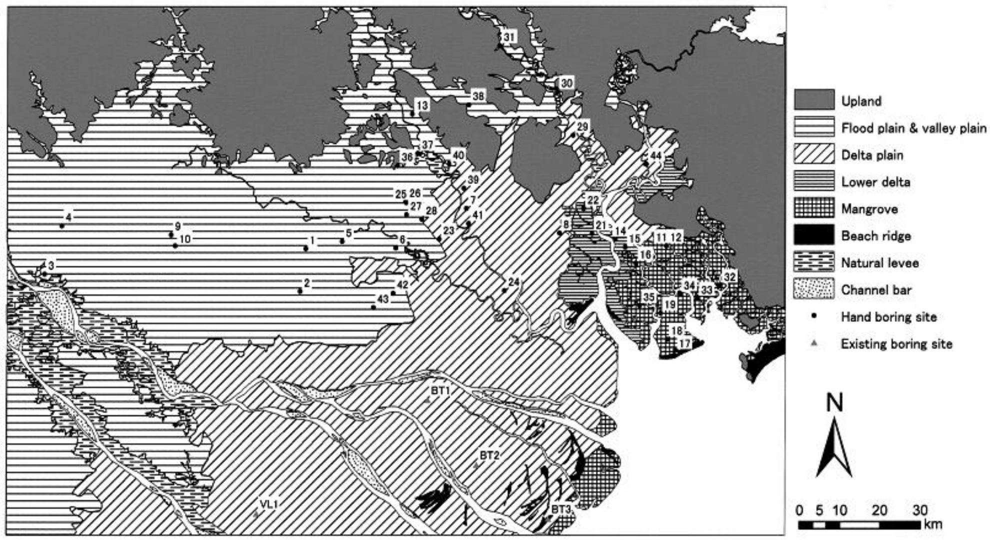

Figure 2. Geomorphological map of the study area with borehole sites designated by numerals.

METHODS

We obtained data from 44 hand boreholes and 29 radiocarbon ages as part of this study. The radiocarbon ages are mainly from mangrove wood fragments and were calibrated to calendar years using CALIB 5.0. These data together with the existing data (Ta et al., 2001, 2002a, b) were then used to examine the geomorphological evolution, mangrove habitat dynamics and sea-level changes.

The elevation of the borehole sites was estimated using SRTM data available from the NASA website (ftp://e0srp01u.ecs.nasa.gov/srtm/) and 1:50,000 topographical maps downloaded from the Vietnam Center and Archive of Texas Tech University website (http://www.virtual.vietnam.ttu.edu/starweb/virtual/maps/servlet.starweb?path=virtual/maps/maps_new.web). When the estimated elevation differed between the SRTM data and the topographical map, the value read from the topographical map was adopted because the SRTM data, which is about 90 m mesh, may be affected by tree and building heights and was sometimes missing. The elevation based on the topographical map was estimated from the values of the nearest two or three control points. When the values differed between these points, the elevation was estimated to be between these values.

The geomorphological map shown in Figure 2 was created from the LANDSAT images taken during 2001 and 2002, which were downloaded from the University of Maryland website (http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp).

DISTRIBUTION OF MANGROVE PEAT LAYERS AND THE TIMELINE OF THEIR FORMATION

The latitude and longitude of the borehole sites, along with their estimated elevations, are shown in Table 1. The results of the radiocarbon dating and the corresponding calibrated ages are shown in Table 2. The values in parentheses for calibrated age represent the median probability. These values are indicated in Figures 3 and 4. The ground elevation of the alluvial plain in the study area is on average between +1 and +2 m (Table 1).

Table 1. Location of borehole sites and their estimate elevation

Site No.	Borehole No.	Area	Latitude (N)	Longitude (E)	Elevation estimated by SRTM(m)	Elevation estimated by topographical map (m)	Land use/condition
1	010303-1	VCTR	10° 37′ 17.0″	106° 05′ 12.9″	0	2	Cultivated field
2	010304-1	MR/VCTR	10° 31′ 35.2″	106° 04′ 28.3″	1	2	Cultivated field
3	010305-1	MR	10° 33′ 53.0″	105° 30′ 14.2″	5	2	Natural levee
4	010608-1	MR	10° 40′ 21.5″	105° 32′ 32.0″	2	2	Paddy field
5	020608-1	VCTR	10° 38′ 15.9″	106° 10′ 04.6″	1	2	*Melaleuca* forest
6	020608-2	VCTR	10° 37′ 22.7″	106° 17′ 17.3″	1	1-2	Paddy field
7	020608-3	VCDR	10° 42′ 42.1″	106° 26′ 42.1″	1	1	Sugarcane field
8	020608-4	DNR	10° 39′ 24.5″	106° 39′ 10.9″	2	1-2	Paddy field
9	020808-1	MR	10° 39′ 09.7″	105° 47′ 10.3″	2	2	Swamp
10	020808-2	MR	10° 37′ 41.9″	105° 47′ 43.2″	6	2	Melaleuca forest
11	040821-1	CG	10° 37′ 40.1″	106° 53′ 31.5″	3	1	Mangrove forest
12	040822-1	CG	10° 37′ 40.1″	106° 53′ 31.5″	3	1	Mangrove forest
13	040828-1	VCDR	10° 55′ 22.0″	106° 19′ 28.2″	1	1-2	Paddy field
14	050819-1	CG	10° 38′ 31.4″	106° 46′ 41.4″	1	1	Abandaned paddy field
15	050819-2	CG	10° 37′ 30.4″	106° 48′ 00.0″	1	1	Abandaned paddy field
16	050819-3	CG	10° 35′ 21.5″	106° 49′ 26.4″	2	1	Mangrove forest
17	050820-1	CG	10° 23′ 44.1″	106° 54′ 45.5″	2	2	Salt field
18	050820-2	CG	10° 25′ 08.6″	106° 53′ 40.5″	1	0-1	Mangrove scrub
19	050820-3	CG	10° 28′ 40.1″	106° 52′ 44.8″	6	1	Mangrove forest
20	050820-4	CG	10° 30′ 55.1″	106° 51′ 29.5″	7	1	Mangrove forest
21	050822-1	DNR	10° 39′ 18.3″	106° 43′ 32.5″	0	1	Paddy field
22	050822-2	DNR	10° 42′ 40.8″	106° 42′ 24.6″	2	?	Waste land
23	050823-1	VCTR/VCDR	10° 38′ 34.8″	106° 23′ 05.5″	1	1	Sugarcane field

Table 1. Continued

Site No.	Borehole No.	Area	Latitude (N)	Longitude (E)	Elevation estimated by SRTM(m)	Elevation estimated by topographical map (m)	Land use/condition
24	050823-2	VCTR/VCDR	10° 31′ 41.7″	106° 31′ 49.4″	1	1	Paddy field
25	050824-1	VCTR/VCDR	10° 43′ 29.0″	106° 18′ 39.7″	0	1-2	Grazing land
26	050824-2	VCTR/VCDR	10° 43′ 37.1″	106° 18′ 35.3″	2	1-2	Cultivated field
27	050824-3	VCTR/VCDR	10° 41′ 51.8″	106° 18′ 41.9″	0	1	Paddy field
28	050824-4	VCTR/VCDR	10° 41′ 14.5″	106° 20′ 46.3″	1	1	Cultivated field
29	050825-1	SGR	10° 52′ 31.4″	106° 40′ 58.1″	0	2	Cultivated field
30	050825-2	SGR	10° 58′ 20.9″	106° 38′ 49.1″	2	?	Cultivated field
31	050825-3	SGR	11° 04′ 31.7″	106° 31′ 07.5″	1	?	Paddy field
32	060821-1	CG	10° 32′ 20.4″	107° 00′ 44.9″	4	1	Mangrove forest
33	060821-2	CG	10° 30′ 36.7″	106° 57′ 41.4″	2	1	Mangrove scrub
34	060821-4	CG	10° 31′ 12.1″	106° 55′ 22.1″	4	1	Mangrove forest
35	060821-5	CG	10° 29′ 39.5″	106° 49′ 56.4″	2	1	Mangrove forest
36	061005-1	VCDR	10° 48′ 34.4″	106° 17′ 16.3″	2	2-3	Paddy field
37	061005-2	VCDR	10° 50′ 05.7″	106° 20′ 13.1″	0	2	Melaleuca forest
38	061005-3	VCDR	10° 56′ 36.8″	106° 27′ 00.3″	0	1	Waste land
39	061006-1	VCDR	10° 45′ 25.5″	106° 26′ 21.5″	1	1	Sugarcane field
40	061006-2	VCDR	10° 48′ 41.1″	106° 24′ 21.6″	0	1	Paddy field
41	061006-3	VCDR	10° 40′ 40.9″	106° 26′ 59.9″	1	1	Cultivated field
42	061007-1	MR/VCTR	10° 31′ 19.8″	106° 16′ 56.3″	3	1	*Melaleuca* forest
43	061007-2	MR/VCTR	10° 29′ 32.1″	106° 14′ 03.2″	2	1	*Eucalyptus* forest
44	070118-1	DNR	10° 48′ 38.1″	106° 50′ 48.7″	0	1-2	Cultivated field

MR: Mekong River, VCTR: Vam Co Tay River, VCDR: Vam Co Dong River, DNR: Dong Nai River, SGR: Sai Gon River, CG: Can Gio

Table 2. Radiocarbon ages obtained from the northern Mekong River Delta and the Dong Nai River Delta

Index point No.	Area	Site No.	Lob.code no.	Depth (cm)	Sample	$\delta^{13}C$	Conventional age (^{14}C BP)	2σ calibrated age (cal BP)	Sampling horizon
1	CG	19	NUTA2-10784	176-178	wood frag.	-28±1	400±30	330-360, 430-(480)-510	upper horizon of lower tidal-flat deposit
2	CG	20	NUTA2-10867	83	wood frag.	-30±1	600±30	550-(600)-650	middle horizon of mangrove organic deposit
3	CG	16	NUTA2-10868	115	wood frag.	-30±1	1320±30	1180-1210, 1230-(1270)-1300	mangrove peat
4	CG	11	NUTA2-8858	70-74	wood frag.	-26±1	330±30	310-(390)-470	mangrove peat
5	CG	12	NUTA2-8859	143-145	wood frag.	-28±1	330±30	310-(390)-470	upper horizon of lower mangrove organic deposit
6	CG	32	IAAA-62134	133-141	wood frag.	-23.2±0.8	360±30	320-400, (410), 420-500	bottom horizon of mangrove peat
7	CG	34	IAAA-62135	146-148	wood frag.	-25.9±0.8	1790±30	1620-1670, 1680-(1720)-1820	lower horizon of mangrove peat
8	CG	35	IAAA-62136	125	wood frag.	-21.1±1.0	2530±40	2480-(2610)-2750	lower horizon of mangrove organic deposit
9	DNR	44	IAAA-70004	84	wood frag.	-28.4±0.5	5530±50	6210-6240, 6270-(6330)-6420	upper horizon of lower mangrove organic deposit
10	DNR	44	IAAA-63122	240	wood frag.	-25.9±0.8	6590±40	7430-(7490)-7520, 7530-7560	bottom horizon of lower mangrove organic deposit
11	SGR	29	NUTA2-10782	80-82	wood frag.	-31±1	5660±40	6320-(6440)-6540	upper horizon of lower tidal-flat deposit
12	SGR	29	NUTA2-10783	494-496	wood frag.	-29±1	6970±40	7690-(7800)-7870, 7900-7930	estuarine deposit
13	SGR	30	IAAA-51733	93-96	wood frag.	-28.6±0.8	4850±40	5480-5540, 5570-(5600)-5660	upper horizon of lower tidal-flat deposit
14	SGR	30	NU-1773	167-200	wood	-28.9	4470±80	4880-(5120)-5310	estuarine deposit
15	VCDR	13	NUTA2-8866	85-86	Plant frag.	-29±1	5240±40	5920-(6000)-6120, 6150-6180	top horizon of mangrove organic deposit
16	VCDR	13	NUTA2-9050	144	peat	-26±1	6240±30	7020-7120, 7150-(7180)-7250	bottom horizon of mangrove peat

Table 2. Continued

Index point No.	Area	Site No.	Lob.code no.	Depth (cm)	Sample	$\delta^{13}C$	Conventional age (^{14}C BP)	2σ calibrated age (cal BP)	Sampling horizon
17	VCDR	39	IAAA-62137	70	wood frag.	-26.8±0.9	5750±40	6450-(6550)-6650	bottom horizon of mangrove organic deposit
18	VCDR	39	IAAA-62138	346-353	Plant remains	-29.5±0.9	6550±40	7420-(7460)-7520, 7530-7560	estuarine deposit
19	VCTR/ VCDR	23	NUTA2-10863	73-75	wood frag.	-25.0±1.0	6130±30	6940-(7010)-7160	upper horizon of mangrove organic deposit
20	VCTR/ VCDR	23	IAAA-51734	195-199	wood frag.	-27.5±0.9	6580±40	7430-(7480)-7520, 7530-7560	botttom horizon of mangrove organic deposit
21	VCTR/ VCDR	25	NUTA2-10784	95-97	wood frag.	-24±1	6090±40	6850-(6960)-7160	upper horizon of mangrove peat
22	VCTR/ VCDR	28	NUTA2-10828	57-63	wood frag.	-29±1	4420±30	4870-(5000)-5060, 5190-5220, 5230-5260	top horizon of mangrove organic deposit
23	VCTR/ VCDR	28	NUTA2-10892	96-99	wood frag.	-29±1	4610±30	5290-5330, 5380-(5400)-5450	bottom horizon of mangrove organic deposit
24	MR/ VCTR	42	IAAA-62139	105-110	wood frag.	-25.0±1.0	6060±50	6750-6770, 6780-(6920)-7030, 7060, 7110-7150	upper horizon of mangrove peat
25	MR/ VCTR	2	NUTA2-3565	138	wood frag.	-25.4	6170±30	6980-(7080)-7170	top horizon of mangrove peat
26	MR/ VCTR	2	NUTA2-3566	244	wood frag.	-33.0	6360±40	7180-7210, 7240-(7300)-7420	bottom horizon of mangrove peat overlying Pleistocene
27	MR	3	NUTA2-4304	200	wood frag.	-26.2	4020±40	4410-(4490)-4590, 4600-4610	upper horizon of mangrove organic deposit
28	MR	3	NUTA2-4306	500	Plant remains	-27.2	6560±40	7420-(7470)-7520, 7530-7560	estuarine deposit
29	MR	10	NUTA2-4545	215-220	wood frag.	-24.4	2130±40	2000-(2110)-2180, 2240-2300	middle horizon of lower mangrove organic deposit

MR: Mekong River, VCTR: Vam Co Tay River, VCDR: Vam Co Dong River, DNR: Dong Nai River, SGR: Sai Gon River, CG: Can Gio.

The Northern Mekong River Delta

The distribution areas of mangrove peat in the northern Mekong River Delta are located about 60 to 80 km inland from the present coastline, in what are now the backmarshes between the Mekong and the Vam Co Tay Rivers, and the Vam Co Dong River and Pleistocene hills (Figures 2 and 3). These mangrove peat layers, which were overlain by about 1 m thick silt or clay layer, were formed between 7000 and 6000 cal BP (Figure 3). We found no mangrove peat layer younger than 6000 cal BP in the northern Mekong River Delta, although mangrove organic deposits indicating ages between 5400 and 4500 cal BP have been found (Sites 3 and 28 in Figure 3). A Peat layer younger than 2100 cal BP at Site 10 has formed under a *Melaleuca* forest but in a mangrove forest. Pleistocene deposits are shallowly buried in the area.

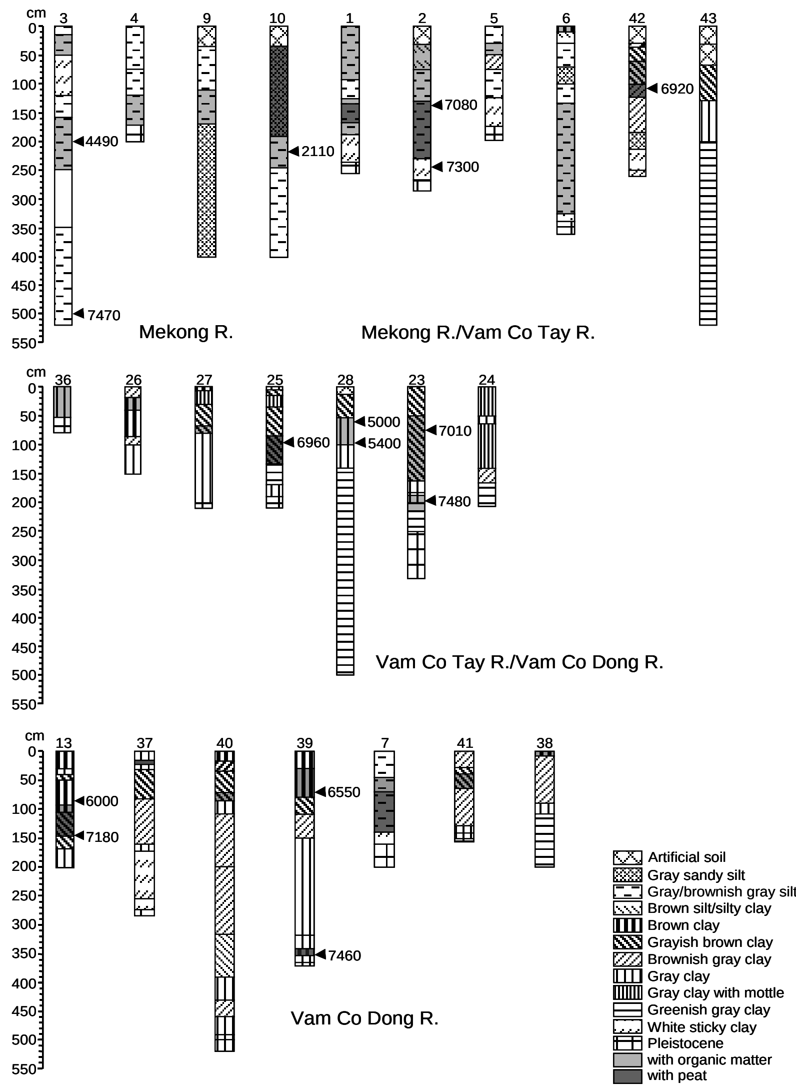

Figure 3. Bore columns from the northern Mekong River Delta.

The Dong Nai River Delta

At the Dong Nai River Delta, mangrove peat layers, formed between 1700 and 400 cal BP and overlain by 0.5 to 1.2 m thick clay layer, were widely distributed in Can Gio (Figure 4). The oldest mangrove organic layer obtained from Can Gio indicated around 2600 cal BP at Site 35. At Site 44, which is located about 50 km inland from the present coastline, a peaty deposit approximately 10 cm thick was found, and calibrated ages of approximately 6300 cal BP and 7500 cal BP were obtained from the upper and bottom horizons, respectively, of underlying the mangrove organic layer. At Sites 8, 21 and 22 on the right bank of the Dong Nai River, mangrove organic layers were not found.

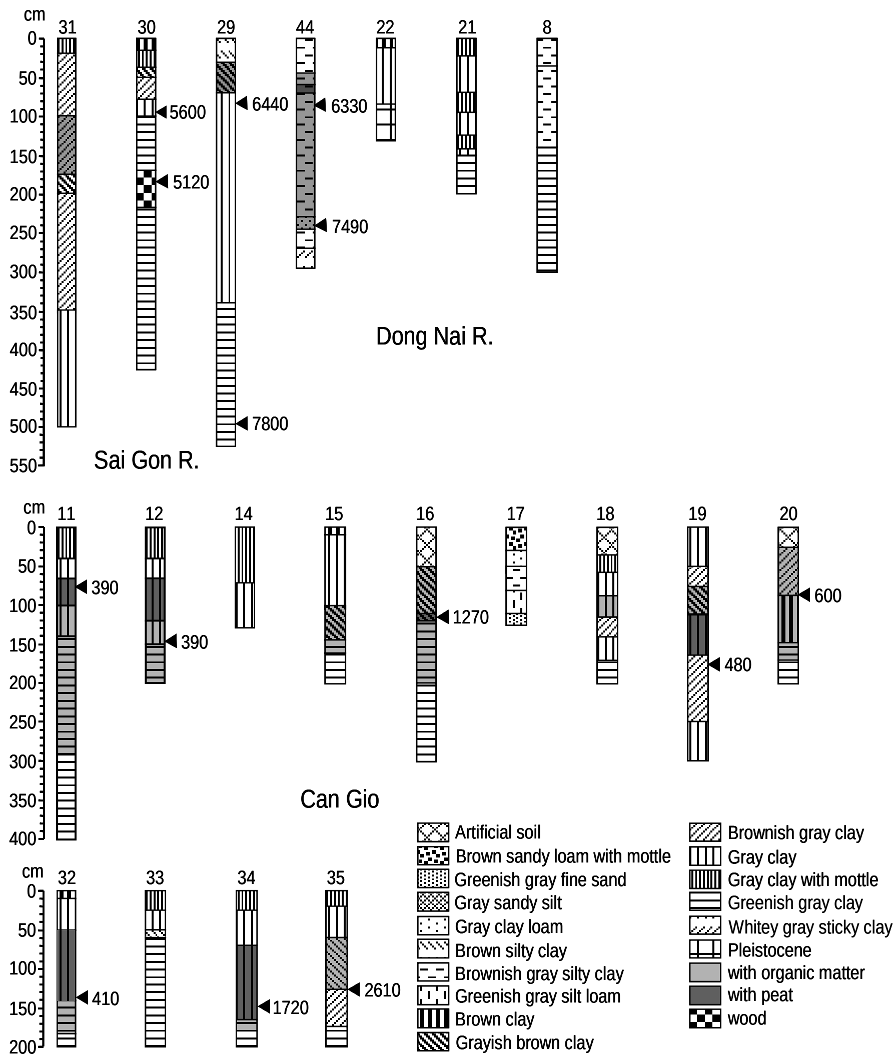

Figure 4. Bore columns from the Dong Nai River Delta.

DISCUSSION

Relative Sea-Level Changes

Figure 5 shows the relationship between the calibrated ages obtained from mangrove organic deposits and the ranges estimated for sea level. The rectangular area shows the range of estimated sea level for each calibrated age, including the uncertainty associated with tidal amplitude and the errors for determining the sampling elevation and radiocarbon dating.

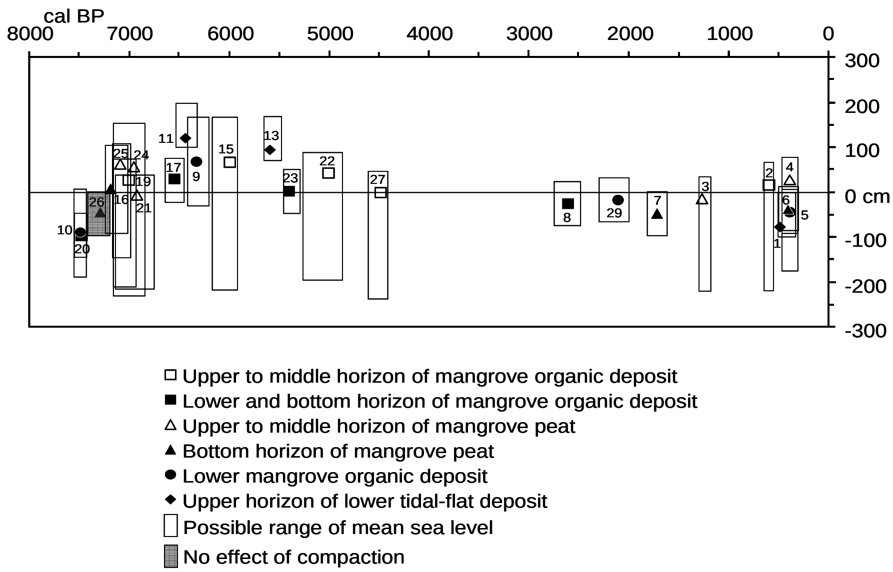

Figure 5. Relationships between the calibrated ages obtained from mangrove organic deposits and the estimated ranges of sea level. Numbers in the figure correspond to the index point numbers indicated in Table 2.

Generally mangrove deposits formed in a tidal environment between around mean sea level and maximum high tide level because mangrove forests only form in the environments. In addition, mangrove peat layers only form under *Rhizophora* forest, which form in a tidal environment between around mean sea level and around mean high tide level (Mochida et al., 1999). The present mean spring tidal range and mean neap tidal range in Can Gio are 370 cm and 310 cm, respectively (Japanese Coast Guard, 2005). Assuming the tidal range has been constant during the Holocene, the estimated paleo-sea level is 0 to 155 cm lower than sampling elevation for samples obtained from mangrove peat, and 0 to 185 cm lower for samples obtained from other mangrove deposits. Since the samples obtained from the bottom horizon of the mangrove deposits, including mangrove peat layers and lower mangrove organic deposits overlain by mangrove peat layers, are thought to have been deposited at approximately mean sea level, the vertical error for these samples in Figure 5 shows the estimated error for elevation only. Moreover, because samples obtained from the upper horizon of lower tidal-flat deposits are thought to have been deposited just below mean sea level, the vertical error was approximated as the elevation error, and the error box was positioned at a slightly higher elevation.

The estimated error for the elevation of the borehole sites was ±50 cm because the elevation data of both SRTM and topographical map were presented in meters.

The data obtained from alluvium required us to consider the effect of compaction. It is clear that the data obtained from Site 2, which indicates sea level of -0.4 ± 0.5 m at ca. 7300 cal BP (Index point No. 26), has not been affected by compaction because the sample was obtained from just above the Pleistocene deposits. There was no significant and unusual elevation gap between No. 26 and adjacent data (Figure 5). The shallowly buried Pleistocene deposits and the thin flood deposits in the study area seem to have attenuated the effect of compaction.

The effect of compaction can also be discussed by comparing the bulk density values for sediments obtained from inland, which are relatively old, against the new sediments from the coastal area. Figure 6 shows the vertical distribution of bulk density for Sites 11 and 12 located in Can Gio and Site 13b (Lat. 10˚ 55' 22.9" N; Long. 106˚ 19' 26.4" E), which was adjacent to Site 13, located about 60 km inland along the Vam Co Dong River. The bulk densities obtained from the marine clay layer below 150 cm depth, which is overlain by mangrove deposits at Site 13b, were lower than those obtained at Sites 11 and 12 in Can Gio. This observation also suggests that there has been no significant compaction in the marine clay layer overlain by mangrove deposits in the inland area.

Figure 5 illustrates that sea level was higher than the present one between 7000 and 5500 cal BP, and at approximately 2000 cal BP was similar or slightly lower than the present level. The highest sea level, recorded between 6500 and 6000 cal BP, was between 1m and 2 m above the present mean sea level. These results are in agreement with data obtained in southwestern Thailand (Fujimoto et al., 1999), but differ significantly from the data obtained in northern Vietnam (Boyd and Doan, 2004). In northern Vietnam, paleo-sea level has been identified at 3.25 m above the present local mid-tide by ca. 5500 cal BP, was decreasing by ca. 3500 cal BP, and was at 1.5 m above the present mid-tide level by ca. 2000 cal BP, based on the elevations of wave-cut notches and radiocarbon data obtained from oyster shells on the wall of limestone cliffs. The differences in paleo-sea level between these two regions may be a result of hydroisostasy and tectonics.

In our study, evidence of the sea level at ca. 4000 cal BP has not yet been obtained, whereas the relative high stand of sea level at this time can be found in the Asia – Pacific region (e.g. Tjia et al., 1983; Fujimoto, 1990; Sinsakul et al, 1985; Sinsakul, 1992; Fujimoto et al., 1996, 1999). The data provided by Boyd and Doan (2004) also suggest two time points of relative high stand of sea level, before 5500 cal BP and between 4400 and 3650 cal BP.

Fontaine (1970a) identified four levels of wave cut notches in Ha Tien and Kien Luong near the border with Cambodia, which were 1-1.5 m, 2 m, 3 m, and 4-5 m above the present sea level. Fontaine (1974) estimated that, based on the highest elevation of notches, the highest sea level in the Holocene was between 4 and 5 m above the present sea level. He also presumed this high stand occurred at ca. 5600 ^{14}C BP, based on the radiocarbon ages obtained from oyster shells in the alluvium at Long Xuyen, located around 100 km east of Ha Tien, despite the lack of radiocarbon data indicating the age of the highest notch. The formation age of the + 2 m notch was estimated to be approximately 4150 ^{14}C BP, based on the age of oyster shell on the wall. However, it is unknown whether the ^{14}C ages reported by Fontaine's studies were conventional age or not. The highest notch possibly formed during the last interglacial period as indicated by Boyd and Doan (2004). The ages of the notches documented in Fontaine's work need to be reexamined due to this insufficient data.

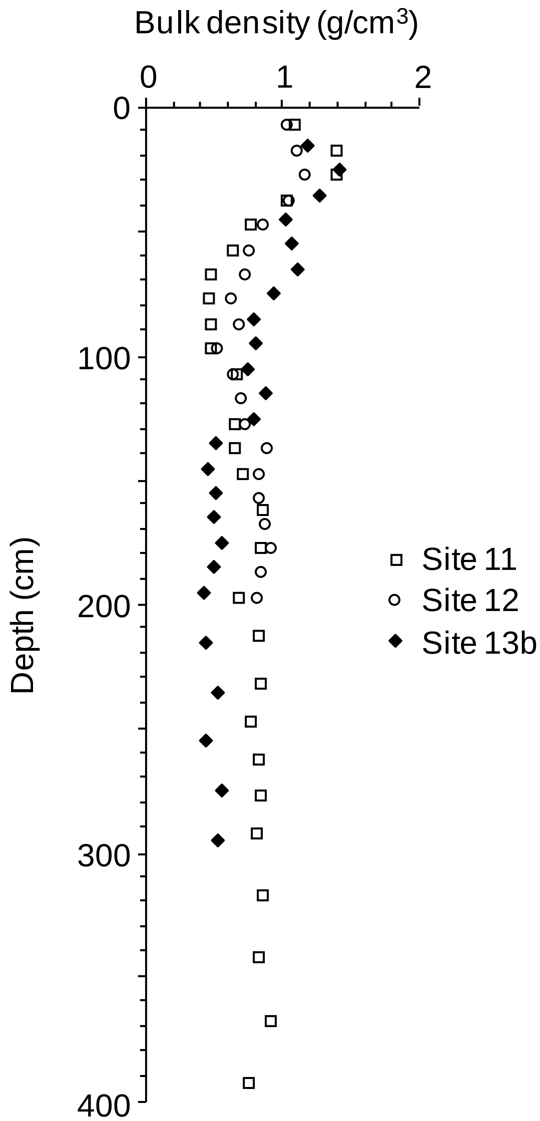

Figure 6. Vertical distributions of bulk density for Sites 11 and 12 in Can Gio and Site 13b at about 60 km inland along the Vam Co Dong River.

Geomorphological Evolution of the Deltas and Mangrove Habitat Dynamics

Based on the distribution of mangrove peat layers and the age of their formation, mangrove forests dominated by *Rhizophora* seem to have formed on the Vam Co Tay and the Vam Co Dong Rivers delta between 7000 and 6000 cal BP. The delta front was situated about 60 to 80 km inland from the present coastline (Figures 7a and b). The postglacial sea-level rise had almost ceased by 7000 cal BP, and many low islands, consisting of Pleistocene deposits, were distributed in the shallow sea. The formation of *Rhizophora* forests started ca. 7000 cal BP on the tidal flats surrounding these islands. Other dominant species of mangrove forests developed on the delta behind the *Rhizophora* forests, where fluvial sedimentation rapidly progressed because of the existence of shallowly submerged Pleistocene deposits. The data obtained from Site 3 show that the delta front of the Mekong River reached about 140 km inland from the present coastline ca. 4500 cal BP. Although the *Rhizophora* forests disappeared after 6000 cal BP, it is likely that mangrove forests with other dominant species were distributed on the deltas of the Vam Co Tay, the Vam Co Dong and the Mekong Rivers (Figure 7c). Between 4500 and 2500 cal BP, the Mekong River Delta expanded rapidly to about 40 km inland from the present coastline (Figures 7c and d), which suggests a fall in sea level during this period. At approximately 2100 cal BP, the mangrove forests without *Rhizophora* were still distributed up to 120 km inland from the present coastline (Site 10, Figure 3), and the mangrove environments subsequently changed to freshwater environments (Figure 7e). This environmental change seems to have been induced by a fall in sea level.

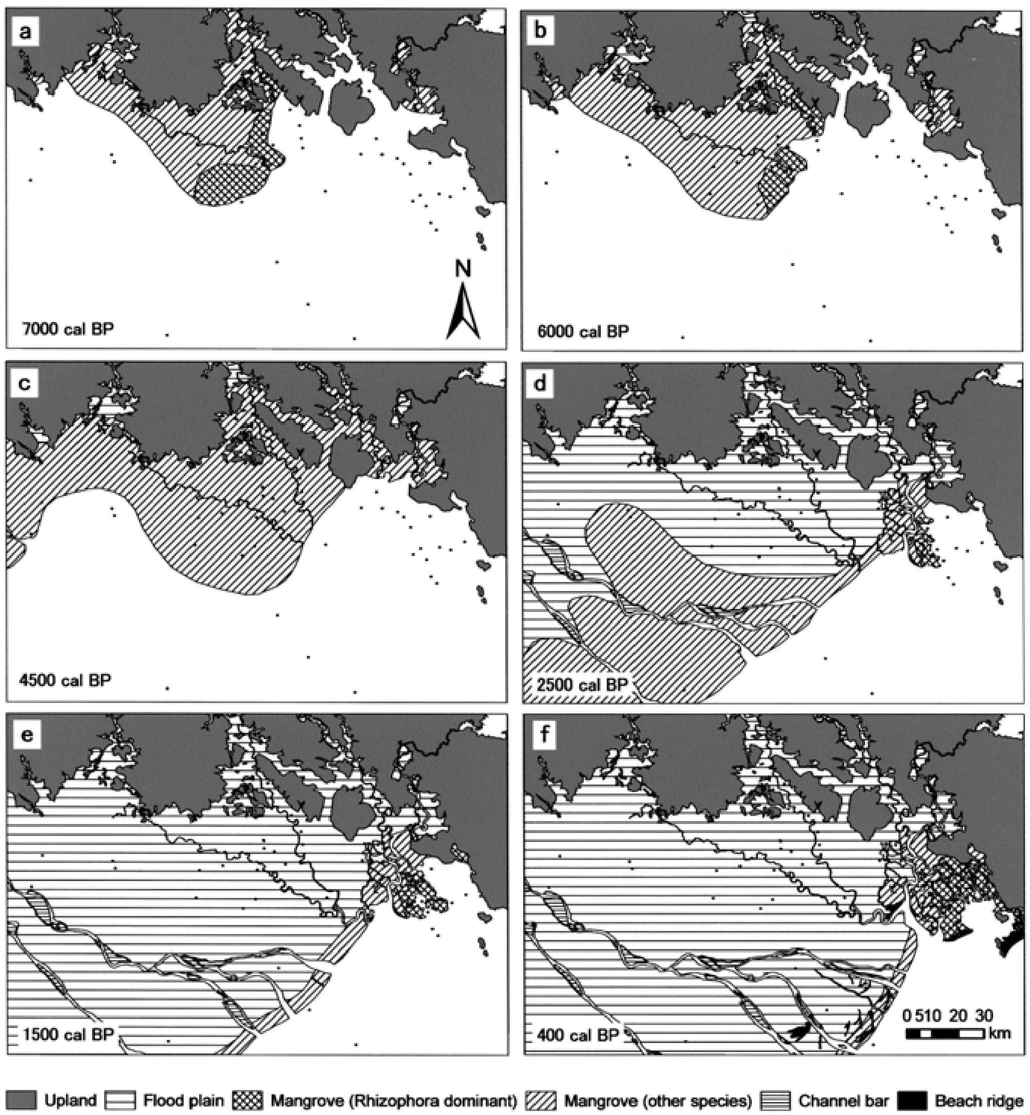

Figure 7. Geomorphological evolution and mangrove habitat dynamics of the northern Mekong River Delta and the Dong Nai River Delta.

Nguyen et al. (2000) estimated the coastline ca. 4550 ^{14}C BP (5350 cal BP) was approximately 60 km inland from the present coastline on the northern bank of the Mekong River, based on the radiocarbon age reported by Fontaine (1970b) of oyster shells found in the beach deposits. Our data indicate that the coastline estimated by Nguyen et al. (2000) was not the delta front of the Mekong River, but that of the Vam Co Tay and Vam Co Dong Rivers.

The delta front of the Dong Nai River reached the Can Gio area by 2600 cal BP, and a *Rhizophora* forest developed first in the southwestern region (Figure 7d). The mangrove forest then expanded toward the northeast with delta evolution, and the mangrove forests covered almost the same area as they do presently by 400 cal BP (Figure 7f). The *Rhizophora* forest has changed to a mangrove forest with other dominant species due to a rise in ground level by the accumulation of mangrove peat and fluvial sedimentation.

CONCLUSION

This study reconstructed relative sea-level changes during the mid to late Holocene and discussed the corresponding geomorphological evolution and mangrove habitat dynamics in the Northern Mekong River Delta and the Dong Nai River Delta with a focus on the distribution of mangrove organic deposits. The results are summarized as follows.

1. Between 7000 and 5500 cal BP, sea level was higher than the present mean sea level and was at an equivalent or slightly lower level ca. 2000 cal BP. The highest sea level record was between 1 and 2 m above the present mean sea level between 6500 and 6000 cal BP.
2. The data used to reconstruct paleo-sea level in this study were unlikely to be affected by compaction due to the presence of shallowly buried Pleistocene deposits and thin flood deposits.
3. Between 7000 and 6000 cal BP, mangrove forests dominated by *Rhizophora* were distributed approximately 60 to 80 km inland from the present coastline on a delta formed by small rivers flowing from the north, not by the Mekong River. The *Rhizophora* forests changed into other mangrove forests after 6000 cal BP with a fall in sea level and sedimentation.
4. Between 4500 and 2500 cal BP, the Mekong River Delta expanded rapidly and after 2000 cal BP, the mangrove forest changed to a freshwater environment with a fall in sea level.
5. The Can Gio mangrove forests on the Dong Nai River Delta have formed from southwest to northeast with delta evolution during the last 2600 years and covered almost the same area as present by 400 cal BP.

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