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DEPOSITIONAL ENVIRONMENT DURING HOLOCENE OF THE RED RIVER DELTA, NORTHERN VIETNAM

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Abstract: The Red River Delta (RRD) is located in the western coastal zone of the Gulf of Tonkin (Vietnam). The Holocene sedimentary of RRD are influenced by rives, wave and tidal processes and more recently to grain-size distribution. In this study, sediment core (~ 36 m) was collected in the wave-dominated region of RRD. The parameter of sediment used to reconstruct the sedimentation environments of RRD, sediment facies can be classified into silt, sandy silt, and silty sand. Besides, the mean grain-size (Md) values show that the sediment in core samples included from fine silt to very fine sand with a dominance of very coarse silt and coarse silt. According to the lithological characteristics, sediment grain-size distribution the sediment core sample can be divided into six deposition environments which consisted of sub-tidal flats and inter-tidal flats (from 36 to 30.1 m); shelf-prodelta (from 30.1 to 18.9 m); delta front slope (from 18.9-11.7 m); delta front platform (from 11.7 to 4.1 m), tidal flat (from 4.1 to 0.5 m) and flood plain (from 0.5 m to surface of sediment). The textural characteristics of the core sample were closely correlated with the core sample from previous study in RRD. In a sediment core from 30.1 to 18.9 m, sediment showed erosion surface during the transgression at 8860 cal. year BP. The textural parameter of the RRD has resulted of the interaction between sea level rise and fluvial inputs. In addition, the dominance of very coarse silt and coarse silt can be indicated the prevalence of comparatively from low to high energy condition in the RRD.

Keyword: Sediment, grain-size distribution, depositional environment, Red River Delta (RRD), Vietnam

1. INTRODUCTION

The reconstruction of environmental changes during the Holocene in coastal zone aims to clarify the characteristics the environments and climate in the past which related to sea level rise (Wilson, et al., 2005), climatic change, and monsoonal variability (Li, et al., 2006, Meyers, 1997, Zong, et al., 2006). Studies on environmental change during the Holocene provide crucial information for simulating and predicting future effects of climate and environmental changes (Wanner, et al., 2008), and understanding the correlation between the environment and humans (Li, et al., 2006).

Climate change (CC) and sea level rise (SLR) have already had an observable effect on ecosystems, biodiversity and natural resource, it changed life on a global scale. Vietnam is one of the most impacted by climate change includes climate extremes, sea level rise, disaster (Schmidt-Thomé, et al., 2015, Thao, et al., 2014). In the last 50 years, the average annual temperature in Vietnam increased by 0.5 °C, sea level tends to fluctuations along the shoreline of Vietnam around 2.8 mm/year, climate extremes as drought, the number of heavy rainfall days, tropical cyclones tend to increase. Studying characteristics of CC was the most important for Vietnam, it will help to build high-resolution capacitance for CC, that way only real effective if it based upon a large amount of new and more comprehensive data about characteristics of climate and environment in the past time (Jansen, et al., 2007). We need to building the data systems in the last time and comparing with characteristics climate and environmental at the moment which supply for assessment and predicting of climate change in the future.

The coastal zone of Vietnam is rich in natural resources, with high population density and concentration of many economic activities, but this area is highly vulnerable by sea level rise and climate change (Mai, et al., 2008). Therefore, reconstruction of relative sea level in coastal environments is fundamental to understanding past, present and prediction the change of environment in this area. Investigation of paleoenvironmental change can provide a mean to develop sea level rise model which used to explain a pattern of climate-driven across coastal areas and to calculate and predict future climate scenarios (Lambeck & Chappell, 2001).

Sedimentary records in the large river deltas along Asian coast are useful to reconstruct the environmental and sea level change during Holocene epoch (Liu, et al., 2014, Ta, et al., 2002, Tanabe, et al., 2003, Tanabe, et al., 2006, Zong, et al., 2006). In these studies, Asian deltas had experienced multiple transgression, regressions, and climate. The environmental and sea level change of the deltas effected by hydrodynamics, sediment discharge, moon soon variability and acceleration of sea level rise (Tanabe, et al., 2006, Zong, et al., 2006).

Spanning some 150 km in width, the Red River Delta (RRD) is located in the western coastal zone of the Gulf of Tonkin. The RRD with about 120 km long and 140 km wide is the fourth-largest delta in Southeast Asia, after the Mekong, Irrawaddy, and Chao Phraya deltas (Chan, et al., 2012). Its catchment covers parts of China and Vietnam and its water and sediment discharge greatly influence the hydrology in the Gulf of Tonkin (Fig. 1).

In this paper, we present new data from newly collected drilling core taken from the RRD. We then compile data on sediment in the previous study which described sediment cores taken from the delta previously. Base on the textural parameters as mean grain-size (Md), sorting (So), skewness (Sk), kurtosis (KG), we reconstruct the depositional environment of sediments during the Holocene.

2. MATERIAL AND METHODS

2.1. Regional setting of Red River delta (RRD)

2.1.1. Geographical setting

The RRD plain can be divided into three subsystems based upon surface topography and hydraulic processes, including of fluvial-dominated, tide-dominated, and wave-dominated (Mathers & Zalasiewicz, 1999, Tanabe, et al., 2006). The fluvial-dominated subsystem includes meandering rivers, meandering levee belts, flood plain, and fluvial terraces. It is located in the western part of the delta, where the fluvial flux is relatively stronger than others. The wave-dominated system spreads in the southwestern section of the delta, where wave energy is high due to strong summer monsoon. The system is characterized by alternating beach ridges and muddy tidal lagoon deposit. Besides, tide-dominated subsystem reaches into the northeastern part of the delta, where Hainan Island shelters the coast from strong waves. The system consisting of tidal flats, marshes, and tidal creeks/channels.

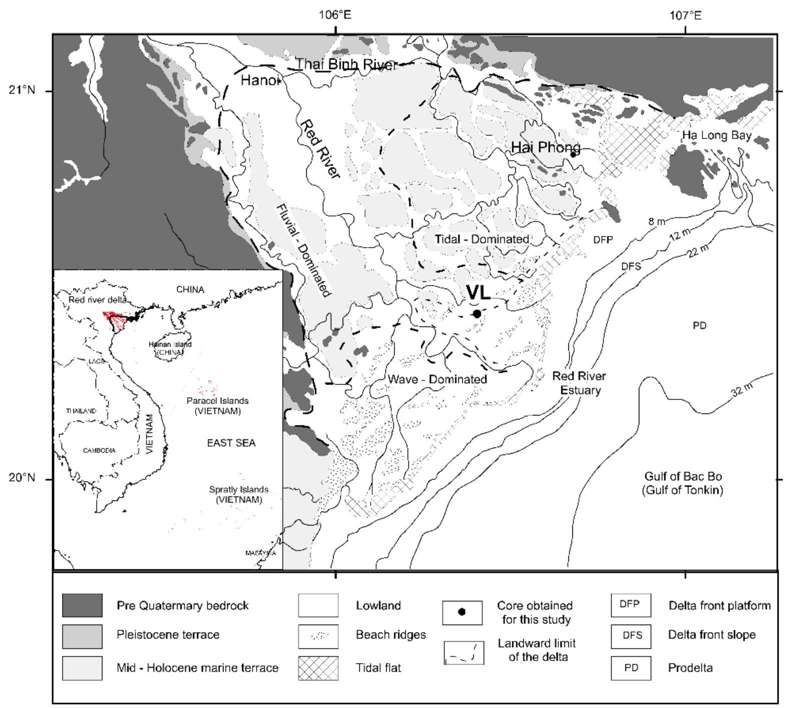

Figure 1. Location of Red river delta, Vietnam (modified from Tanabe et al., 2006)

The regional climate is characterized by a tropical monsoon climate with four seasons (spring, summer, autumn, winter) and humidity averaging from 84-100 % throughout the year (Lieu, 2006). While in the summer monsoon from May to October with heavy rainfall, hot and humid weather. In the dry season lasts from November to April of the following year, the climate is dry and cold. The average temperature is 29 - 30 °C the highest is 42 °C in summer (but it lasts a few days per month): May, June, July and the lowest is 9 °C (but it lasts a few days per season) between January and February. The climate in the investigation area is therefore by cool, dry winters (December until March) and warm, wet summers (May until October) characterizes (Pruszak, et al., 2005, Van Maren, et al., 2004).

The behavior of wave nearshore part is varied from direction west-southwest (from June to September) to west, northwest (from December to March of the following year). The mean tidal in this area ranges 1.9-2.6 m with the maximum height of the wave is 2-3 m (in the winter) and 5-6 m (in the summer). The tidal is characterized by there is one time of high level and one time of low level. The range of the tide at the coast is about 4 m. In the summer monsoon season, tidal influences within the delta are restricted because of the overwhelming effect of the high freshwater discharge, but in the dry season, tidal effects are evident in all of the major distributaries almost as far inland as Hanoi (Mathers, et al., 1996).

According to the data given by the General Department of Meteorology and Hydrology (Vietnam), from 1884 to 1989, there were 1,993 storms and tropical depressions influenced on Vietnam territory (about 5 storms/tropical depressions per year) and 148 of which (30 %) came to the RRD (Lieu, 2006). The statistics of data showed an increase in the frequency and duration of storms and typhoons during the second half of the 20th century. The increased storms and tropical depressions lead to the raising of the annual average wave height. It results in changing the geomorphology and sedimentology (erosion, accretion, shoreline, distribution of sediment) of this area (Lieu, 2006).

2.1.2. Geological setting

The RRD is surrounded by mountainous areas formed of Precambrian crystalline rocks and Palaeozoic and Mesozoic sedimentary rocks and the structure is dominated by NW-SE aligned faulting trending sedimentary basin approximately 500 km long and 50-60 km wide. RRD developed overlying one trough valley which was formed by faults. The NW-SE aligned Red River fault system regulates the distribution of the mountainous areas, the drainage area, and the straight course of the Song Hong. However, fault movements have been considerably minor since the late Miocene (Pruszak, et al., 2005). The trough valley was developed from early Cainozoic and filled with Neocene and Quaternary sediments with a thickness of more than 3 km and the subsidence rate of the basin is 0.04-0.12 mm/year (Mathers & Zalasiewicz, 1999).

The Quaternary sediment, which unconformably overlies the Neogene deposits and consists mainly of sands and gravels with lenses of silt and clay. In the RRD, the sediment is thick approximate 100 m beneath Hanoi and thickens eastwards to attain 200 m beneath parts of the coastal area (Mathers & Zalasiewicz, 1999, Pruszak, et al., 2005). In the coastal area of delta, the shallow water depths in the Gulf of Tonkin (< 50 m) suggest that much of the sequence is preserved in the floor (Mathers & Zalasiewicz, 1999). The Quaternary depression in the RRD was mainly filled by continental deposits in five geological cycles as follows: early Pleistocene (Lechi formation), middle to late Pleistocene (Hanoi formation), late Pleistocene (Vinhphuc formation), early to middle Holocene (Haihung formation) and late Holocene (Thaibinh formation) (Nghi, et al., 1991) (Fig. 2).

The simplified onshore and nearshore Quaternary stratigraphy developed by Vietnamese workers comprises two main series: sea-level lowstand sediments (Pleistocene) and sea-level highstand sediments, the latter building the modern delta (Holocene) (Tran & Nguyen, 1991).

2.1.3. Hydrology

The catchment area of the Red River (RR) is about 169.000 km^2 with the annual discharge of the RR is about 137 × 109 m^3 of water and 116 × 106 tons of suspended sediment, ranking among the 15 largest sedimentary discharges in the world (Milliman & Meade, 1983, Pruszak, et al., 2005). The Red River distributes its flow through five branches with 25% of the flow of the Red River discharging into the sea via the Ba Lat mouth (Song Hong mouth). The water discharge in RRD region varies seasonally because most of the drainage area is under a subtropical monsoon climate regime. The averages of year precipitation in the summer is about 1,600 mm (occupy 85-95 % of the total yearly rainfall occurs). Approximately 90 % of the annual sediment discharge occurs during the summer monsoon season, when the sediment concentration may reach 12 kg/m^3 (Mathers & Zalasiewicz, 1999).

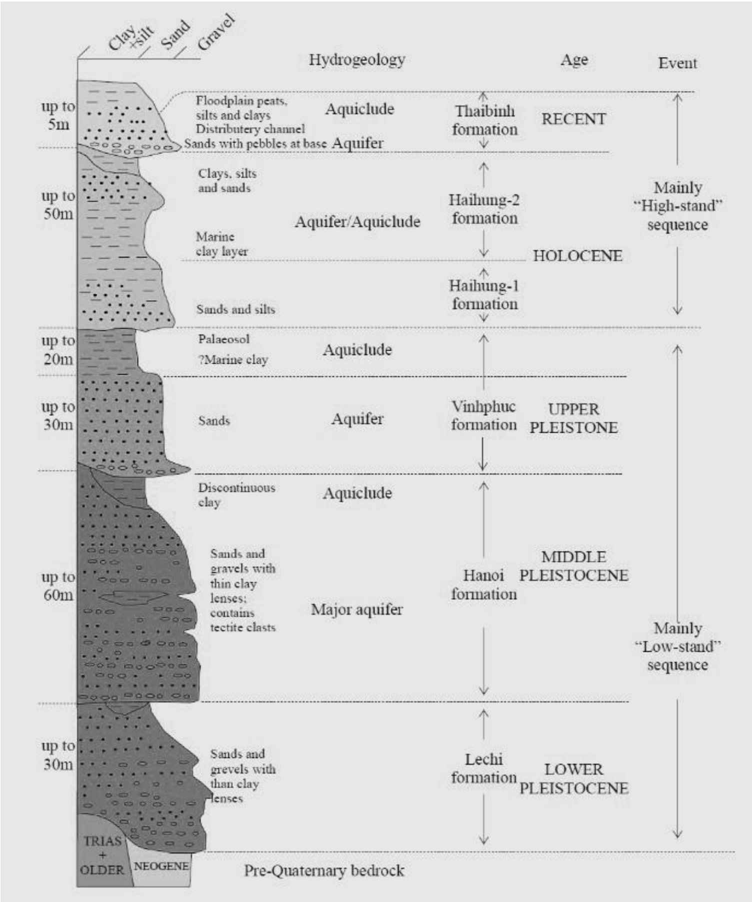

Figure 2. Simplified onshore Quaternary stratigraphic column of the RRD Basin (Modified from Tran & Nguyen, 1991)

2.2. Sediment core sampling processing

The core sample was collected by a rotary drill (diameter 10 cm) from the wave-dominated system in the RRD. The geographical location was 106°24'7.46" E, 20°25'39.86" N (core VL) with an altitude of 0.5m. Immediately following collection, the core sample was placed in PVC tubes and transported to the laboratory in cool condition.

In the laboratory, sediment cores were processed within 12 h of collection by first removing of the outer layer (0.5 cm in thickness), then sliced into 154 samples at 20 cm intervals. The sediment samples were packed in labeled polyethylene bags for further analysis.

2.3. Sample preparation and analysis

Variation of the grain-size distribution can be an important facies indicator, sedimentary development and environmental change (Blott & Pye, 2001, Bui, et al., 1989, Folk & Ward, 1957, Friedman, 1979).

In the laboratory, five grams of fresh sediment was put into a beaker. Then, the sediment sample was pretreated with H_2O_2 solution (10 %) and HCl 1N to assure complete removal of organic matter and carbonates. In these processes, organic matter fragments and roots were removed by a stainless steel forceps. Prior to analysis, 10 ml of distilled water was added and dispersed using an ultrasonic cleaner for three minutes. Sediment grain-size was used laser beam diffraction, using a Particular LA-950 (Horiba) instrument at the GEO - CRE (Key Laboratory of Geo-environment and Climate Change Response), Vietnam National University (VNU). This device can measure suspension samples liquid in the grain-size range 0.01-3000 μm. Each sediment a sample was analyzed in triplicate to yield the percentages of the related fraction of a sample with a relative error of less than 1 %. Mean, mode, sorting, skewness and other statistics were calculated by a grain-size distribution and statistics program (GRADISTAT program) (Blott & Pye, 2001).

3. RESULTS

The parameters shows sediment grained size distribution, which used to reconstruct the sediment environments (McLaren & Bowles, 1985). They are controlled by the direct of transport and the sedimentary processes. In this study, Md values showed the sediments were classified from the fine silt to very fine sand, with a dominance of very coarse silt and coarse silt followed geometric Folk and Ward graphic measures (Folk & Ward, 1957).

Figure 3. Photographs of typical sediment facies of the VL core in the RRD, Vietnam

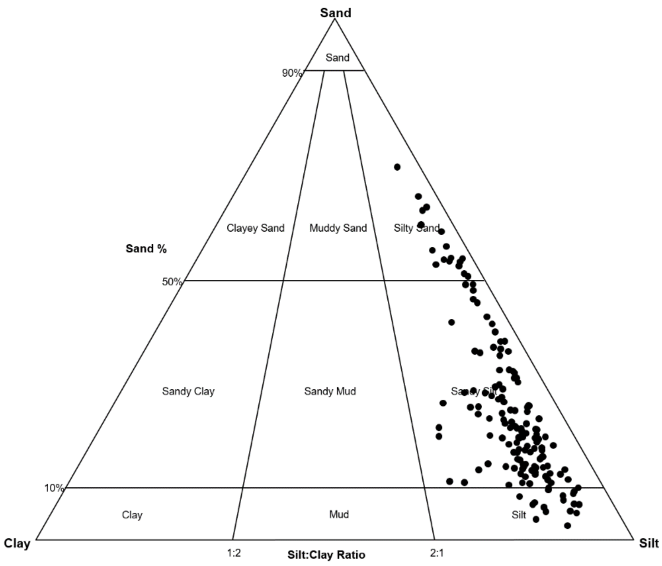

Figure 4. Tri-plot for textural analysis of all sediments in core sample RRD

Sediments of core samples mainly consist of sand, silt and clay, which ranged from 3.3-73.4, 22.9-87.2, and 1.5-25.5 %, respectively. Sediment facies of core sample can be classified as sandy silt, silty sand and sand (Fig. 4). Base on lithology, color and grain-size parameters, the sediment can be divided into six sections and two second sedimentary units with the following depth range: unit 1- estuarine sediments (from 36 m to 30.1 m); unit 2 - deltaic sediment (from 30.1 m to 0 m) (Fig. 6). The depositional environment during the Holocene of the RRD was resulted of the interaction between sea level rise and fluvial inputs.

3.1. Core section 1: at the depth from 36 to 30.1 m

This section is characterized by reddish gray and consisted of very fine sand and clay lamination (as faint lenses 3-8 mm thick) and a large portion of this facies is bioturbated. Mud content of the sediment slightly decreases from the core bottom to the smallest value at the depth of 32.3 m (Fig. 6). The mean grain-size (Md) tended to gradually increase upward with average value was 18.39 µm. The average value of sorting (So) was 4.45±0.46 and a large portion of value is classified as very poorly sorted. The mean of skewness (Sk) ranged -0.29±0.1, it divided into very fine skewness and fine skewness sediment. Kurtosis (KG) values tended to increase upward with two high value were 1.65, 1.28 at the depth 32.3 m, 31.3 m, respectively. The KG value can be divided three, but a large portion value indicated platykurtic sediment (Fig. 5). The lithological characteristic of core sample was closely correlated with the core sample from and previously study by Tanabe el al., (2006). Therefore, the geochronology of the sediment was calculated according to the sedimentation rates with the result of accelerator mass spectrometry (AMS) ^{14}C for RRD (Tanabe, et al., 2006) (Fig. 6).

In the early part of the Holocene, the sea level in Vietnam was about 31 m below prevent and increased at a relatively constant rate of about 9 mm per year (Tjallingii, et al., 2014). The reddish-gray color of the sediment showed erosion processes during low stands. In addition, below 30.1 m in depth, sediments consist of the reddish-gray color, which corresponds to erosion processes during low-stands. The sedimentary parameters illustrated a large portion of coarse silt and fine sand sediment which were mainly formed in high energy environments (McLaren&Bowles, 1985, Rajganapathi, et al., 2013).

Plant and shell fragments are scattered in core sediment and a large portion of shell fragments is concentrated from 31.6 to 32.5 m. Therefore, this section was interpreted as a sub-tidal and inter-tidal flat environment with a high frequency of tidal flooding (Tanabe, et al., 2006). Sedimentation rates in this section interpreted as 0.42 cm/year (Li, et al., 2006).

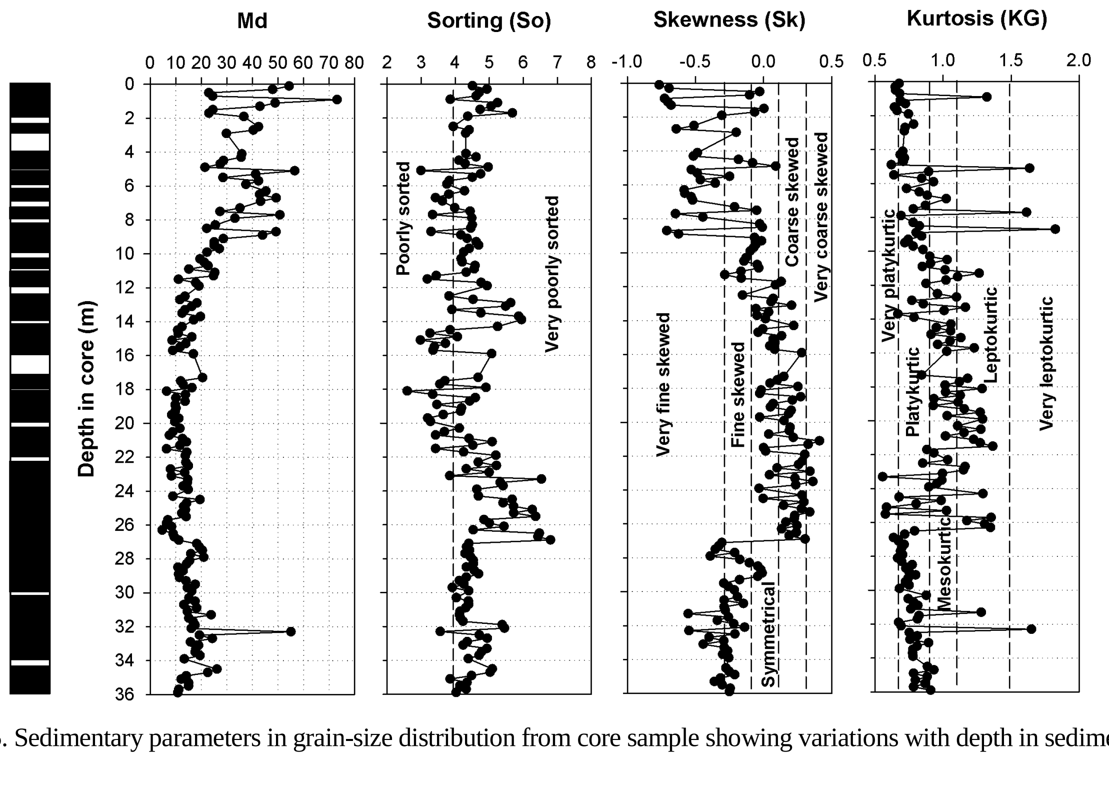

Figure 5. Sedimentary parameters in grain-size distribution from core sample showing variations with depth in sediment core

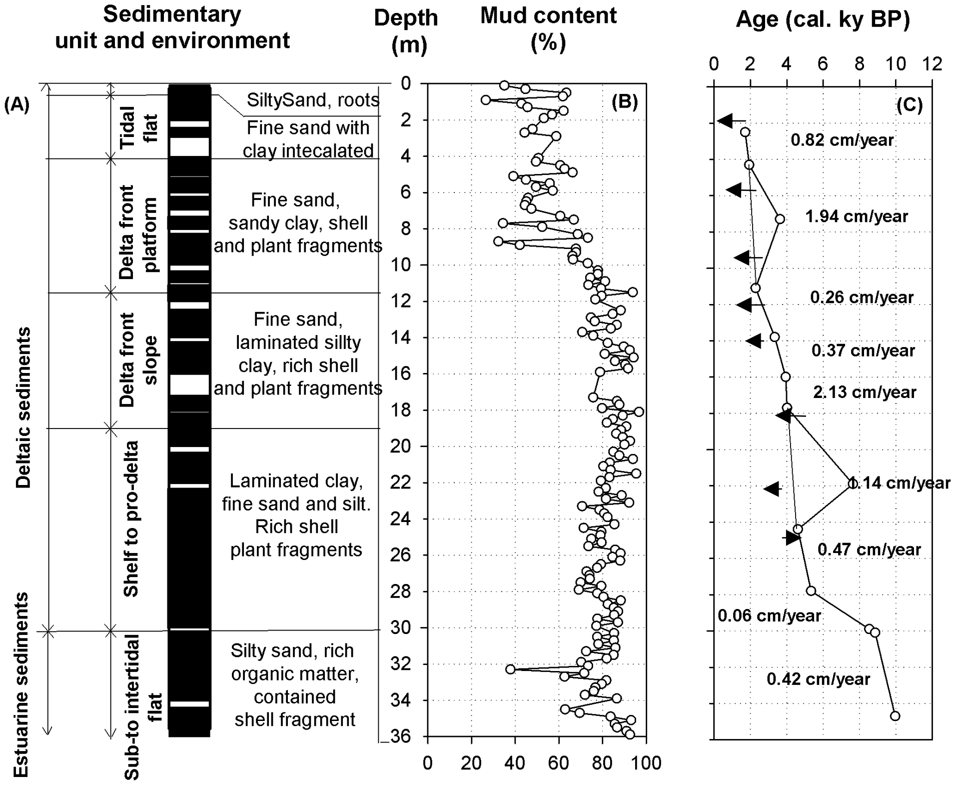

Figure 6. Sedimentary columns of the core sample in RRD. (A) Lithological characteristic of sediment core; (B) Mud content in sediment core; (C) Sedimentation rates were calculated by linear interpolation between ^{14}C ages (Li, et al., 2006, Tanabe, et al., 2006)

3.2. Core section 2: at the depth from 30.1 to 18.9 m

In the section, surface erosion formed during a transgression and separated by others section (depth core sample about 30 m) (Tanabe, et al., 2006). Sediment was characterized by blue-gray bioturbated clay and consisting of laminated fine sand, silt with reddish-gray in color. Besides, sediment was bioturbated by gray clay and rich in shell fragments. Mud values in this section ranged from 69.16 to 95.48 %. Md values tended to gradually increase upward from the erosion surface to 27.5 m and decreased to the depth 18.1 m. The value of sorting (So) were divided into two types with a high portion of values were very poor sorted sediments (30-21.9 m of the depth sediment core) and other was poorly sorted sediments. Based on Sk values, sediments can be divided into 4 types, consisting of very fine skewness, fine skewness, symmetrical and coarse skewed sediments. KG values showed the stability of values which indicated for platykurtic sediments (from 30-26.5 m in the depth) and the upper layer fluctuated in a high range which indicated form very platykurtic to leptokurtic.

In the middle part of the Holocene, the sediments can be divided into two part. At the lowest part, sediment facies suggested as a ravinement surface during the transition (Tanabe, et al., 2003, Tanabe, et al., 2006). Between 30.1 and 27.5 m in depth sediment core showed the transgressive sand sheet was overlain the erosion surface, characteristics of Sk corresponds to lower energy environment and abundant sources of sediment inputs. Between 26.7 and 18.7 m in depth of core sediment, the Md and Sk values varied over a small range, which corresponds to low hydrodynamic energy condition. A large portion of mesokurtic and leptokurtic sediments suggested continuous addition of coarse grain-size after the winnowing and retention action of tidal currents.

The environment of this section was interpreted as shelf to pro-delta sediments because shell fragments in this section were decreased than lower layers and the increased mud content (Tanabe, et al., 2006). The sedimentation rate in this section ranged from 0.06 to 1.14 cm/year (Li, et al., 2006).

3.3. Core section 3: at the depth from 18.9 to 11.7 m

This section was characterized by reddish gray or black and laminated silt clay that was rich in shell fragment and plant matter. Mud content tended to slightly decrease with ranged from 70.77 to 96.70 %. Md values between from 6.40 to 20.49 µm and tended to gradually increase upward. Sk values were gradually decreased upward and classifying it as symmetrical and coarse skewed sediment. The values of kurtosis showed relative low variation from 0.69 - 1.29, classified as platykurtic, mesokurtic and leptokurtic sediment. Between 18.9 and 11.7 m in depth sediment core, values of Md and sand content slightly increased upward which indicated higher hydrodynamic energy.

The sediment with abundant shell and plant fragments is typical of delta, therefore the environment of this section changed to delta front slope sediment (Tanabe, et al., 2006). The sedimentation rate in this section ranged from 0.26 to 2.13 cm/year (Li, et al., 2006).

3.4. Core section 4: at the depth from 11.7 to 4.1 m

The section was characterized by gray, fine sand and clay sediment with rich of plant matter. Mud values in sediment tended to decrease and the minimum value at a depth of 8.7 m (32.4 %). Md values tended to increase and ranged between 11.06 and 56.55 µm. So, values were a small range from 2.99 to 4.97 with mainly categorized very sorted sediment. Sk value fluctuated and indicated as very fine skewed, fine skewed and symmetrical sediment. KG values fluctuated and predominantly indicating platykurtic and mesokurtic sediment.

Between 11.7 and 4.1 m in depth sediment core, the sedimentation rate markedly increased to the high value of 1.94 cm/year within the study area (Li, et al., 2006). The sediment volume supplied by the Red River during the last 2000 cal. yr BP was much higher than others, correspond to an increase in the progradation of the delta system (Hori, et al., 2004). The coarsening succession upward which suggested that the energy of the environment increased.

The environment of this section was interpreted as delta front platform sediment (Tanabe, et al., 2006). The sedimentation rate in this section ranged from 0.82 to 1.94 cm/year (Li, et al., 2006).

3.5. Core section 5: from 4.1 to 0.5m

This section consisted of gray fine sand, silt and peat lenses 1-5 cm thick. Mud content tends to decrease. Inversely, sand content tended to slightly increase upward with a maximum value at the depth of 0.5 m (36.5 %). Md values varied in across a wide range, continuously decreasing from underlying facies to the depth of 1.7 m upward. The So values tended to slightly increase from underlying facies and reached a peak at a depth of 1.7 m. In this layer, most of the sediment was categorized as very poorly sorted. Sk values continuously fluctuated widely from very fine to fine-skewed sediments. KG values varied marginally with the exception at depth 0.9 m in which there was an indication of platykurtic sediments. The increasing of clay content and a decrease in Md values suggested decreasing tidal and wave energy.

Between 4.1 and 0.5 m in depth sediment core suggested decreasing tidal and wave energy. In this section, abundant plant fragment and root and laminated clay indicated it influenced by tidal environmental (Tanabe, et al., 2006). The sedimentation rate in this section interpreted 0.82 cm/year (Li, et al., 2006).

3.6. Core section 6: at the depth from 0.5 to the core surface

Sediments in this section consisted of reddish brown clay silt, fine sand and abundance of fine roots because it is corresponds to a lateritic weathering profile develop in the floodplain (Tanabe, et al., 2006). The mean of grain-size (Md) tended to increase upward. Base on the changes in sediment parameters, sediment in this section can be classified as very poorly sorted, very fine skewed and platykurtic sediment. Sand content was form 36.5 to 64.9 % and mud content markedly dropped to the lowest levels of 35.08 % which suggested the sediments were mainly formed in high energy environments. The Md values in the surface were high because it was influenced by channel-levee sediment at the land surface of the core site.

4. CONCLUSIONS

The depositional environment of the RRD result of the interaction between sea level rise and fluvial inputs. Base on lithological characteristics, sediment grain-size distribution core sediment can be divided into six depositional environments during the Holocene, including of (1) sub-and inter-tidal flats; (2) shelf-prodelta; (3) delta front slope; (4) delta front platform; (5) tidal flat and (6) flood plain. The lithological characteristic of core sample was closely correlated with the core sample from and previously by Tanabe el al. (2006). The variation of sedimentary parameters showed generally deposited at environment conditions from low to high energy. In the late part of the Holocene, the sedimentation rate increased to the maximum of value (1.94 cm/year) with higher energy environment condition at the depth from 11.7 to 4.1 m.

Acknowledgments

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