GIS AND IMAGE ANALYSIS TO STUDY THE PROCESS OF LATE HOLOCENE SEDIMENTARY EVOLUTION IN BALAT RIVER MOUTH, VIETNAM

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ABSTRACT

The GIS database of the Holocene sedimentary processes occurred in Balat River Mouth, its evolution and distribution in space and time. The remotely sensed satellite imageries including Landsat TM, Landsat 7 ETM are processed, visually interpreted in integration with GIS data to clarify the Holocene sedimentation, its face conditions and characteristics. The relationships of Holocene deposits and the interpretation pattern recognition of satellite remotely sensed data are established. The database in GIS environment is created and GIS spatial and attribute data analysis is applied to draw the change of Holocene lithofacies in horizontal/vertical space directions and time in relation to the sedimentary evolution of the coastline. The relation between sedimentary evolution and global sea level change expressed the sedimentary rate and it also describes the process of Land-Ocean interaction in relation with Present Sea level change. Finally, the paper gives the picture of litho-dynamic characteristics and distribution of lithofacies of Balat river mouth in Holocene. The principal lithofacies are fallow: sandy ridge, mangrove swamp, delta's flood plain tidal channel and tidal flats.

1. INTRODUCTION

Lithofacies map in Balat river mouth was established based on analysis of Landsat TM images of Dec. 22, 1988, Dec. 23, 1994, and ETM image of Aug, 05, 2001 **(Fig. 2)**, and field work investigation on sedimentology in 1999. The lithofacies map (**Fig. 6**) of Q_{IV}^{1-2} in North part of the Red River delta was created based on bore hole data using Digital Elevation Modeling (DEM) interpolation showing the terrain morphology condition in time and space. Each litho-facies formation was characterized by one specific color of Landsat imageries as follows: 1. Silt-sandy delta flood plain facies were according to green color, distributed in large surface in delta plain of Balat area. 2. Mud-clay mangrove facies were characterized by grey color in narrow area intercalated with mud-sandy tidal inlet facies and sandy ridge facies. 3.Silt-sandy delta plain facies were expressed by grey red color, associated with sandy ridge facies, but occupied in lower land of sandy ridge. 4. Sandy ridge facies composed old sandy ridge distributed in delta plain of late Holocene and modern sandy ridge (Vanh and Lu ridges) that were characterized by red color. 5. Shrimp culture lake and mangrove forests were expressed by black color. 6. And finally, modern mud sandy tidal flat facies corresponding to sea-greenish color distributed in coastline or inlet of the river mouth. By Comparison of three time series of Landsat generations (in 1988 and 1994, 2001) it shows that the coastal zone was quickly changed. The velocity of sedimentary rate from land to the sea has been of 49,68m/year (Northern part of Balat river mouth) and 53,53m/year (Southern part) in which deposition velocity inside sea dikes (Q_2^3 tb1) was less than outside sea dikes (Q_2^3 tb2).

2. STUDY AREA AND GEOLOGICAL SETTING

The Balat river mouth system belongs to a strongly aggradational delta (**Fig. 1**). In the central part, the rate of deposition resulting from suspended matter load (8.7×10^6/year) is higher than the tectonic subsidence of 2mm/year and the rate of sea level rise (1-2mm/year). Continuous and periodical facies changes from delta front environment into delta plain environment due to combining sand bars and centripetal sediment fillings is a characteristically feature for the Red-River delta. Accordingly, the development of the Balat mouth was related to the Holocene evolution of the whole Red-River delta. As above mentioned, this development was controlled by internal and external forces such as tectonic movements, river activities, sea level processes (transgression and regression) and wind activity as well. Besides these forces, the development of Balat mouth has been also strongly affected by human activities, especially, since the 11th century. However, among the mentioned forces, the tectonic movement was always dominant and controlling other processes (**Fig. 3**).

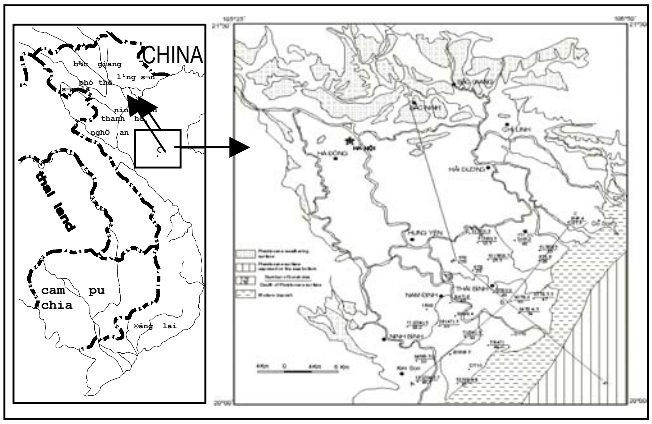


Figure 1. The study area

3. FACIES CLASSIFICATION

The founding sedimentary fancies units characterizing the general depositional architecture of the Holocene are bellows (from base to top; of. **Fig.4**) (**Tab.1**).

1.Dark grey clay-mud of coastal marshy mangrove forest facies rich in organics which characterizes the period before Middle Holocene maximum transgression and occurring at the depth of 30-60m. (below present sea level)

2.Greenish grey mud of lagoon facies rich in montmorillonite which is classified for the Middle Holocene maximum transgression and is observed at the depth of 15-30m mbsl.

3.Dark grey clay-mud of remnant old marshy mangrove facies showing the beginning of a regression. It is found at the depth of 15m in boreholes and, moreover, on the deltaic surface inland 50km far from the sea (outside of study area).

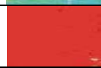
4. Dark grey clay-mud of mangrove tidal flat facies and brownish grey clay-mud facies of tidal channel facies are deposited within two river mouth sandbars. These sub modem facies units were formed in low land relief and being

Figure 2. Land sat ETM false color composite RGB 432, August 05/2001 Balat river mouth (part of Scene path row 126_046)

changed with time.

5. Fine sand facies of remnant river mouth sandbars as well modem sand bars having bow-shaped form facing towards the sea with heights of 1,5-3,5m.

Table 1. Comparison between lithofacies and landsat images in Balat river mouth area

Index	Sediment lithofacies	Fotolandsat	Color
1	Silt-sandy flood delta plain		Green
2	Mud – clay mangrove		Grey greenish
3	Silt – sandy delta plain		Grey – red
4	Silt – sandy tidal flat		Cyan greenish
5	Sandy ridge		Red
6	Shrimp culture lake and mangrove		Black
7	Water surface		Dark violet

In order to clarify the nature of regional tectonics in the Holocene as applied to the study area, firstly a temporal and spatial differentiation of tectonic movements is needed. This can be deduced from the evolution of sediment formations. On one hand, processes of transgression and regression caused the sedimentary facies changes in space and time, and on the other hand, these strongly result from the different tectonic movements. The obtained results on the sedimentary evolution can be used as the basic information on evaluating tectonic movements in the Holocene. Therefore, we focus in this paper mainly to the following aspects: a)Characteristics of differentiation of the surface of the Holocene base; b) Structural element's during the Holocene; c)Evidences for recent tectonic movements. Two Holocene faults (BL1 and BL2) (**Fig. 3**), form a graben within Vinh Ninh fault which can be seen in an echo-sounding profile in the direction of 45^0. This justifies that Vinh Ninh fault is active with a subsidence magnitude of ≈ 0.57cm/year.

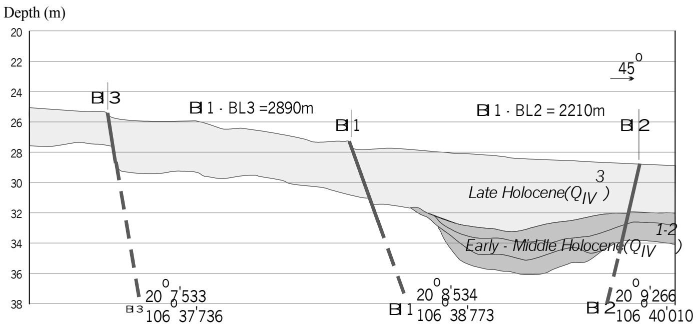


Figure 3. Echo sounder cross section in front of Balat mouth

4. SEDIMENTARY RATE CYCLES

Moreover, changing sedimentation rate cycles can be deduced also by spatial variations of geomorphologic characteristics. This can be done in the area of Balat river mouth by means of sandy mouth bar-records and, additionally, by sea dike generations made by human activities throughout the past centuries. Positions of both sandy mouth bars and sea dikes reflect older (ancient) shore lines by increased sediment deposition and enlargement of land accumulation from the period of maximum Holocene transgression to present times. These processes, especially, are dominant environment-controlled factors in the formation of modern Red-River delta in general and Balat river mouth in particular. Some sandy mouth bar-generations can be clearly observed in the Northern and Southern parts of Balat river mouth. They usually are bow-shaped (crescentic) and sharp in form towards the sea and characterize different periods of coastal zone evolution (**Fig. 4**). These mouth bars are significant products of sedimentary evolution cycles showing absolute ages of 2000-1000 years B.P and are found at a distance of almost 10km (9600m) away from present shore line (according to data determined by the Northern Division of Geological Mapping Survey).

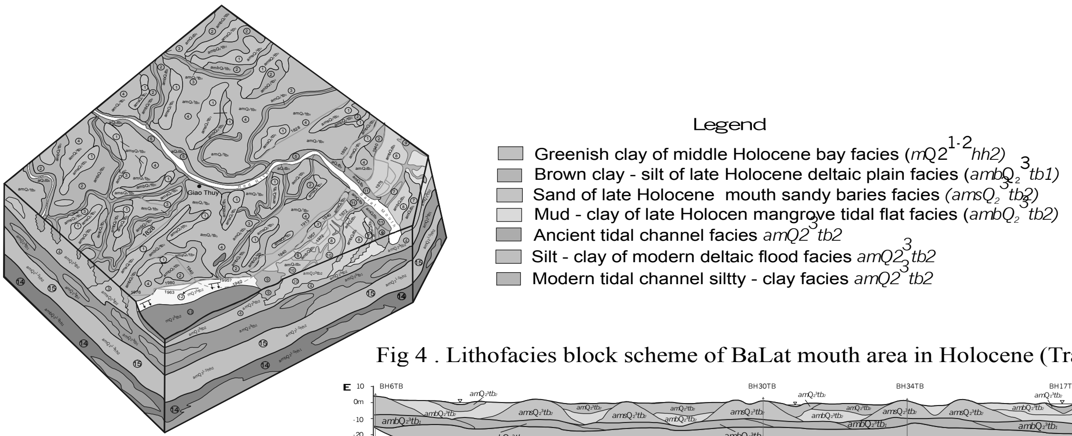


Fig 4 . Lithofacies block scheme of BaLat mouth area in Holocene (TranNghi, 1999)

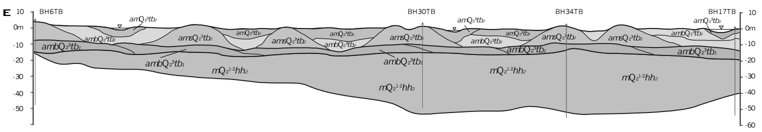


Fig 5: Lithofacies section from E to F

Sea dike generations were constructed for enlarging the reclamation and cultivation of land. In the past the Red-River dike-constructions began rather before the Ly-Dynasty (11th century), while the sea dikes were constructed several centuries later since the Nguyen-Dynasty (19th Century). There is evidence of first sea dikes for this historical period in 1828; further sea dike generations follow in 1915, 1940, 1956, 1976, 1998 (**Fig. 4**). Due to the most favorable conditions all sea dike generations have been constructed in sandy mouth bar-complexes. Thus, the distance between two sea dike-systems and their time of construction can be used for the calculation of sedimentation rate from mainland to the sea for each single cycle, while sedimentary rate of the whole coastal zone is an average value of sedimentation rates of all depositional cycles.

Phase 1*:* Formation of sandy river mouth bar due to high amounts of suspended load and continuous interactions (turbulence) in fluvial hydrodynamics. These turbulent fluvial interactions effect processes of widespread redeposit ion on the highly accreted delta-plane surface. In this process, rapidly decreasing river current energy is less important and wave energy is predominant, especially, due to tropical storms.

Phase 2*:* Process of centripetal sediment deposition showing two growing marshy tidal flats which have a inclined relief and overlaying a pre-existing sandy mouth bar originating a gradual reduction of near coastal sea area. Finally, a single broad tidal channel (estuary) or a tidal channel system develops which are controlled by the watershed towards south (for example, Vop River and Tra River).

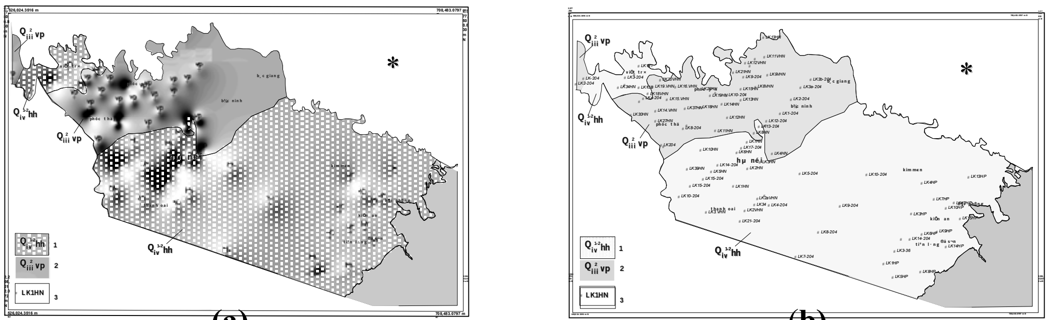
Phase 3*:* Degradation processes of tidal channels and mangrove forest by gradual infilling of muddy sediments and tidal flat progradation. Moreover, coastal mangroves stop both their growth and extension when tidal channels become swamps. The aforementioned cyclic environmental and depositional evolution including tectonical position strongly effects morphogenesis and facies distribution as well the landscape relief of the study area. The following morphogenetic and facies characteristics can be observed:

- Highly raised relief of sandy bars having simple bow shaped form and ramifying southwards or south-earthwards. The elevation of sandy bars varies from 2,5m to 5,0m.
- The flat delta-plain relief covering almost the whole area of the Red-River delta slightly inclines towards the highly raised relief running in NE-SW direction. The elevation of the deltaic tidal flat ranges from 1,0m to 2,5m.
- The relief of the low-lying coastal marshes shows separate structures and extends into a basin area connecting with the Red-River fluvial and deltaic system being characterized by artidal channel mouth.
- The relief of modern river mouth sandbars (Vanh, Lu, Mo, and Ngan sandbars) consists of small islands having shape facing towards the sea. Their heights vary from 3m to 5m, which correspond to maximum sea level rise due to storm events (**Fig. 4**).
- The modern relief of low mangrove marshy tidal flat is wide and slightly inclined being situated between two generations of sand bars and has been formed by sediment deposition under rather quiet dynamic conditions (**Fig. 4**).
- The rather flat-lying sandy tidal flat showing inclinations of $0.5\text{-}1^0$ extends from 150m (East of Lu sand bar) to 1000m (Hai Hau) in width. Modern tidal channels extend in SW-direction (Vop River, Tra River), while secondary tidal channels run in perpendicular to NE-SW direction.
- The bottom relief of the Red-River delta front shows differentials along the coast. At a water depth between 5 and 30m in front of the Balat mouth it becomes steeper (1-20'). Perpendiculars to the coastline the delta front section is wedge-shaped in growth direction. Towards the south the bottom relief is more differentiated. This suggests that the depositional growth of the river mouth area be of great value. However, in Hai-Hau area the material deficit causes strong erosion. In comparison with the Balat river mouth strong erosion has taken place along Hai Hau coastline. This should be due to a general lack in sediment supply caused by marine current processes, which carry away the Red-River suspended load from coast. Additionally, strong coastal wave dynamics due to sea level rise as well controls coastal erosion along this section. F: Geo-dynamic characteristics of Balat estuary area in Holocene. These depths increase from mainland towards the sea from 12,5m (NW) to 56m below sea level (SE) and, moreover, from both margins to center from 20m-25m to 56-63m below sea level. There are no data available on the depth of the base surface in the part from shore line toward the sea with water depths of 25-30m, but according to the general dipping tendency from shore line to the sea, obviously, the base should be accurate a depth of more than 30m beneath sea bottom. Outside bathymetric depths of 25-30m the base surface emerges at the sea bottom without a sediment cover or only with a very thin layer (0.2 to 0.8m thick) of mainly gravel sand with shell fragments.

5. RESULT AND CONCLUSIONS

The study on the Holocene evolution of the Balat river mouth representing apart of the large Red-River delta system in Northern Vietnam revealed on relation between remote sensing and some new basic morphogenetic, sedimentological, geo-dynamical and environmental results which are summarized as follows. Basically, the sedimentary and geomorphologic evolution of Balat river mouth has acrylic character in space and time. The beginning of each cycle is marked by the formation of river mouth sandbars whereas the cycle end is marked by the deposition of dark clays of tidal inlet or swampy mangrove tidal flat facies rich in organics. Moreover, there is a spatial and environmental coincidence between each sedimentation cycle and mangrove evolution cycle:

Periods of abundant swampy mud-clay facies correspond with periods of abundant mangrove growth. The distribution of both lateral and vertical facies associations is characterized by groups of delta accretion facies which are closely related to each other, to changes in global climate and, especially, to the enormous amount of suspended matter transported by the Red river. There is also clear evidence of human activities, which locally influenced the sedimentary evolution and the interaction between land and ocean. We have found that these effects originate by the constructions of Red River dikes since the 11th century, especially, for the So-river dike (1950), the Hoa Binh dam and sea dikes. The construction of So-river dike resulted in increased strong erosion due to deficits in sediment supply. Moreover, river dike constructions also resulted in increasing suspended matter loads transported directly to the sea. The river responded to these technical measures which obstructed drainage processes by rapid changes in the temporal flow regime. But, the Nguyen, Cong-Tru-sea dikes constructed behind sandbars much better agree with natural depositional processes. In contrast, the recent sea dike system (1965 to present) has been constructed outside sand bar formations and should not be support these natural processes of sand bar evolution by causing a restricted sediment distribution of the particular coastal landscape.



(a) **(b)**

Figure 6 . Lithofacies: 1. Silt Clay bay lagoon and delta plain facies of Vinhphuc Formation (Late Pleistocene, am, m Q_1^3 vp; 2. Grey-greenish clay bay lagoon facies of Hai Hung Formation (Early- Middle Holocene) m Q^{1-2} hh; 3. -Bore-holes and letter assigned the surface name of an litho-facies
(a)- Shaded relief and (b)- Lithofacies in planar

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