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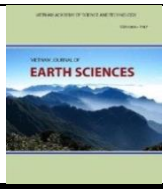

Holocene sedimentary facies in coastal plain of the Song Ma Delta, Thanh Hoa Province

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ABSTRACT

The Ma river delta located in the North Central of Vietnam is the third largest ones in Vietnam following the Mekong Delta and the Red River Delta. However, a few of study dealing with sedimentary of the Holocene deposit in this delta. This study aims to determine the Holocene sedimentary facies in coastal plain of the Song Ma Delta based on sedimentary structure and analysis of grain size, diatom, spore-pollen and ^{14}C dating collected from the drill core of LKTH2 borehole from the coastal plain of the Song Ma river delta. As study results, 08 sediment facies were established among which 02 facies of transgression period and 06 facies of regression period. During transgression period, 02 facies of tidal flat clayish silt and bay silty clay facies were formed. Of which, tidal flat clayish silt facies was formed in 7,883 ± 43 yr BP. After the sea level had reached a highest, the delta was initiated and 06 facies were formed during the regression period i.e. prodelta silty clay, delta front clayish silt, tidal flat sandy-silty clay, sand ridge, lagoonal sandy silty clay, and flood plain silty clay facies. The tidal flat sandy-silty clay facies formed in 6.951± 38 yr BP caused by sea level fall and the coastline was identified around the LKTH2 bore hole at that time. Integration of sedimentary facies of the sand ridge and lagoonal sandy silty clay facies shows that the Song Ma Delta was dominated by wave process during its evolution.

Keywords: Holocene sedimentary facies; Song Ma Delta; Thanh Hoa coastal plain.

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1. Introduction

Many deltas in the world were formed during the Holocene, almost of the world's deltas initiated during 7.5–9 ka BP (Stanley and Warne, 1994). There are many studies on the reconstructed Holocene sedimentary history of Asian megadeltas (e.g., Nguyen VL et al., 2000; Goodbred and Kuehl, 2000; Saito et al., 2000; Hori et al., 2000, 2002, 2007; Ta et al., 2001; Tanabe et al., 2003, 2006; Storms et al., 2005). Holocene delta initiation is

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closely related to the Frandrian transgression which started around 18,000–20,000 years BP at 120 m water depth. From about 6.000 to about 7000 years BP, sea level reached the highest point of 4–5 m above present sea level. Then, sea level gradually dropped to the present level by this regression (Hanebuth, 2000; Tran Nghi, 2000; Trinh The Hieu, 2003, Schimanski, 2005). The aims of this research are to identify Holocene sedimentary facies and to clarify evolution of the Ma River Delta in the Holocene based on analysis of LKTH2 borehole in the coastal plain.

Ma River Delta (Fig. 1) is ranked as the third largest area in Vietnam following the Mekong Delta and the Red River Delta. Although there are many researches on geology for the Red River and the Mekong River Delta, only a few study dealing with the Ma River Delta, especially the Holocene geology is noted.

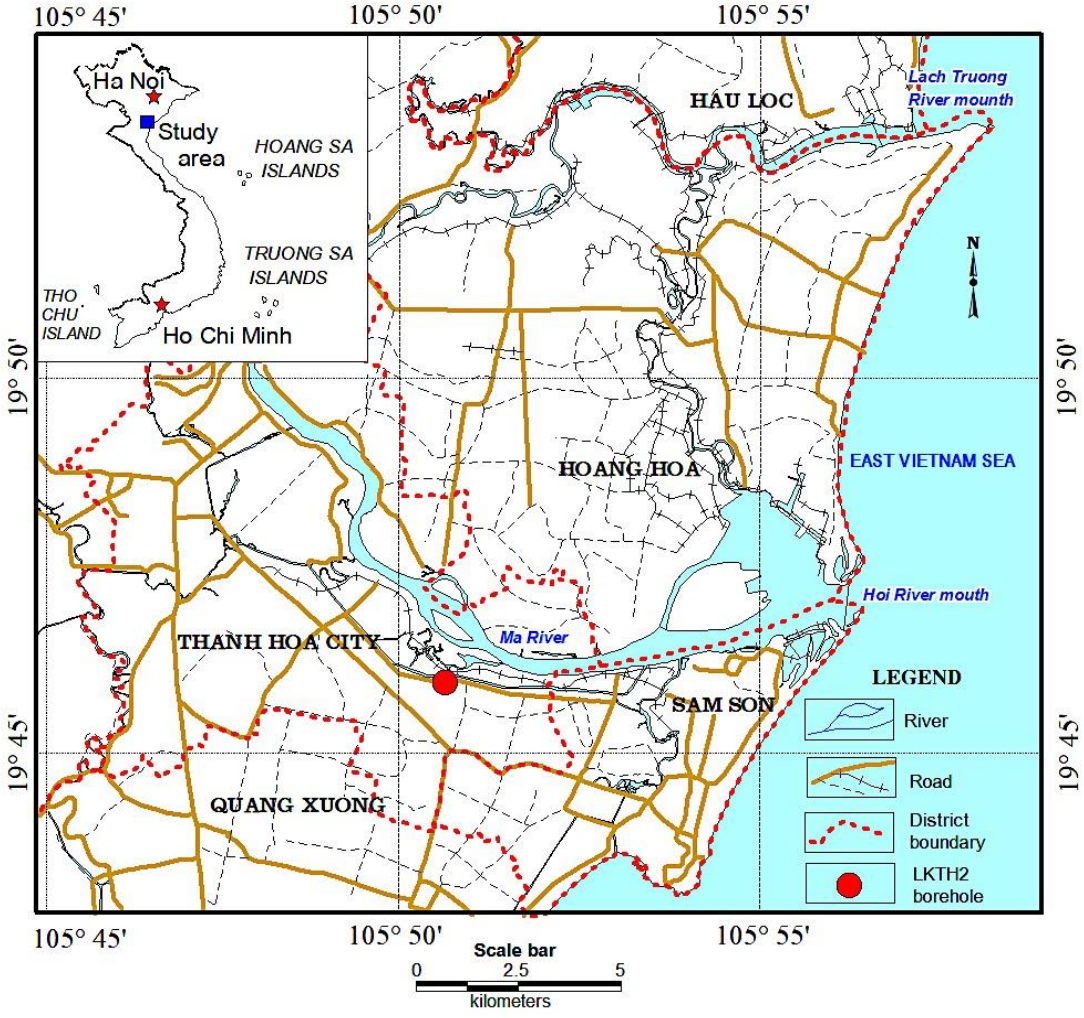

Figure 1. Geographic distribution of the Ma River Delta and LKTH2 borehole

Coastal area of the Ma river plain is quite flat with terrain elevations from 0 m to 3 or 4 m (Hoang Ngoc Quang et al., 2008), consisting of Nga Son, Hau Loc, Hoang Hoa,

Sam Son, and Quang Xuong districts (Fig. 1). Moreover, Thanh Hoa Plain (part of the Ma River Delta) includes the lower Holocene deposit (Thai Binh Q_2^3tb Formation), the lower-middle Holocene deposit (Thieu Hoa $Q_2^{1-2}th$ Formation), and the upper Pleistocene deposit (Vinh Phuc Q_1^3vp Formation). There are also bedrock mountains scattered on the plain (Dang Tran Quan et al., 1980).

The Ma River originated from Dien Bien, flowing through Laos into Vietnam in the territory of Thanh Hoa province consists of 90 tributaries, forming and discharging into the sea via three estuaries including Hoi (the main estuary), Lach Truong, and Len. Annually, the Ma River carries a large amount of sandy mud into estuarine areas (at a rate of about 5.17 million tons/year) (Nguyen Van Cu et al., 1999; Nguyen Van Cu and Pham Huy Tien, 2003). The amount of sandy muds increases significantly during the flood season.

The studied area is characterized by an irregular tide of a 24 hour cycle; semi-diurnal tide days occasionally appear. The area deeper than 20m, the tidal currents direct towards the Northeast and Southwest. High tide is from 7 to 8 hours and low tide is from 15 to 16 hours daily. Monthly, two times are recorded for a high tide and low tide, the maximum tidal range is 3.19 m (Nguyen Van Cu and Pham Huy Tien, 2003; 2004).

2. Materials and methods

This study base on the results of the sample analysis of a sediment core in LKTH 2 borehole located in Quang Tam Commune, Thanh Hoa, Vietnam (X:105°53'48.20"; Y: 19°45'33.70") (Fig. 1). The sediment cores were collected from the borehole at the depth of 0–17.3 m continuously.

In the laboratory, the sediment cores were divided lengthwise, photographed and described. Visual descriptions were performed immediately after photographing the core using the working and archive halves side-by-side. Descriptions consisted of grain size, sorting color, macro and ichnofossil content, bioturbation intensity, lithologic accessories and physical structures were described.

The sedimentary facies were classified into units base on grain size, color, physical sedimentary structures, presence of bio-turbation, and content of organic material. For grain size analysis, samples were pretreated to remove organic matter and biogenic carbonate. A total of 39 samples were analysed by Mastersizer-2000 laser particle size analyzer (Table 1). Three radiocarbon dating samples which were collected from plant fragments, mollusca shells and analyzed in DirectAMS lab (United State). Pollen spore and diatom analysis were carried out for 39 samples (Figs. 3, 4).

3. Results

3.1. Tide flat silty clay facies (Bay head delta)

This facies consists of dark gray, greenish gray silty clay (sand: 1.2–11.1%, silt: 27–52%, and clay: 30.3–62.3%); grain-size parameters: median (Md): 0.002–0.015mm, Sorting (So): 3.04–9.33, skewness (Sk): 0.81–2.06). Plant fragments are common from 10.4 m to 12.7 m thick (Image 1a). Small shell fragments are scattered throughout the facies. The clayich clasts are typical of the intertidal environment is present in this facies. Diatom species, *Dip. interrupta,* are common. This species often lives in the brackish-water and salinity $<30^0/_{00}$. There are some other benthic brackish water diatoms such as *Nitzschia cocconeiformis*, *Diploneis smithii* were found with *Dip. interrupta.* Diversity and abundance of pollen types, especially mangrove and back mangrove pollen increase upward (Fig. 4).

The tidal flat clayey silt facies is distributed in the LKTH2 borehole at the depth from 10.4 m to 12.70 m dated at 7,883 ± 43 yr BP (Fig. 2). This showed that the sea reached the study area.

3.2. Bay clayey silt facies

This facies consists of greenish gray and dark gray silt, clay. It is found in LKTH2 from 9.7 m to 10.4 m depth and 70 cm thick (Fig. 2). The bay sediment has small shell fragments (10.22 m and 10.38 m depth). The composition of this sediment includes clay (59.1–61.7%), silt (37.3–40%), sand (0.9-1%); grain-size parameters: median (Md): 0.002–0.003, sorting (So): 3.49–3.96, skewness (Sk): 1.51–1.96. Diatom and pollen types show strong decrease in this facies (Fig. 3 and 4). Only two diatom species including *Caloneis formosa* and *Cyclotella striata* were found. Back mangrove pollen types including Palmae gen. indet. are disappeared or strongly decreased while mangrove pollen show low value.

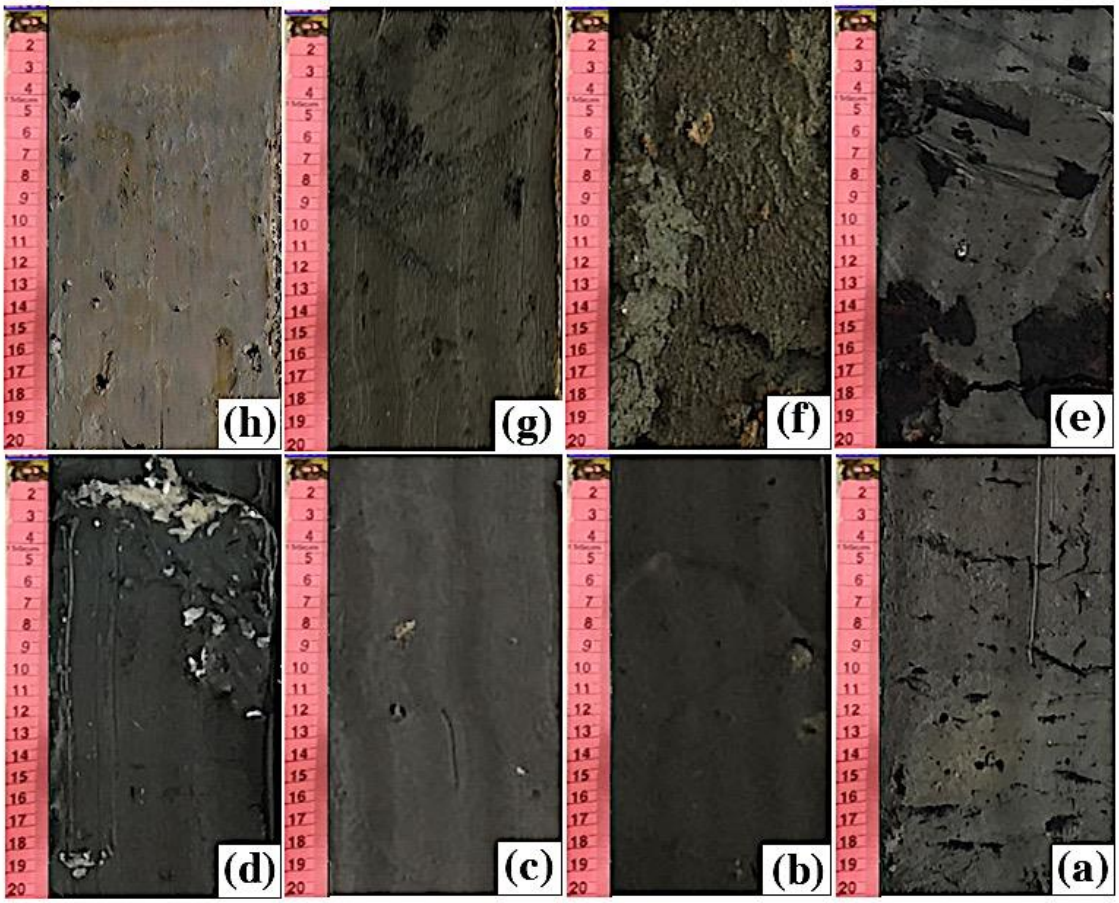

Image 1. Sediment of the LKTH2 borehole

Notes: (a) Bay head delta/tide flat silty clay facies; (b) Bay clayey silt facies; (c) Pro delta clayey silt facies; (d) Delta front silty clay facies; (e) Tide flat sandy-silty clay facies; (f) Sand ridges facies; (g) Back shore sandy-silty clay facies; (h) Flood plain clayey silt facies

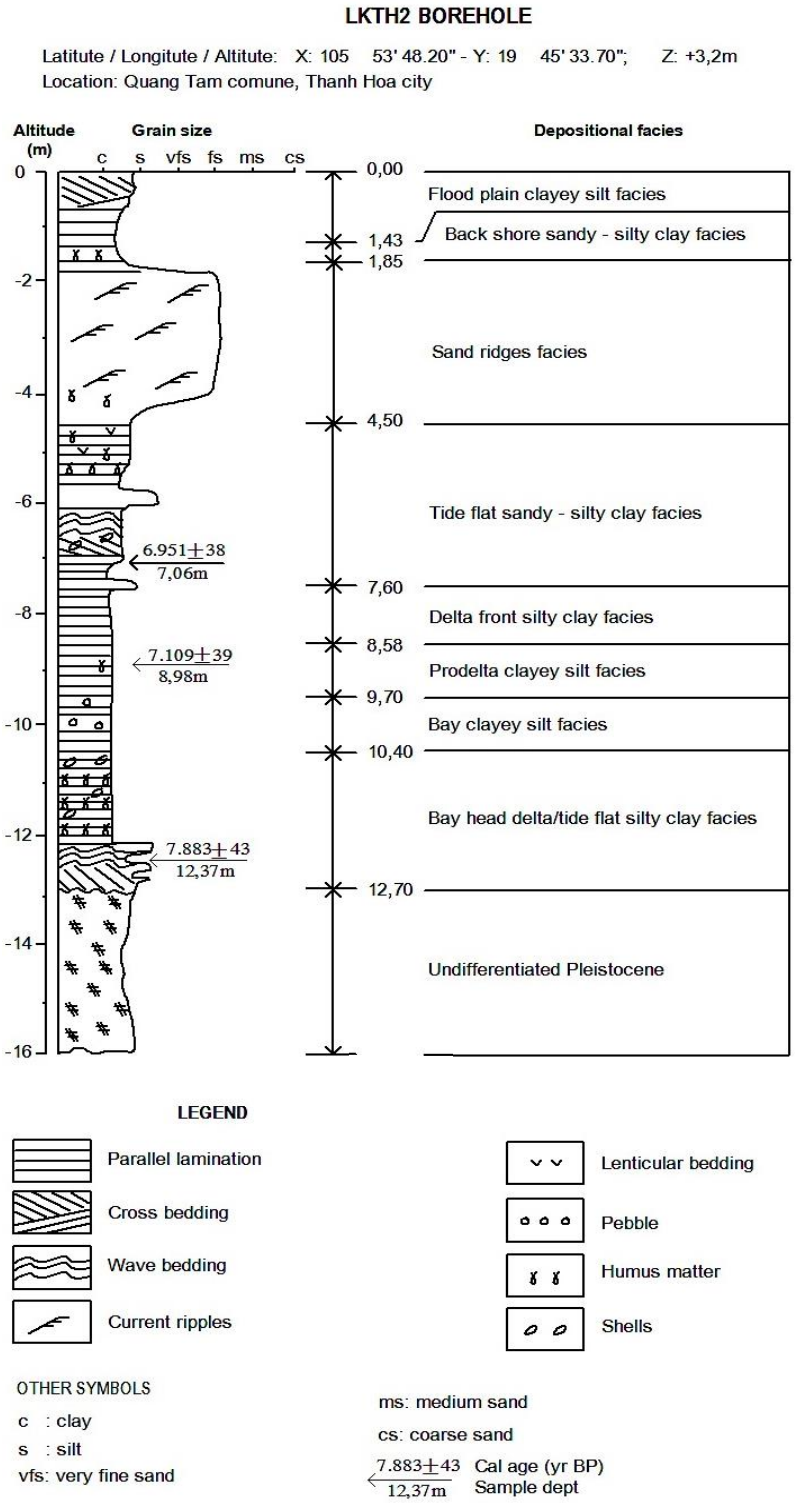

Figure 2. Sedimentary facies columnar section of LKTH2 borehole

Table 1. Grain-size analysis LKTH2 core

Samples	Depth (m)	Composition (%)			Parameters		
		Clay	Silt	Sand	Md	So	Sk
ĐH01	0.4	56.20	34.2	9.6	0.003	3.870	1.150
ĐH02	1.56	37.1	34.9	28.0	0.011	6.974	1.190
ĐH03	2.96	0.0	10.2	89.8	0.106	1.168	0.902
ĐH04	4.34	3.7	19.0	77.3	0.143	1.715	0.649
ĐH05	4.66	30.3	41.7	28.0	0.015	5.610	0.902
ĐH06	4.84	39.5	52.7	7.8	0.006	3.036	0.805
ĐH07	5.65	46.9	37.1	16.0	0.005	4.870	1.629
ĐH08	5.75	36.1	27.1	36.8	0.015	9.328	0.840
ĐH09	5.86	53.9	41.8	4.3	0.003	3.804	1.271
ĐH10	6.10	56.4	42.4	1.2	0.003	4.323	1.563
ĐH11	6.37	54.6	41.9	3.5	0.003	4.113	1.164
ĐH12	6.62	58.5	39.9	1.6	0.003	3.680	1.376
ĐH13	6.86	51.7	42.5	5.8	0.004	3.974	1.147
ĐH14	7.12	62.3	36.5	1.2	0.002	3.404	1.307
ĐH15	7.37	61.1	37.1	1.8	0.002	4.104	2.060
ĐH16	7.62	44.9	50.6	4.5	0.005	3.801	0.723
ĐH17	7.87	57.4	41.2	1.4	0.003	4.271	1.929
ĐH18	8.10	58.8	40.2	1.0	0.003	3.591	1.612
ĐH19	8.34	60.5	37.3	2.2	0.003	3.059	0.891
ĐH20	8.58	58.7	40.5	0.8	0.003	3.947	1.801
ĐH21	8.82	58.7	41.3	0.0	0.003	3.927	1.604
ĐH22	9.07	59.9	40.1	0.0	0.002	3.830	1.698
ĐH23	9.31	60.6	39.4	0.0	0.002	3.796	1.753
ĐH24	9.55	60.2	39.0	0.8	0.002	4.083	1.701
ĐH25	9.79	59.1	40.0	0.9	0.003	3.493	1.151
ĐH26	10.04	61.0	38.0	1.0	0.002	3.962	1.963
ĐH27	10.28	61.7	37.3	1.0	0.002	3.680	1.279
ĐH28	10.53	61.1	36.7	2.2	0.002	4.274	2.307
ĐH29	10.86	63.6	35.6	0.8	0.002	3.866	1.842
ĐH30	11.19	58.1	40.2	1.7	0.003	3.823	1.468
ĐH31	11.54	61.7	37.1	1.2	0.002	3.791	1.715
ĐH32	11.85	58.5	39.1	2.4	0.003	4.018	1.701
ĐH33	12.26	45.6	43.9	10.5	0.005	4.493	0.918
ĐH34	12.63	35.5	47.7	16.8	0.011	4.667	0.545
ĐH35	12.92	43.9	38.0	18.1	0.006	6.228	1.572
ĐH36	13.21	42.0	35.1	22.9	0.008	6.218	1.301
ĐH37	13.50	38.1	34.7	27.2	0.010	6.501	1.072
ĐH38	13.80	38.6	36.2	25.2	0.011	5.978	0.899
ĐH39	14.16	44.3	41.9	13.8	0.006	5.341	0.873

Notes:
- Clay: <0.004 mm
- Silt: 0.004 – 0.063 mm
- Sand: 0.063 – 2.0 mm

3.3. Prodelta clayey silt facies

The prodelta clayey silt facies shows a coarsening-upward succession and consists of dark gray silty clay to very fine sand. It is found in LKTH2 from 8.58 m to 9.7 m depth, and 112 cm thick. Interbedded greenish gray silt and silty clay layers are found in the lower part of this facies, and parallel lamination containing very fine sand layers in the upper

part. The composition of this sediment includes sand: < 1%, silt: 39–41.3%, and clay: 58.6–60.6%. Diatom species, especially brackish species such as *Nitz. coccconeiformis* and *Cyclotella striata* are more common in this facies (Fig. 3). Pollen and spore also shows increasing in diversity and abundance, especially mangrove and back mangrove pollen (Fig. 4). This sediment facies dated to 7.109 +/– 39 yr BP.

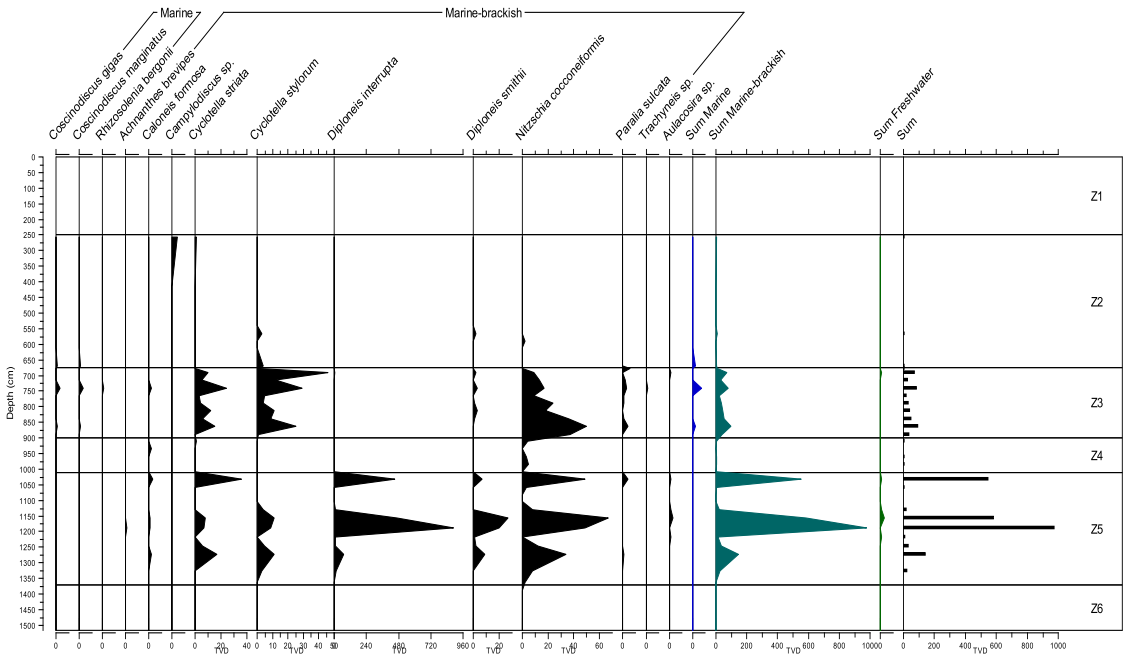

Figure 3. Distribution of diatom in LKTH2 borehole

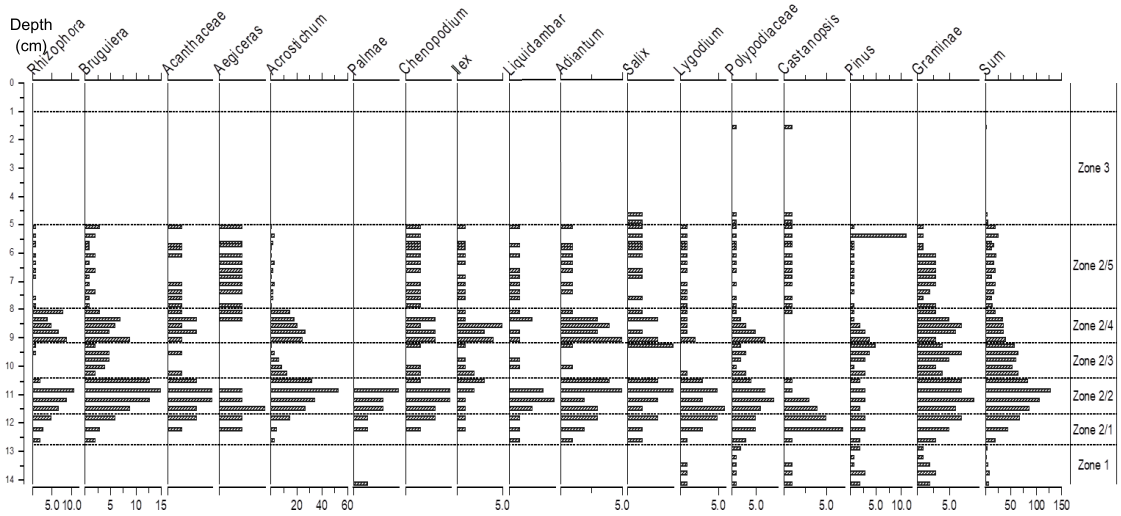

Figure 4. Distribution of pollen spores in the LKTH2 borehole

3.4. Delta front silty clay facies

This facies consists of dark gray silty clay and fine sand (sand: 1–4.5%, silt: 37.3–50.6%, and clay: 44.9–60.5%; grain-size parameters: median (Md): 0.003–0.005, sorting (So): 3.06–4.27, skewness (Sk): 0.72–1.92). It is found at 7.6m to 8.58 m depth, (98 cm thick) (Fig. 2). Diatom are more common than prodelta facies. Benthic brackish diatom species, *Nitzschia cocconeiformis,* is the most common in diatom assemblage. Besides, there are some other brackish species like: *Diploneis interrupta,Cyclotella stylorum, Cyclotella striata, Diploneis smithii* (Fig. 3). Pollen and spore are poor in this facies. Mangrove and back mangrove types are still found in low value.

3.5. Tide flat sandy-silty clay facies

This facies is characterized by interbedded coarse and fine grain size. Interbedded greenish gray silty clay containing organic material and dark gray fine sand lenticular bedding is very typical structure. It is found from 4.5 m to 4.9 m depth. There is organic matter that decomposes at 5.15 m–5.7 m depth (Fig. 2).

Tidal flat is characterized by wave ripple structure at 5.83–7.55 m depth. The composition of this sediment includes sand: < 1.2–11.1%, silt: 27.1–52.7%, and clay: 30.3–62.3%; grain-size parameters: median (Md): 0.02–0.15, sorting (So): 3.036–9.33, skewness (Sk): 0.8–2.06. Diversity number of diatom species is the highest in the sediment interval from 7.6 to 6.7m depth. Occurrence of tidal flat indicator species including *Nitzschia cocconeiformis* and *Diploneis smithii* (Chiba et al., 2016, Gomes et. al., 2017) supports for the tidal flat facies (Fig. 3). Mangrove and back mangrove types are still found in low value but it is poorer than delta front facies.

Tide flat sandy-silty clay sediments dated to 6,951±38 yr BP were found at 7.06 m depth. It is found at 4.50–7.60 m depth, where it is 310 cm thick.

3.6. Sand ridge facies

The sand ridge facies is formed by the process of creating a sandy beach. The impact of waves, coarse-grained sediments are deposited in sandy beaches and fine-grained sediments leave the shore in quiet areas. The sand ridge facies consist of sandy strata with ripple cross beddings. It is found at 1.85–4.5 m depth, where it is 265 cm thick (Fig. 2).

3.7. Back shore sandy-silty clay facies

The backshore area of a beach extends from the limit of high water foam lines to dunes or extreme inland limit of the beach. It is only affected by waves during exceptionally high tides or severe storms. Sediment in this area is well-rounded. Its grain sizes are mainly coarse sand and medium sand, which are larger than that in littoral barrier dune.

This facies consists of dark gray sandy - silty clay (sand: 28%, silt: 34.9%, and clay: 37.1%) (Table 1, Image 1g). It is found at 1.43–1.85 m depth, where it is 42 cm thick (Fig. 2). Diatom species includes *Campylodiscus* sp. and *Cyclotella striata*.

3.8. Flood plain clayey silt facies

A flood plain is an area of land adjacent to a stream or river which stretches from the banks of its channel to the base of the enclosing valley walls. This facies consists of gray clayey silt parallel bedding, sand: 9.6% silt: 34.2%, and clay: 56.2 % (Table 1, Image 1h). It is found at 0–1.43 m depth, where it is 143 cm thick (Fig. 2). Freshwater diatom facies includes *Aulacosira* sp., *Eunotia clevei*. Pollen and spore are rarely found in this facies (Fig. 4).

List of the samples for radiocarbon dating have been processed and measured by AMS. The following results were obtained:

D-AMS 024732
Lab Code
LKTH2/C14/6.7–9(100 cm)
Radiocarbon Age BP 6951 +/– 38

Calibration data set:	intcal13.14c	# Reimer et al., 2013
% area enclosed	cal BP age ranges	relative area under probability distribution
68.3 (1 sigma)	cal BP 7729–7832	1.000
95.4 (2 sigma)	cal BP 7686–7858	0.973
	7904–7918	0.027

Median Probability: 7778

D-AMS 024733
Lab Code
LKTH2/C14/9–11.4(80 cm)
Radiocarbon Age BP 7109 +/– 39

Calibration data set:	intcal13.14c	# Reimer et al., 2013
% area enclosed	cal BP age ranges	relative area under probability distribution
68.3 (1 sigma)	cal BP 7874–7893	0.236
	7928–7972	0.764
95.4 (2 sigma)	cal BP 7853–7906	0.283
	7915–8007	0.717

Median Probability: 7943

D-AMS 024735
Lab Code
LKTH2/C14/13-15(27-28 cm)
Radiocarbon Age BP 7883 +/- 43

Calibration data set:	intcal13.14c	# Reimer et al., 2013
% area enclosed	cal BP age ranges	relative area under probability distribution
68.3 (1 sigma)	cal BP 8598–8727	0.925
	8737–8752	0.075
95.4 (2 sigma)	cal BP 8585–8795	0.857
	8827–8867	0.056
	8882–8900	0.016
	8910–8975	0.071

Median Probability: 8690

4. Discussions

The Frandrian transgression began to influence the study area as demonstrated by the appearance of tidal flat clayey silt facies. It is found at 10.4–12.7 m depth, where the tidal flat sediments dated to 7,883±43 yr BP were deposited. At this time, the sea level began to enter the study area and continued to advance further to make the sedimentary environment in the study area shift from tidal flat environment to the bay environment until the maximum transgression. The bay clayey silt facies is at 9.70–10.20 m depth, where it is 70 cm thick.

After the maximum transgression, the study area shifted to the regression. In addition, the Ma River Delta had prograded

seaward. The prodelta clayey silt facies is found at 8.58–9.7 m depth, where it dated to 7,109 ± 39 yr BP.

Rapid accretion delta from continental material form prodelta silty clay facies and delta plain faices. The tidal flat sandy-silty clay faices is 7.06 m depth, where it is 6,951 ±38 yr BP. At this time, the coastline has retreated to the LKTH2 borehole.

In late Holocene period, the Ma rive delta was dominated by wave, so that many sand bar and swarm sediments are deposited in coastal plain area.

5. Conclusions

Results of sediment core analysis for LKTH2 borehole identified 8 facies that help clarify the evolution of the Ma River Delta.

Evolution of the Ma River Delta was affected by the Frandrian transgression directly. During the Holocene, the transgressive shoreline was identified by the appearance of a tidal flat silty clay facies (bay head delta) which distributed at depth between 10.4 m and 12.7 m and dated at 7,883±43 yr BP, whereas the regressive shoreline characterized by a tide flat sandy-silty clay facies that distributed at depth between 5.15 m and 5.7 m and dated at 6,951±38 yr BP.

Dominant wave in the Ma River Delta evolution and formation is characterized by sand bar and back shore facies. Sand bars are formed in parallel with the shoreline, and including many generations of sand bars distributed the landward direction. The back shores are also formed in the low-lying terrain.

Acknowledgments

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